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In the Aalborg East Port Industrial Area

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INDUSTRIAL SYMBIOSIS EMERGENCE

IN THE AALBORG EAST PORT INDUSTRIAL AREA

BY
LUCIA MORTENSEN

PUCLICATION BASED ON THE PH.D. THESIS

AALBORG UNIVERSITY
DENMARK

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Puclication based on the Ph.d. thesis

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“*This is the beginning of a thought process that moves towards a consciousness way of being, as well as a way of doing in the world which is […] always a process of becoming”.*

(Maguire, 2018, p.103)

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Lucia Mortensen
Aalborg, 2020

PREFACE

A three-year (January 2017–December 2019) industrial PhD project, equally financed by Innovation Fund Denmark (Innovationsfonden) and Port of Aalborg Logistics Ltd., shaped the characteristics of the research undertaken and presented in this thesis. As an industrial PhD, I was expected to collaborate with a company for producing applied results in real contexts and leading to commercial gains, and an university to address new areas of research and strengthen relationships among company and university (Innovation Fund Denmark, 2019). To achieve this, I was employed by the Port of Aalborg Logistics Ltd. (the company) and enrolled at the Technical Doctoral School of IT and Design at Aalborg University within Danish Center for Environmental Assessment (DCEA) (the university). Both the Port of Aalborg and DCEA are the co-founders of Environment^{++}, the strategic initiative aiming at initiation of industrial symbiosis in Aalborg East port industrial area and at transforming the port industrial area in Aalborg East into a national and international role model for symbiotic relationships. The Environment^{++} seeks to transform the environmental awareness, planning, and management into important opportunities and decisive competitive factors in retaining and attracting new businesses and jobs in the region.

Involving both academics and practitioners, Environment^{++} initiative became the research context. Integrated within Environment^{++}, the PhD project aimed at providing inputs to both academia and practice through 1) this academic PhD thesis focusing on the IS emergence process and factors that can facilitate it in port industrial areas by taking an applied science approach; and 2) the practice-oriented report presenting specific actions that the company and other actors in Aalborg can take to support IS emergence in the local port area.

The process of the PhD project and the research within this thesis results not only in a contribution to academia and practice, but also a contribution to my own personal and professional development. The research within this thesis was a continuation of the research undertaken during my master's degree studies and became a steppingstone for my future research and practice interests. It is thus the connecting dot between my past experiences with facilitative processes and my interests in future activities encouraging industrial symbiosis emergence in Aalborg. In this way, this thesis is the knotting point between knowledge and experience, and between my past and future.

SUMMARY

Industrial symbiosis (IS) is a recognized strategic tool for implementing circular economy and sustainable business development at European, national, regional, and local levels. Its environmental, social, and economic benefits are recognized, and efforts are intensified around the world to encourage it in various contexts. Although successful examples exist in practice, empirical evidence shows that they apply various approaches to IS initiation. While these explain the IS emergence in those specific contests, they challenge the understanding of IS emergence in other contexts. Contexts that present various (organizational, informational, technical, economical, institutional, etc.) characteristics can enable or challenge IS emergence. Such contextual characteristics provide initial conditions for IS emergence and shape its process. Research tailored to a specific context, analyzing its characteristics could provide knowledge on its capacities for fostering IS emergence and can point on the further capacity that needs to be built so that further symbiotic linkages can emerge.

Modern ports are given an interesting role in circular economy and IS initiatives and are perceived as laboratories for IS emergence processes implementation. Following their (environmental) evolution, they engage with industrial symbiosis strategies for both port and hinterland development. Industrial areas at the port perimeter and its hinterland are found to be areas with considerable resources that can foster IS emergence. Various initiatives that aimed at fostering IS emergence in the Aalborg East port industrial area took place during the last decade. However, few symbiotic relationships arose, as more insights and understanding were needed on the process through which IS emerges and the factors that facilitate it. The initiation of Environment^{++} and its sub-project, the Sustainable Synergies project, allowed following a real-time IS emergence process in real-life context and achieving the research aim.

Rooted in the research gap identified in the IS literature and the practice of IS emergence in the Aalborg East port industrial area, the present research aims at providing insights into and a better understanding of IS emergence, contributing to both theory generation and further support of IS emergence in practice. To meet this aim, the research was guided by the following main research question:

How can industrial symbiosis emerge and what factors can facilitate the industrial symbiosis emergence in the Aalborg East port industrial area?

Answering the research question, an engaged scholarship approach was taken and an alternation among various modes of research followed. Making use of an embedded case study where data were collected through a triangulation of methods (individual and group interviews, observations, and document analysis) the research builds around a synthesis across findings documented in four academic articles and the

primary case of IS emergence in the Aalborg East port industrial area. The research aimed at enriching the scientific understanding of industrial symbiosis emergence and of specific factors that can facilitate it. Likewise, the research sought to provide insights into contextual characteristics of port industrial areas as factors fostering IS emergence. Simultaneously, this research aimed at contributing to the practice of IS emergence in the Aalborg East port industrial area through collecting inputs from the on-going IS-aiming initiative Environment^{++} and providing inputs for further IS emergence.

Answering *how IS can emerge*, it is found, based on a synthesis across cases and contexts, that industrial symbiosis emerges through an IS emergence process. This is a dynamic social process that is integrated within a specific geographical and institutional context and builds on existing contextual factors, existing symbiotic linkages, and the uncovered unexploited resource potentials to develop bilateral symbiotic linkages and an IS network. A conceptual model for IS emergence is developed that represents IS emergence as the phase in the IS evolution between pre-emergence and post-emergence. Empirical evidence from IS emergence processes in port industrial areas shows that in practice boundaries between pre-emergence, emergence, and post-emergence are fluid and these are interconnected and difficult to separate. The second conceptual model developed—IS reproduction model—explains the different reproduction paths that, through various degrees of interconnectivity among existing and new emerging symbiotic linkages, lead to the emergence of bilateral relationships and symbiotic network formation. These in their turn can encourage new symbiotic relationships' emergence. The real-life process of IS emergence in port industrial areas present evidence for symbiotic linkages emerging through facilitation and reproduction dynamics. A multitude of actors can engage or be engaged within various (self-organized, facilitative, and/or reproductive) interactions activating the existing contextual factors and capacity to form new symbiotic linkages from scratch or/and from existing linkages. Thus, IS appears to emerge through a combination of multiple IS dynamics. These are found to combine in an evolutionary journey that are expected to lead to emergence of IS through following multiple iterations and non-linear paths.

Concerning the *factors that can facilitate the industrial symbiosis emergence,* the research identifies factors related to the contextual (geographical and institutional) characteristics and capacities of port industrial areas as enablers. Synthesizing across cases and contexts, the present research confirms the fact that port industrial areas present important geographical, technical, and institutional characteristics and capacities that can facilitate IS emergence. However, these are not leading to IS emergence by default. Significant mobilization capacity is needed to activate the existing capacity within IS emergence processes. Focused facilitative processes applying various mobilization techniques are necessary. Such processes can be initiated and unfolded by dynamic collaborative structures formed by multiple actors across sectors. Within these facilitation entities, specific professional and personal skills and capacities must exist. IS emergence is found to be fostered by institutional structures such as partnerships accommodated by IS-aiming platforms. Thus, institutionalization of IS is necessary to assure its emergence.

To conclude, it can be stated that this thesis produces actionable knowledge with direct contributions to both academia and practice. The two conceptual models developed—the IS emergence model and the IS reproduction model—are the immediate scholar contribution. The two models present important implications for the IS field of research generating initial theoretical insights on how IS emerges with rich empirical evidence from real-life processes of IS emergence in port industrial areas. Regarding the contribution to practice, this research, besides providing insights into contextual characteristics of the Aalborg East port industrial area, questions the capacities present in the context and challenges the roles of different actors, inviting them to take a strategic and pro-active attitude towards IS emergence process. The research provides recommendations for further facilitation of IS emergence in the port industrial area of Aalborg East, pointing at the need of a focused and collaborative network for IS emergence. While multiple actors are already involved in an IS emergence process, the findings of this thesis point at a need for IS emergence to be institutionalized, meaning internalized at the individual and organizational level, and transformed into a strategy at institutional level. Specific institutional collaborative network structures need to be formed and a focused process needs to be initiated and monitored. Such a process needs to accommodate self-organized, reproductive, and intentional facilitative actions and interactions to secure capacity building for further IS emergence.

RESUMÉ

Industriel symbiose (IS) er et anerkendt strategisk værktøj til implementering af cirkulære økonomi og bæredygtig forretningsudvikling på europæisk, nationalt, regionalt og lokalt niveau. Det miljømæssige, sociale og økonomiske fordele er bredt anerkendt, og bestræbelserne på at få IS til at opstå intensiveres over hele verden for at tilskynde til det i forskellige sammenhænge. Selvom der findes succesrige eksempler i praksis, viser empiri, at de anvender forskellige tilgange til IS-opståen. Mens disse forklarer IS opståen i specifikke kontekster, udfordrer de forståelsen af hvordan IS kan opstå i andre kontekster. Kontekster med forskellige (organisatoriske, informationsmæssige, tekniske, økonomiske, institutionelle, osv.) egenskaber, kan aktivere eller udfordre IS-opståen. Sådanne kontekstuelle karakteristika stiller indledende betingelser for IS-opståen og former dens proces. Forskning, der er målrettet en specifik kontekst, ved at analysere dens egenskaber og producere viden om dens kapacitet til at fremme IS' opståen, kan pege på hvilken yderligere kapacitet, det er nødvendigt at opbygge, for at symbiotiske forretningsmodeller kan opstå i den givne kontekst.

Moderne havne kan opnå en interessant rolle i cirkulær økonomi og IS - initiativer og opfattes som laboratorier til implementering af processer, der understøtter IS-opståen. Som følge af deres miljømæssige udvikling, engagerer havnene sig i og implementerer strategier og processer, der understøtter IS-opståen målrettet havnens og baglandets bæredygtig udvikling. Erhvervsområder nær havnene og i deres bagland viser sig at være områder med betydelige ressourcer, som kan muliggøre IS-opståen. I Aalborg Øst erhvervsområde, nær ved Port of Aalborgs bagland og dermed dennes bagland, har flere initiativer fundet sted gennem det sidste årti med det formål at fremme IS-opståen. Der opstod dog kun få symbioser, da der var behov for mere indsigt i og forståelse for den proces, hvorigennem IS opstår, og de faktorer, der bidrager dertil. Igangsættelsen af Miljø$^{++}$ initiativet og dets delprojekt, Bæredygtige Synergier, gjorde det muligt at følge faciliterings processer hvorigennem IS-opstod i virkeligheden og dermed opfylde forskningsformålet.

Forankret i forskningsbehovet identificeret i IS-litteraturen samt erfaringer med praksis i forhold til IS-opståen i erhvervsområdet i Aalborg Øst, sigter denne forskning efter at få bedre indsigt i og forståelse af processen, der fører til IS-opståen. Dermed bidrager forskningen til både teoriudvikling og IS-opståen i praksis. For at nå dette mål blev forskningen udviklet på baggrund af følgende hovedforskningsspørgsmål:

Hvordan kan industriel symbiose opstå, og hvilke faktorer muliggør den industrielle symbioses opståen i Aalborg Øst erhvervsområde?

En forskerengageret tilgang og en veksling mellem forskellige forskningsformer blev anvendt for at besvare forskningsspørgsmålet. Ved hjælp af casestudie, hvor data blev indsamlet gennem en triangulering af metoder (som fx individuelle og gruppe interviews, observationer og dokumentanalyse) bygger forskningen på en syntese på tværs af indsigter dokumenteret i fire akademiske artikler og det empiriske arbejde beskrevet i denne afhandling, der relatere sig til processen for at støtte IS -opståen i Aalborg Øst erhvervsområde. Forskningen i denne afhandling beriger den videnskabelige forståelse af IS-opståen og af de specifikke faktorer, der muliggør den. Ligeledes søger forskningen at skabe indsigt i de kontekstuelle karakteristika for havneerhvervsområder som faktorer, der faciliterer IS-opståen. Samtidig bidrager forskningen til processen målrettet IS-opståen i Aalborg Øst erhvervsområde i praksis gennem indsamling af input fra det igangværende Miljø$^{++}$ initiativ og Bæredygtige Synergier projektet ved at belyse faktorer, der kræver yderligere fokus hvis IS -opståen skal yderligt faciliteres.

Vedrørende hvordan IS opstår, baseret på en syntese på tværs af undersøgelser og kontekster, finder forskningen præsenteret i denne afhandling, at IS opstår gennem en langvarige proces. Denne er en dynamisk og social proces, der er integreret i en specifik geografisk og institutionel kontekst, og som bygger på eksisterende kontekstuelle faktorer, eksisterende symbiotiske relationer og de afdækkede uudnyttede ressourcepotentialer. Endelig bidrager processen til udvikling af bilaterale symbiotiske relationer og et efterfølgende IS-netværk. Gennem denne forskning udvikles der to konceptuelle modeller. Den ene, ”model for IS-opståen”, præsentere IS-opståen som en fase i IS-udviklingen positioneret mellem en præ-opståen og post-opståen fase. De empiriske data fra processen målrettet IS-opståen i havnerelaterede erhvervsområder viser, at i praksis er grænser mellem disse faser flydende, og disse er sammenkoblet og vanskelige at adskille.

Den anden konceptuelle model, ”IS reproduktionsmodellen”, forklarer de forskellige reproduktionsmåder, der gennem forskellige grader af afhængighed mellem eksisterende og nye symbiotiske relationer fører til fremkomsten af bilaterale forhold og dannelsen af et symbiotisk netværk. Disse, kan fremme sandsynligheden for, at nye symbiotiske relationer opstår. Den undersøgte reelle proces, hvor IS opstår i havnerelaterede erhvervsområder præsenterer evidens for, at symbiotiske relationer opstår gennem facilitering og reproduktions-dynamikker. Adskillige og forskellige aktører kan engagere sig eller blive engageret i forskellige (selvorganiserede, faciliterede og/eller reproduktive) interaktioner, der aktiverer de eksisterende kontekstuelle faktorer og kapacitet til at danne nye symbiotiske forbindelser. Således konkludere forskningen, at IS opstår gennem en kombination af flere IS-dynamikker, som kan kombineres i og danne en evolutionær rejse, der forventes at føre til IS-opståen gennem flere iterationer og en ikke-lineær proces.

Hvad angår de faktorer, der kan facilitere IS' opståen, identificerer forskningen faktorer, der relaterer sig til de kontekstuelle (geografiske og institutionelle) træk og eksisterende kapacitet i havnerelateret erhvervsområder. Syntesen på tværs af undersøgelserne bekræfter at disse områder har vigtige geografiske, tekniske og institutionelle ressourcer og kapacitet, der kan facilitere IS-opståen. Disse fører imidlertid ikke nødvendigvis direkte til IS-opståen. Der er behov for en betydelig mobiliseringskapacitet for at aktivere de eksisterende ressourcer og kapacitet gennem processer målrettet IS-opståen. Fokuserede processer, der faciliterer og anvender forskellige mobiliseringsteknikker, er nødvendige. Sådanne processer kan initieres og støttes af dynamiske samarbejdsstrukturer dannet af flere aktører på tværs af sektorer. Indenfor disse skal der eksistere facilitatorer med specifikke faglige og personlige færdigheder og kapaciteter. IS-opståen viser sig at være muliggjort af institutionelle strukturer, såsom partnerskaber, der er støttet og opfostret af platforme, der sigter efter IS. Institutionalisering af IS er således nødvendig for at sikre dets opståen.

Afslutningsvis kan det konkluderes, at forskningen i denne afhandling har produceret anvendt viden med direkte bidrag til både det teoretiske felt og praksis. De to udviklede konceptuelle modeller – model for IS-opståen og IS - reproduktionsmodellen – er direkte bidrag til IS-forskningsfeltet. Disse, baseret på både input fra den eksisterende viden og empiriske data gennem denne forskning, skaber en indledende teoretisk indsigt i, hvordan IS kan opstå generelt og i havnerelaterede erhvervsområder. Udover at skabe indsigt i de kontekstuelle karakteristika af erhvervsområdet i Aalborg Øst, bidrager forskningen i denne afhandling til praksis ved at oplyse om de eksisterende kapaciteter i dette område, og stille spørgsmålstegn ved forskellige aktørers roller og invitere dem til at tage en strategisk proaktiv attitude målrettet IS-opståen. Afhandlingen kommer med forskellige anbefalinger for yderligere facilitering af IS-opståen i Aalborg Øst erhvervsområdet, og peger på behovet for et fokuseret samarbejdsnetværk af aktører, der arbejder for at facilitere IS-opståen. Mens flere aktører i området allerede er involveret i en sådan proces, peger forskningsresultater på et behov for, at IS-opståen institutionaliseres. Det betyder at der er behov for at IS integreres på forskellige niveauer: individ, organisatorisk og institutionel. Specifikke institutionelle samarbejdsstrukturer skal dannes og en fokuseret interaktiv proces skal igangsættes og monitoreres. En sådan proces skal rumme selvorganiserede, reproduktive og faciliterende dynamikker, så den individuelle, organisatoriske og institutionelle kapacitet opbygges og fører til yderligere IS-opståen.

TABLE OF CONTENTS

PART 2

APPENDECES

LIST OF PUBLICATIONS

[1] Mortensen, Lucia, Kørnøv, Lone, 2019. Critical factors for industrial symbiosis emergence process. *Journal of Cleaner Production*, 212, 56–69. doi: 10.1016/j.jclepro.2018.11.222

[2] Mortensen Lucia, Kørnøv Lone, Lyhne Ivar, Raakjær Jesper, 2020. Smaller ports' evolution towards catalysing sustainable hinterland development. *Maritime Policy & Management.* doi: 10.1080/03088839.2020.1711978

[3] Mortensen Lucia, Kringelum Louise Brøns, Gjerding Allan Næs, pre- print version. How Industrial Symbiosis Emerges as Partnerships: Collaborative Business Models in Port Industrial Areas. (The final version of the article is published in the *International Journal of Innovation and Sustainable Development*, Vol. 17., no. 1-2, and can be accessed at https://doi.org/10.1504/IJISD.2023.127927)

[4] Schlüter, Leonie, Mortensen, Lucia, Kørnøv, Lone, 2020. Industrial symbiosis emergence and network development through reproduction. *Journal of Cleaner Production, 252,* doi: 10.1016/j.jclepro.2019.119631

Reference to these four publications is given in the text by using the following format: (cf. author(s) year #no.) e.g. (cf. Mortensen et al., 2020 #2).

1 INTRODUCTION

Industrial symbiosis (IS), inspired by mutualistic biological relationships (Frosch & Gallopoulos, 1989) is conceptualized as a systemic approach to organizing industrial systems through development of mutually beneficial relationships by making use of otherwise underutilized materials, energy, water, capacity, expertise, assets, etc. (Lombardi, Lyons, Shi, & Agarwal 2012; Lombardi & Laybourn, 2012b). Physical exchange and sharing of excesses of underutilized materials, energy, water, by products, knowledge, expertise, and assets among traditionally separate (business) organizations form the essence of symbiotic linkages (Chertow 2000; Lombardi & Laybourn, 2012a). Industrial symbiosis supposes (sustainable) business relations interconnected through symbiotic (mutualistic and commensalistic) business models in order to achieve more efficient resource management and networked economic activity (Ashton, Chopra, & Kashyap, 2017; Lombardi & Laybourn, 2012a).

IS is acknowledged to increase the business organizations' economic performance (Verguts, Dessein, Dewulf, & Lauwers, 2016) through decreased economic costs for waste disposal and raw material acquisition (Doménech, Bleischwitz, Doranova, Panayotopoulos, & Roman, 2019), as well as product, business, and market diversification by encouraging innovative business ideas and fostering eco-innovation (Lombardi & Laybourn, 2012a). Environmentally, IS has proved to improve the ecological footprint of industrial processes (Boons, Chertow, Park, Spekkink, & Shi, 2017) through landfill diversion of discarded materials and by-products, saving of virgin raw materials and water, and reducing hazardous waste and greenhouse gas emissions (Doménech et al., 2019). Moreover, IS has proved to bring along social development in form of new jobs generation and increased quality of life through environmental benefits, thus increasing regional attractiveness (Behera, Kim, Lee, Suh, & Park, 2012; Gibbs & Deutz, 2007; Mirata, 2004; Cohen-Rosenthal, 2000).

Due to its environmental and social benefits and economic potential, IS was recognized as an important strategy for achieving a circular economy at EU level (EU Commission, 2011; 2014; Horizon 2020, 2015), being named by the European Resource Efficiency Platform (EREP, 2014) as a top priority area with significant potential to trigger the transition towards sustainable businesses and societies. At regional level, IS has been adopted as a strategic tool for eco-innovation, sustainable (economic) growth, and resource efficiency (Laybourn & Lombardi, 2012), and as a marketing strategy for geographical regions and their development (Deutz & Gibbs, 2004).

Modern ports are important regional industrial systems (Boons, Spekkink, & Mouzakitis, 2011) that accommodate large industries, production companies, waste management firms, and various other types of organizations. These have proved to have significant potential for development of symbiotic relationships due to the co-location of a diversity of organizations within geographic proximity offered by the port industrial areas at the port's perimeter and hinterland. Various large ports are found to engage with IS strategies for various reasons, among which driving the port and its hinterland's competitiveness and sustainable development (Cerceau et al., 2014; Mat et al., 2016; Merk, 2013) is the most common. Likewise, the smaller Port of Aalborg engages with IS for similar reasons. Adopting environment as a growth parameter and engaging with IS strategies, the Port of Aalborg seeks to catalyze the port and hinterland sustainable development and increase the attractiveness of the region.

Despite the growing interest in IS as a tool for achieving circular economy and sustainable development in general, and port and hinterland competitiveness specifically, the creation of IS in practice proves to be challenging (Chertow, 2007). The existing IS examples (Doménech et al., 2019; Deutz, Lyons, & Bi, 2015) allowed scholars to examine the evolutionary phases of IS, focusing on its emergence and development (Boons, Spekkink, & Jiao, 2014; Doménech & Davies, 2011), and to uncover drivers, determinants, challenges, and barriers for IS emergence and development (Tudor, Adam, & Bates, 2007; Madsen, Boisen, Nielsen, & Tackmann, 2015). Some researchers describe the IS dynamics (Boons et al., 2017; Sun, Spekkink, Cuppen, & Korevaar, 2017) and others present geospatial, technical, economic, human, organizational, informational, and institutional factors as initial conditions for IS emergence and development (see e.g. Yap & Devlin, 2016; Mirata, 2004; 2005). However, scholars seem to not make a clear distinction between IS emergence and IS development and thus do not obtain a deeper understanding of which factors contribute specifically to the creation of IS (before its development). Moreover, the highly embedded character of IS (Boons & Howard-Grenville, 2009) requires more contextualized research that can uncover the capacity and potential of a specific (institutional and geographical) context for fostering IS emergence and development (Mirata, 2004; Boons, et al., 2017).

Likewise, despite of being described in IS literature as laboratories for the implementation of industrial symbiosis (Cerceau et al., 2014), the emergence and development of symbiotic linkages in port areas is still scarce. For example, despite the engagement of the Port of Aalborg with IS since 2011 and the numerous research activities directed toward IS emergence in Aalborg East port industrial area, few (if any) symbioses have emerged. Moreover, the IS literature is scarce in studies addressing port industrial areas' characteristics and capacities for fostering IS emergence (see e.g. Cerceau et al., 2014). Empirical studies focus, instead, on describing lessons from IS-aiming programs (e.g. Park, Park, & Park 2016; Park, Duque – Hernández, & Díaz-Posada, 2018) and recently focus has been on gathering lessons from on-going projects and processes (Wang, Deutz, & Chen, 2017) with the aim of feeding the results back into local processes.

The initiation of Environment^{++} in Aalborg East port industrial area (Miljø$^{++}$, 2020), aiming at fostering and promoting IS emergence provides an optimal possibility to follow an IS emergence process and collect first-hand insights into such a process. This permits identification of specific characteristics of IS emergence and factors that enable the coming about of symbiotic relationships within port industrial areas. At the same time, the insights gathered from the ongoing process permit identification of specific characteristics and capacities of the Aalborg East port industrial area for fostering IS. Gathering insights in both specific characteristics of the IS emergence process and contextual capacities characterizing Aalborg East port industrial area can shed light on the capacities that need to be fostered for further IS emergence processes.

Thus, based on challenges with IS initiation in Aalborg East port industrial area, the possibilities that Environment^{++} initiative presents, and the gaps identified within IS literature pointing at the need for a deeper understanding of IS emergence, the following research question is raised to guide the present research:

How can industrial symbiosis emerge and what factors can facilitate the industrial symbiosis emergence in Aalborg East port industrial area?

By answering the research question, it is sought both to enrich the scientific understanding of the IS emergence by providing deeper insights into factors and contextual characteristics that port industrial areas present for facilitating IS emergence, and to inform the practice in Aalborg East port industrial area and other port contexts. Pursuing both a conceptualization of IS emergence and providing inputs to practice, the present research seeks to generate both scientifically rigorous and actionable knowledge, i.e. knowledge useful to both academia and practice (Adler & Shani, 2001). The intention of the research is to develop theoretically based knowledge that provides solutions to the immediate real-world challenges with IS emergence in port industrial areas. The focus is thus both 1) on extending the boundaries of scholars' understanding of the coming about of symbiotic relationships and thus creating knowledge for informing the theory and developing deeper theoretical insights into the IS emergence process; and on 2) knowledge utilization i.e. bringing support to practitioners in their quest for IS emergence in Aalborg East port industrial area.

Revolving around the IS emergence process in Aalborg East port industrial area as a primary case, an embedded case strategy is applied. Rooted in the challenge of having IS emerge at the Aalborg East port industrial area and aiming at contributing to the IS research field, an engaged scholarship approach to research (Van de Ven, 2007) is applied. This facilitates the interplay and the dilemma of connecting theory to practice by, on one hand, analyzing IS emergence empirically through application of a case study-based research strategy on contemporary contexts (generating in this way initial theoretical thoughts on IS emergence) and, on the other hand, uses theory to shape empirical studies and address practice possibilities when supporting IS emergence.

Port industrial areas are the *context* of this research. These refer to the industrial areas that port perimeters and their hinterland (i.e. area in port vicinity and proximity) accommodate. Such areas do not only accommodate a large spectrum of industries and organizations but are also logistical hubs and possess various pools of resources. Ports engage with *sustainable development of* their *hinterlands* to produce growth within these in a (economically, environmentally, and socially) responsible manner.

Industrial symbiosis refers, within this thesis, to the physical inter-firm symbiotic linkages that rely on flows of knowledge, material, and liquids. *IS emergence* is then the coming about of symbiotic linkages understood and conceptualized in this thesis as the collaborative process among various actors across sectors who engage in collective efforts of establishing inter-firm symbiotic linkages (from which these can develop into IS networks or terminate). Conceptualizing IS emergence this way relates to the concept of a "*gestation period*" (Van de Ven, Polley, Garud & Venkataraman, 1999, p. 23) and the process that occurs before any bi-lateral synergistic relation is formed (Sun et al., 2017).

Facilitating factors relate to factors that make IS emergence processes possible and/or easier (Cambridge Dictionary, 2019) by enabling, encouraging, supporting, stimulating, and advancing it. Within this thesis, these relate to the (geographical and institutional) contextual characteristics and capacities that port industrial areas present, the actors involved in the process of IS emergence, their (individual and organizational) capacities and roles, and the institutional capacity available in port industrial areas in the form of shared knowledge and frames of reference, relations among actors, the mobilization capacity expressed through the existence of a facilitative entity and process, and specific IS-aiming initiatives and programs that can activate the existing capacity and build it for further IS emergence. Facilitative factors are used interchangeably with enabling and/or fostering factors.

1.1 THESIS' LOGIC AND STRUCTURE

This thesis builds on the research conducted and described in the four academic articles developed along the PhD project and supplemented by the deep insights from real-time IS-aiming initiative Environment^{++}. Two parts constitute the structure of this thesis as presented in Table 1.

Table 1: Thesis structure.

	Introduction
	1. Introduction
	Setting the research scene
Part 1	2. Contexts, challenges, gaps and research questions 3. Theoretical framework 4. Methodological reflections
	Research findings and discussion
Part 2	5. Conceptualizing of industrial symbiosis emergence: Process and facilitative factors 6. Empirical insights from industrial symbiosis emergence within 'Sustainable Synergies' project in Aalborg East port industrial area 7. Initial conditions for industrial symbiosis emergence 8. Developing a deeper understanding of industrial symbiosis emergence
	Conclusion
	9. Conclusion

Part 1 focuses on **s**etting the practice and academic scene for the research undertaken. It includes a section presenting the engagement of modern ports and the Port of Aalborg with industrial symbiosis and describes the challenges and opportunities that exist at the Aalborg East port industrial area regarding IS emergence. Moreover, it includes a state-of-the-art review of the IS literature, and theoretical perspectives on institutional capacity which provide the theoretical framework for this research. A presentation of the research design and methodological reflections on both doing research and being a researcher follows.

Part 2 is the synthesis of research findings, which includes a compilation of articles developed along the PhD project carefully knitted together with and discussed against empirical insights from the IS emergence process in Aalborg East port industrial area to form the logic story this thesis seeks to present.

Chapter 5 introduces an initial conceptualization of IS emergence as developed by Mortensen and Kørnøv (cf. 2019 #1). The authors develop an IS emergence conceptual model presenting IS emergence as a social and dynamic process with three sub-phases enabled by specific factors found to be critical for the process. This conceptualization is then supplemented by another approach to IS emergence developed by Schlüter et al. (cf. 2020 #4), which explores the influence and interconnectedness between existing symbiotic linkages and the emergence of new ones. Schlüter et al. (cf. 2020 #4) makes use of the analogy to biologic processes of reproduction to develop a new conceptual model describing possible paths for IS emergence. The existing symbiotic linkages are found to be important contextual factors that could encourage emergence of new ones through different reproductive dynamics. Such dynamics provide a new understanding of the IS emergence process and complement the initial understanding developed by Mortensen and Kørnøv (cf.

2019 #1). Hence, contributing to a richer conceptualization of IS emergence process and deeper insights in the factors that can facilitate it.

Chapter 6 takes an empirical approach to IS emergence through the Sustainable Synergies project, a sub-project to Environment^{++} initiative in Aalborg East port industrial area, and applies the initial conceptualization developed by Mortensen and Kørnøv (cf. 2019 #1) to analyze the empirical data. The empirical data, collected through individual and focus group interviews, observations, and document analysis are in turn used to complement, enrich, and develop further the IS emergence conceptualization. Additionally, the IS reproduction model developed by Schlüter et al. (cf. 2020 #4) is then applied to the empirical findings to develop a deeper understanding of the facilitative and reproductive dynamics, and how these complement each other.

Chapter 7 deep-dives into the contextual factors that can enable IS emergence in Aalborg East port industrial area. This chapter focuses on the Aalborg East port industrial areas' characteristics and capacity for facilitating IS emergence. Within such areas, ports play an important role. Within IS emergence in Aalborg East port industrial area, the Port of Aalborg was one of the two co-founders of the IS-aiming initiative, Environment^{++}. Understanding the underlying motives for the port's engagement in IS emergence as well as the actions it took prior to this, may raise awareness of specific initial conditions enabling IS emergence in such contexts. Mortensen et al. (cf. 2020 #2) explored the case of Port of Aalborg and mapped its environmental evolution, which explains how the port became the catalyzer of the IS emergence process. This section, therefore, includes this article complemented by a discussion regarding port characteristics found to be important through observations, informal discussions, and participation in various meetings during the PhD project.

Having understood the process of IS emergence in Aalborg East port industrial area, *chapter 8* turns the gaze towards other port industrial areas and explores how IS emerges and what factors enable it. The two-fold aim is 1) to dive deeper into the understanding of IS emergence in port industrial areas and the factors that can facilitate it in such contexts; and 2) to provide inspiration to practice in Aalborg East port industrial area. Mortensen et al. (cf. under review #3) explored IS emergence within three cases of European port industrial areas and the article is included here. A discussion section is integrated to put the process of IS emergence in Aalborg East in perspective with IS emergence process in other port industrial areas.

A *conclusion chapter* discusses the findings of this research and explains how these answer the research questions raised. Moreover, it presents the findings' contribution to both the field of IS research and the practice of IS emergence in Aalborg East port industrial area.

PART 1

Setting the research scene

2 CONTEXTS, CHALLENGES, GAPS AND RESEARCH QUESTIONS

As mentioned in the introduction, this thesis addresses and builds on the challenges and opportunities of IS emergence in practice and in the IS literature. Understanding first the challenges and existing gaps in both practice and the IS literature help identify new research possibilities. The challenges, possibilities, and the gaps provide the basis for this research's problem formulation and subsequent research aim, objectives, and design (presented in section 2.3.). Thus, this chapter first introduces the industrial symbiosis emergence within port industrial areas and focuses on the ports' engagement with IS. Then it unfolds the challenges and possibilities for facilitating industrial symbiosis emergence encountered at the practice level in Aalborg East port industrial area (section 2.1.2.). Furthermore, section 2.2 presents the state-of-the-art of industrial symbiosis literature, which allows identification of research gaps that are addressed by this thesis.

2.1 INDUSTRIAL SYMBIOSIS WITHIN PORT INDUSTRIAL AREAS

Ports and their adjacent industrial areas function as geographical contexts for the study of industrial symbiosis emergence. A general understanding of ports' engagement with IS and the specific challenges and opportunities that exist in regard to the IS emergence in the port industrial area of Aalborg East is necessary. The following section examines these aspects, situating this research within the specific practice field of IS emergence in port industrial areas. First, the engagement of ports with industrial symbiosis strategies is introduced to situate this research within a broader context. Then, specific characteristics of the Port of Aalborg and its industrial area in Aalborg East, the challenges with IS initiation through the years, and opportunities provided by the Environment^{++} are presented as the background and motivation for this research.

2.1.1 Ports' implication with industrial symbiosis emergence

From gateways for goods and passengers, modern ports have evolved into being logistical hubs and service centers integrated into globalized supply chains and continue to evolve towards integrating port-city regions and catalyzing hinterland development (cf. Mortensen et al, 2020 #2). Current cases from all over the world, as depicted in the Table 2, portray ports as facilitators of sustainable business development. Socio-economically, these can contribute to "*the local employment rate, the development of education and knowledge, the 'livability' of the surrounding area, and the overall relation between the port and the city*" (cf. Mortensen et al., 2020, p. 4, #2). Environmentally, ports consider activities supporting environmental management systems, and engage with facilitation and implementation of industrial symbiosis and ecosystem initiatives between the port, industries, and the city (cf. Mortensen et al., 2020 #2). The ports' engagement with industrial symbiosis marks a change from a traditional port orientation, as a logistical hub and service operator, to a wider managerial role within the local community and as a sustainable industrial system developer (ESPO, 2012; Gjerding & Kringelum, 2018).

Ports as laboratories for IS emergence processes implementation. In this regard, ports are described as "*laboratories for the implementation of industrial ecology*" (Cerceau et al., 2014, p. 2) and given an interesting role in industrial ecology and circular economy initiatives (Merk, 2013; Cerceau et al., 2014; Mat et al., 2016). Ports, implementing IS-aiming initiatives, develop resource exchanges and utility sharing initiatives as symbiotic forms of collaboration among companies leading to the formation of symbiotic networks and can transform themselves into recycling hubs, eco-industrial parks, (social, industrial) community managers, or/and systemic coordinative agents (Merk, 2013; Hollen, van den Bosch, & Volberda, 2015; Gjerding & Kringelum, 2018). Mat, et al. (2016, p. 373) mentions that such initiatives "*allow (…) to implement new models of [local and regional] development, more collaborative and more complex*," which can contribute positively to regional socio-economic growth with considerable environmental gains (Xiao & Lee Lam, 2017). The ports' engagement with IS, developing industrial ecosystems at port perimeters and in the region, can drive port competitiveness and the sustainable development of the entire port and urban region (Cerceau et al., 2014).

Table 2: Overview of ports implementing IS-aiming initiatives. Sources: Merk (2013); Cerceau et al. (2014); Mortensen et al. (cf. under review #3); Mortensen et al. (cf. 2020 #2); Mannino. Ninka, Turvani, & Chertow (2015); van Berkel, Fujita, Hashimoto, & Fujii (2009). This is not an exhaustive list, as numerous other ports implement such initiatives as a strategy for achieving sustainability, while their efforts remain unknown to the academia; or might be involved at different degrees in such processes at their hinterlands or cities' level (see e.g. LOOP Ports, 2020).

Continent	Ports implementing IS initiatives
Europe	Port of Amsterdam (NL) Port of Zeeland Seaports (NL) Port of Rotterdam (NL) Port of Moerdijk (NL) Port of Antwerp (BE) Port of Ghent (BE) Port of Brussels (BE) Port of Fos-Marseille (FR) Port of Bristol (UK) Port of Galicia (ES) Porto Marghera (IT) Copenhagen Malmö Port (DK, SE) Port of Aalborg (DK)
Asia	Port of Osaka (Japan) Port of Kawasaki (Japan) Port of Kitakyushu (Japan) Port of Tianjin (China) Port of Ningbo (China) Port of Ulsan (Korea) Port of Map Ta Phut (Thailand)
North America	Port of New York/New Jersey (USA) Port of Long Beach (USA) Port of Houston (USA)
Africa	Port of Jorf Lasfar (Morocco) Port of Morocco (Morocco) Port of Bejaïa (Algeria)

Examining the ports in Table 2, it appears that these differ from one another by covering various sizes of land area, handling various amounts of goods, having varied sizes of geographically related clusters of industries and resource flows, and being integrated with urban areas to different degrees. A review of the literature addressing port engagement with IS shows that the ports' various forms of engagement with IS are shaped by the ports' characteristics (Merk, 2013; Mat, Cerceau, Lopez-Ferber, & Junqua, 2017).

Ports' involvement in urban symbiosis. Examining the literature describing the ports' engagement with IS, it can be stated that some ports, such as Port of Rotterdam, Port of Osaka, Port of Kawasaki, and Port of New York are perceived as merely metropolitan port regions (Cerceau et al., 2014). Despite that, these also accommodate various industries; these ports are integrated in urban areas, while also presenting a concentration of general cargo, energy flows, and import of goods (Ducruet & Itoh, 2016). Such ports seem to engage with development of urban symbioses rather than industrial symbioses. These include "*technical-material functioning, economic rationale (e.g. generating new economic activities, improving resource efficiency), and environmental benefits*" (Lenhart, van Vliet, & Mol, 2015, p. 595). An urban symbiosis, according to Lenhart et al. (2015) differs from an industrial symbiosis in that it focuses on the entire urban system, not only the port perimeter or its direct hinterland.

Ports' involvement in industrial symbiosis. Some other ports, such as Port of Antwerp, Port of Galicia, Porto Maghera, and the Port of Ulsan can be mostly characterized as industrial port regions (Cerceau et al., 2014). These are port areas located close to, but not integrated into, metropolitan areas that accommodate large industrial (e.g. petro-chemical, manufacturing, etc.) clusters with a variety and diversity of companies. Such ports can be characterized by a large amount of traffic and large container terminals, that many times operate along with industrial hubs. These are often integrated within a dense global supply chain network, as their main function is to distribute cargo across national and international borders. (Ducruet & Itoh, 2016) Such ports are prone to engage with industrial symbiosis at different geographical levels, i.e. symbioses between business organizations at the same industrial area, between business organizations at the port industrial area and the businesses organizations outside it but still in the same region, and/or between business organizations at the port industrial area and business organizations outside the regional and national borders. For example, Rotterdam created symbioses across local and regional borders with Port of Antwerp, the Port of Moerdijk and the Terneuzen region for creating a large, world-leading petro-chemical eco-industrial system (Cerceau et al., 2014).

Thus, ports continue to function as gateways to goods, as distri-hubs and/or peripheral hubs (Ducruet & Itoh, 2016), regulators, landlords, and system operators (Gjerding & Kringelum, 2018). These characteristics present possibilities and opportunities for ports regarding engagement with IS at different geographical scales.

IS dynamics and rationale within port industrial areas. The engagement of ports with IS is not only dependent on the specific profile, geographical placement of the port in relation to urban settlements, and the availability of a critical mass of companies that are clustered in specific types of industries. This can also depend on other developments at organizational, local, regional, and national levels regarding IS. Different motivations and rationales encourage ports to engage with IS. Cerceau et al. (2014, p. 11) group these reasons into three main rationales: 1) a short-term reaction to a declared urgent situation; 2) a middle-term strategy of precaution in response to environmental challenges; and 3) a long-term ambition in order to provoke needed change.

For example, in Port of Rotterdam, engagement with IS initiatives was initially a companies' response to tighter regulation and environmental issues, and since then, it developed into the port's vision, which integrates industrial ecology pro-actively in the port's strategy (Cerceau et al., 2014). Lastly, named processes point at a middle-out approach to IS emergence (Costa & Ferrão, 2010). Such an approach builds on a combination of top-down and bottom-up processes with high engagement of various stakeholders from across sectors, as also used in the case of the Port of Ulsan. Even though IS implementation was sought through the National Eco-Industrial Park Development Program, government, industry, researchers, and other stakeholders where engaged in various activities facilitating IS emergence and development (Park et al., 2016). The process of IS development in the industrial area of the Port of Jorf Lasfar in Marocco seem to also have developed through a collaborative middle-out initiative engaging a multitude of stakeholders for water and energy consumption optimization (Cerceau et al., 2014).

In North American ports, such as Port of New York the relevance of applying IS to the port area was evaluated by 70 institutions, prior to it being used as the tool for reducing contaminant flows within the watershed and a tool to plan for sediment management (Cerceau et al., 2014). Such an approach points rather at top-down and planned processes for IS implementation. Also, this approach can be seen at many of the Asian ports. Especially Chinese port industrial areas play an important role in implementing the country's "*National Pilot Eco-Industrial Park Program.*" Within the port industrial area of Ningbo, for example, the district authorities promote a strategy for emission reduction and efficient energy use. (Cerceau et al., 2014) The same is the case of the Ports of Kawasaki, Osaka, and Kochi (van Berkel et al., 2009). These were part of the larger Eco-Town program in Japan where local authorities planned for industrial symbiosis implementation as a strategy for industrial rejuvenation of harbor areas, for expansion of a cluster of recycling industries at the port industrial areas, or as a strategy for "*a national model for recycling oriented urban society*" (van Berkel et al., 2009, p. 1548).

In the cases of large port industrial areas such as Tianjin in China and Porto Margera in Italy, large industrial sectors have existed for decades. Such industrial areas have passed through several restructuration periods and mostly self-organized for industrial symbioses and transformed into eco-industrial parks "based on opportunistic exchanges in bilateral relationships" (Mannino et al., 2015, p. 292) and for "*economic cost-savings reasons*" (Shi, Chertow, & Song, 2010, p. 198). Later, the eco-industrial park in Tianjin developed through coordinative and facilitative processes that activated the existing capacity in the region and also built it further for IS development (Wang et al., 2017). The purpose of IS application in the Port of Tianjin was maximization of the energy performance of the area (Cerceau et al., 2014), while in Porto Maghera, IS initiatives sought a remediation of the environmental damages of larger industries and diminution of social mis-complacency with these (Mannino et al., 2015).

In the case of the Port of Long Beach, for example a Port-to-Port collaboration initiative based on synergistic relations was triggering the pro-active initiative of six ports regarding the problem of managing contaminated dredged materials (Cerceau et al., 2014). Such initiatives point at a pro-active attitude of ports and at a high level of engagement with IS. Such proactiveness can be found at the Port of Amsterdam and the former Port of Zealand, now the North Sea Port (Spekkink, 2013; 2015).

Ports seem to engage with IS for different reasons and through different dynamics. Some initiate IS-aiming projects by themselves and pro-actively engage in IS emergence and development, while others are participants in IS-aiming programs. Some are part of self-organized processes, and others are part of facilitative processes or both. When considering IS emergence within such contexts one may spot the need for approaching each context separately, considering each context's characteristics, motivations, and rationales for IS, as these seem to shape the process and the port's engagement with IS. While this overview of ports' interaction with IS can present inspiration for facilitation of IS emergence in other port industrial areas, it appears that processes within one port industrial area may not be the same as in other port industrial areas. While acknowledging the inspirational role of such examples, a specific focus on each port's characteristics, rationales, and motivations appears to be necessary.

Ports roles within IS emergence processes. The different ways of engaging with IS can mean that ports play different roles for IS emergence and development. Examining further the examples of ports from Table 2, it is found that in Port of Antwerp, for example, the port authority provides funding for synergies, leads various IS-aiming projects, and mediates among actors (city, companies, and other institutions) in IS-aiming projects (Cerceau et al., 2014). Such a type of support is also mentioned by Spekkink (2015) regarding the involvement of the former Zealand Sea port and now North Sea port. However, while out of the 17 ports studied by Cerceau et al. (2014), 11 port authorities were found to provide financial support; not all ports seem to be leading actors for IS emergence and development processes. Some examples exist where port authorities, of e.g. Port of Long Beach, Port of Moerdijk and Port of Amsterdam, played facilitative and coordinative roles for IS-aiming processes. However, in many cases the role of ports and port authorities in IS emergence and development are not clear as not much evidence exists on these (see e.g. Park et al., 2016; Shi et al., 2010). As those examples that address the ports roles in IS emergence processes point at an important leading, coordinative, and facilitative function, understanding the role that ports can play within similar processes in different context can be necessary. First, understanding the variety of the roles that ports can play enriches the understanding of ways through which these can engage with IS. Identifying the range of roles in different contexts can provide inspiration for other ports, in other contexts, to engage with such processes. Then, engaging with IS through playing different roles can be thought to have implications for both the port and the IS emergence and development. For example, a port leading the processes of

IS emergence and development is expected to have a larger influence degree on the course of IS development, than a port that is only supporting the process financially.

To conclude, it appears that ports engage in different ways with IS emergence and development, and play different roles that allow them various degrees of influence on these. Furthermore, the ports' characteristics seam to shape the dynamics of IS emergence and set the focus on the need of examining each context separately in order to understand IS emergence and development. As this research is an integrated part of the process of IS emergence in port industrial area in Aalborg East, it is thus necessary to focus specifically on both this exact process (implemented by the Environment^{++} initiative) and the Port of Aalborg's characteristics and capacities for accommodating the port industrial area in Aalborg East. Before examining the IS emergence process in this specific context, it is necessary to have an introduction to both the area and the challenges and opportunities with IS emergence, as these motivate the present research.

2.1.2 Industrial symbiosis emergence in the Aalborg East Port industrial area: Challenges and possibilities

Port of Aalborg, situated in Northern Jutland, Denmark and being a public limited company with Aalborg Municipality as the only shareholder, is one of the few Danish ports that pro-actively integrates sustainable development into port strategy and uses it for port and hinterland development. Anchored in the port's philosophy from 2009 (cf. Mortensen, et al., 2020 #2) and in its Intelligent Port strategy, the port's Sustainability Strategy, and the 2050 Development plan (Port of Aalborg, 2019b), environment is perceived by the port as a promising competitive growth parameter. As an inland port, it acknowledges the economic potential that lies in adopting the strategic use of industrial symbiosis for environmentally and socially responsible economic development in both the port and the industrial area at its hinterland

Industrial symbiosis application at the Port of Aalborg perimeter and its industrial areas is expected to create growth through raising the attractiveness of the region and generate new jobs by sustainably developing the existing companies in the port industrial area and attracting new ones to the area. Furthermore, the port, by applying a Triple helix model to collaboration (Etzkovitz, 2011), enters collaborative relationships across private and public sectors to create symbiosis and sharing economic platforms. These accommodate initiatives and activities directed to the increase of the competitive advantage of port and companies at its industrial area.

Out of the five coastal areas that Port of Aalborg sits on, the port industrial area in Aalborg East is the one where the Port of Aalborg concentrates its port and industrial activities. This area is considered an industrial park with great potential for economic and environmental development. As pictured in Figure 1, it accommodates more than 100 companies (Port of Aalborg, 2019a) at the port perimeter and more than 150 companies at its direct hinterland, i.e. port's immediate vicinity (Erhvervsnetværket 9220, 2020). These present a combination of large, medium , and small companies (conform the EU definition of these [EC, 2003]), active within a variety of sectors organized in several industrial clusters such as cargo, logistics, services, waste management, green energy, wind power, agriculture, metal, food processing, and cement.

Figure 1: Aalborg East port industrial area. Courtesy to Port of Aalborg.

This port industrial area has been a subject for IS-aiming initiatives since around 2011. Becoming a co-founder to the Business Network 9220 in 2011, the port-initiated collaborations with Aalborg Municipality and the Network for Sustainable Business Development in Northern Jutland (NBEN) aiming at facilitating IS emergence in port industrial area in Aalborg East. From 2013 to 2015, a national Green Industrial Symbiosis program unrolled in which Business Network 9220, the port, and the NBEN network collaborated closely for the initiation of symbiotic relations among the business organizations in the area. Networking events, workshops, and site-visits were organized and continuous meetings among actors from various sectors were held by the Business Network 9220 at the port's initiative and involvement and in collaboration with other actors (Schlüter & Milani, 2018).

During this period, the port entered into symbiotic collaborations with companies in the port industrial area. One of these is the synergy between the port and Aalborg Portland, a cement manufacturer. Port of Aalborg provides dredged sand from periodic cleansing of the sailing path in the Limfjord to Aalborg Portland, which uses it in cement production (Schlüter & Milani, 2018)

Researchers and students from Aalborg University were likewise engaged in uncovering the possibilities for the initiation of industrial symbiosis relations in the port industrial area in Aalborg East. Research activities were initiated examining enablers and barriers for IS emergence and the potential of the port industrial area for fostering IS emergence with the aim of identifying ways and mechanisms through which IS could become a reality. Almasi, Soque, Strandgaard, and Sacchi (2011), for instance, focused on examining the potentials and barriers for IS emergence and development in Aalborg. Examining the way the Kalundborg symbiosis functioned, the authors distinguished between a physical, an organizational, and a social dimension of IS. Applying the same way of emergence to the port industrial area in Aalborg East, they found physical and technical potentials, while IS emergence was challenged by social and organizational factors. The authors recommend the establishment of a common communication platform and frequent social interactions among companies, among others, that could foster willingness to join IS and provide access to information. The Business Network 9220 and the NBEN seem to provide these kinds of platforms where their members were involved in the different workshops and networking events.

Then, Madsen et al. (2015) focused on identifying drivers and barriers for IS initiation in Aalborg East industrial area and on developing guidelines for companies to enter symbiotic linkages. They find that among the factors that can enable IS emergence and development are facilitative programs and the presence of a facilitator can guide the flow of knowledge and information needed for initiating IS relationships. The authors also mention trust as important for enabling IS emergence: The trust among the companies and the trust between companies and the facilitator.

Initial research at master's level continued to uncover IS possibilities in the port industrial area in Aalborg East and a focus was shifted to the ways to facilitate IS initiation. Examples from other port areas are presented to Port of Aalborg to provide inspiration for how to engage with IS emergence. For instance, Mortensen (2016), exploring the IS emergence in the Port of Rotterdam industrial area presents the stakeholder engagement and the need for a multitude of interactions among various actors as important mechanisms for IS initiation. Exploring further how various actors could be involved in the environmental processes that can enable IS emergence in the industrial area in Aalborg East, the study proposes a stakeholder engagement model that could benefit the processes of IS emergence. Furthermore, Milani, Schell, & Schlüter (2017), exploring the case of Port of Amsterdam, referred to industrial symbiosis development in the port industrial area in Aalborg East. The authors, supporting the findings of Almasi et al. (2011), find that shared platforms for information and knowledge exchange, together with networking events for relationship formation can function as mechanisms for organizational and social proximity formation. However, instead of pointing at business networks as providing such platforms, the authors point at the Port of Aalborg as one of the various actors that could provide a shared platform for development of symbiotic relations among companies.

The study by Roesen, Troelsen, Vinde, and Jensen (2016) seems to complement Milani et al. (2017) and Mortensen (2016). Their study explored the possibilities of Port of Aalborg facilitating industrial symbiosis at the port industrial area in Aalborg East by making use of discourses. The authors propose that facilitation should engage a multitude of actors, especially companies, in identifying issues to be addressed. Furthermore, the authors point at different ways that the Port of Aalborg can engage with facilitating IS emergence, such as being itself a facilitator or letting a third party facilitate and "*participate in the facilitation process on equal terms as other participating actors*" (Roesen et al., 2016, p. 38).

Despite the fruitful research results, the port's own experiences with IS, and the many meetings, workshops, and site-visits, IS seemed to be slow to emerge in the port industrial area of Aalborg East. A representative of the port mentioned the following at one of the meetings:

"*We needed more knowledge on how to do it. It seems that we have a wrong approach to IS emergence. People and companies are positive, but nobody takes initiative to enter IS. We decided therefore to stop [facilitating IS emergence]*."

(Meeting notes, 2016)

A deeper understanding of the IS emergence process, its characteristics, and the 'ingredients' as factors that could lead to IS emergence was needed. With the implementation of the Environment^{++} initiative, where the focus was set on sustainable business development through an industrial symbiosis strategy, a possibility for approaching existing challenges with IS emergence and learning from ongoing processes appeared.

Environment^{++} is a strategic initiative created in collaboration with The Danish Center for Environmental Assessment (DCEA) at Aalborg University (AAU) with a pre-start period in 2016 and official start in January 2017. Launching this initiative, Port of Aalborg and DCEA aim to transform environmental awareness and management into a sustainable development parameter that has potential to be one of the decisive factors for competitiveness in retaining and attracting companies and new jobs at the port perimeter and its industrial area. The objective is to transform the port industrial area in Aalborg East into an incubator and "*a living lab*" (Port of Aalborg, 2017, p. 14) for sustainable solutions and environmentally sound business models based on industrial symbiosis. The goal is that companies' competitive advantage raises when entering symbiotic relationships, through cost savings, transforming waste into resources, and/or innovation application through developing new products, services, and markets. (Miljø$^{++}$, 2020)

Environment^{++} takes a broader perspective on coordinating IS emergence and engages a multitude of actors in various processes that aim at 1) activating and building a fruitful context for IS emergence and IS initiation, and 2) initiating and developing industrial symbioses among companies in the port industrial area. The initiative focuses, as also represented in Figure 2, on four strategic areas.

Facts box	Environment^{++} focuses on four strategic areas:
Miljø++	• Frameworks for supporting sustainable business development • Strategic and pro-active stakeholder engagement • Developing attractive environments for development of green business models • Platforms for attracting companies through symbioses and resource optimization

Figure 2: Strategic areas of Environment^{++}, based on Miljø$^{++}$ (2020)

Environment^{++} is the framework that accommodates several other initiatives and projects presented in Figure 3 on the next page. As it can be seen in the figure 3 the initiative accommodated until now two sub-projects besides the present PhD project: RUM project and Sustainable Synergies. While RUM project is out of the scope of this research, Sustainable Synergies is included and forms the research subject described in chapter 6.

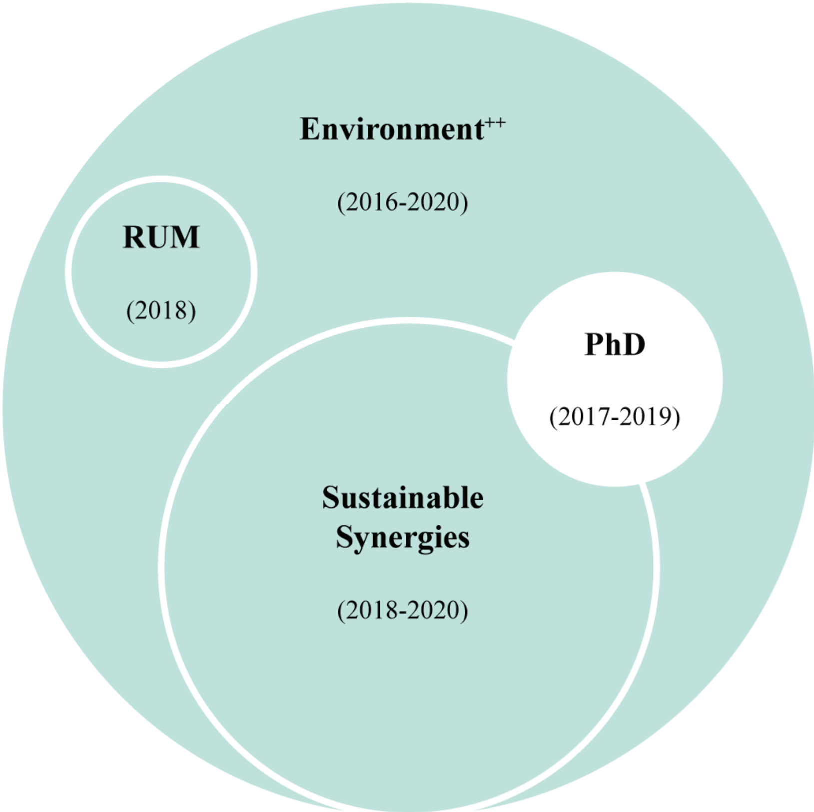

Figure 3: Environment++ and its sub-projects. Developed by the author.

Environment++, with its sub-projects and initiatives, especially the Sustainable Synergies project, which aimed at initiating industrial symbioses among companies in the port industrial area, offered the possibility for following IS emergence in the real-life context of Aalborg East port industrial area. Using this, learning about how IS can emerge and the factors that can facilitate the IS emergence within this context was possible.

Thus, Environment++ provided the possibility for an industrial PhD project where an applied and contextualized research approach was taken towards studying the IS emergence and "ingredients" facilitating it in port industrial area in Aalborg East. The challenges with IS emergence before Environment++ encouraged the focus of this research. Moreover, the unfolding of Environment++ initiative and its sub-project Sustainable Synergies provided a unique possibility to follow the real-time processes leading to IS emergence. Learning from first-hand experiences and contributing to elucidating *how IS emerges and what factors can contribute at its emergence in*

Aalborg East port industrial area was of crucial importance to the actors involved with IS emergence in Aalborg East and became the questions leading my research.

2.2 Emergence of industrial symbiosis: Identifying the gaps

As presented in the previous section 2.1, IS is widely adopted as a strategy for port industrial areas' development around the world and in Aalborg East. Ports engage with IS in various ways and various IS dynamics are implemented at port industrial areas. In the port industrial area in Aalborg East, however, despite the pro-activeness of various actors in the region, the Port of Aalborg's engagement with IS since decades ago, and the development of a large body of research, the creation of symbiotic relationships seems to be challenging in practice. The questions raised by the challenges and opportunities provided by Environment^{++} and its sub-projects—how IS emerges and what contributes to its emergence—seem to be a continuous subject of interest for researchers in the field. A rich body of research over the past several decades has addressed subjects including IS evolutionary phases, IS dynamics, key determinants, and enablers of IS. Research presents experiences with IS-aiming initiatives in various contexts (see e.g. Park et al., 2016; Park et al., 2018) and considers ways of learning how to improve the IS development from such initiatives (Wang et al., 2017). The following sections highlight the state-of-the-art within the IS literature, identifying the research aspects that need more attention and presenting the research questions guiding this research.

2.2.1 Dynamics of industrial symbioses' emergence

Ehrenfeld (2009) defines IS emergence as the process of coming about with new, dynamic, evolving, and adaptive industrial system properties, formed by the desires and good will of the system components: human actors and context. Such an interpretation is shared by the researchers raising focus on understanding IS emergence as a social collaborative process (Boons et al., 2014; Wang et al., 2017) that can lead to formation of symbiotic inter-firm linkages. Conceptualizing IS as a social process implies the consideration of IS evolution through *emergence*, *development,* and *decline* phases (Boons et al., 2014). While there is agreement among IS scholars concerning the phasic evolution of IS, the definitions of IS emergence are varied, as is the understanding of boundaries and characteristics.

For instance, Doménech & Davies (2011) describe IS *emergence* as the phase that "*sets the basis of the dynamics of cooperation*" (p. 288) occurring through self-organized or facilitated processes before a *probation* phase that accumulates the feedback from initial IS experiences and that encourage further *developments and IS network expansion* or its *termination*. Building on theoretical perspectives presented by Boons & Berends (2001) and Baas & Boons (2004), Chertow (2007) argues that symbiotic linkages emerge through an initial *period of self-organization*, followed by a "*period of sustaining interfirm exchange, including some new entrants and some die-offs*" (p.24) before symbiotic linkages are uncovered by a third party and "*choices concerning efforts to coordinate and attract additional symbioses' are made*." (p.24)

Chertow & Ehrenfeld (2012) propose IS emergence through *sprouting* and *uncovering* phases where firms explore opportunities for new linkages from previous and future possibilities along the supply chain, until they are recognized by a third party. Then they move into an *institutionalization and embeddedness* phase, where structures and institutions aiming at IS initiation form. Paquin & Howard-Grenville (2012, p. 87), refer to the IS network evolution, and describe network emergence as going through a "*pre-network development"* phase, which embraces activities/processes through which actors learn of IS and its benefits and learn about their potential partners. Then this phase is followed by the "*earlier network development"* phase, where partners connect to each other and new symbiotic linkages can be born. Following these two phases, comes the *"later network development*" phase, where "hands-on selection of particular IS opportunities and participants" takes place.

While this body of research provides common ground for understanding IS evolution, it remains unclear about IS emergence, as it is based on different empirical cases where IS evolution unfolds through different dynamics. Some refer thus to self-organization of firms into symbiotic relations, while others refer to a third party facilitating symbiotic relations and middle-out processes. Some refer to bilateral linkages and some to the symbiotic network formation. This disparate understanding of IS emergence, based on multiple cases, challenges the common ground among IS researchers when defining IS emergence. This, in its turn can challenge practice when engaging with IS emergence, as no clear understanding of IS emergence exists. Development of a common conceptualization of IS emergence could facilitate a better understanding of this specific phase as different from IS development and its termination, which can facilitate its initiation in practice.

Boons et al. (2017) try to solve this problem of equivalence among the different empirical cases by proposing seven dynamics leading to IS emergence and development: self-organization, organizational boundary change, facilitation by brokerage, facilitation by collective learning, pilot facilitation, governmental planning, and eco-cluster development. Sun et al. (2017) identify an eighth dynamic, anchoring, which is perceived as a convergence between the self-organization and facilitation dynamics proposed by Boons et al. (2017). Anchoring emphasizes the importance of events, actions, and specific activities taken by various (individual, organizational, or networked) actors in a specific context to support IS emergence and development. The research on IS dynamics raised focus on the processes, mechanisms, and approaches to IS emergence and development in specific contexts. Furthermore, these encouraged researchers to consider initial contextual conditions for a better understanding of mechanisms that can lead to symbiotic linkage emergence and network formation.

The necessity of considering contextual characteristics to understand mechanisms through which IS emerges is expressed by the presence of a large body of contextualized research encompassing a multitude of examples. For example, Park et al. (2018) provide a description of a pilot program in Colombia in which, through a specific program and workshops with a multitude of actors, multiple symbiotic linkages were identified and an emerging IS network was forming. Park et al. (2016) provide insights from the Korean government-initiated facilitation model of IS emergence and development. Costa and Ferrão (2010) argue for a middle-out approach, where IS is encouraged through a combination of top-down and bottom-up[1] processes. Mirata and Emtairah (2005) provide insights from Landskrona industrial process based on networking. Mirata (2004) provides insights from facilitative inputs during the first stages of NISP program in the UK through a brokerage approach. Cutaia et al. (2015) provide a platforming model for facilitating IS emergence and development in Italy. While these examples contribute to the academic field of IS by presenting examples of the various IS dynamics, they also provide inspiration to the practice in other contexts.

2.2.2 Factors enabling industrial symbiosis emergence

IS literature refers to multiple (contextual) factors that can enable IS emergence. Referring to the enablers for IS emergence and development through various IS dynamics, Boons et al. (2017) do not distinguish the factors specific only for IS emergence. Instead, they argue that "*it is possible to identify conditions that are generally more or less favorable to most of these*" (Boons et al., 2017, p. 9). They summarize these into four groups of factors: technical, economic, geospatial, and social/institutional conditions, while Mirata (2005) adds political, informational, human, and organizational to these. Park et al. (2018) complement these groups and adopt the same grouping as Boons et al. (2017) with a differentiation between the social and institutional factors. Velenturf (2016) maps the factors affecting IS emergence and development and proposes the concept of "proximity" for classification of these into several groups: geographical proximity, organizational proximity, social proximity, institutional proximity, and cognitive proximity. Yap and Devlin (2017) complements these by arguing for the importance of a favorable institutional context. Thus, several groups of factors can be perceived as enablers for IS emergence: geospatial factors, technical factors, economic factors, human and organizational factors, informational factors, institutional factors, and social factors

Such factors are observed to refer to both IS emergence and development, with unclear distinction among these. A few cases (e.g. Doménech & Davies, 2011; Yap & Devlin, 2017) seem to refer specifically to the initial phase of IS emergence and identify

[1] 'Top-down' referring to the high engagement of a facilitation team and its coordination of the process. 'Bottom-up' refers to the freedom of engagement that each actor had during the process, without being steered by the facilitation team.

factors that could influence it. However, even within these studies, the definition and boundaries of IS emergence are blurry, as are the insights on factors affecting it. Exploring specific factors only for IS emergence can raise focus on these factors and provide understanding of mechanisms through which these can be addressed.

Connecting these groups of factors to IS emergence within a specific context, it can be observed that these describe the characteristics and capacities of the context. Mirata (2004) and Costa and Ferrão (2010) refer to specific institutional environments that have supportive policy and regulatory frameworks, as well as specific incentives and structures supporting and encouraging IS emergence and development. Contexts that accommodate various factors that enable IS emergence and development are considered fruitful contexts. Fruitful contexts can also accommodate specific IS-aiming initiatives that can function as platforms for actors' engagement and interaction. Such platforms can accommodate the processes of unveiling the possibilities that lie within the unused and available resources, specific procedures for negotiation and cooperation, for learning by doing, and for further building on the existing collaboration culture (Doménech & Davies, 2011).

Doménech and Davies (2011) suggest further that institutional contexts accommodating a culture of cooperation built on the experience with collaboration, and actors that can take coordinative roles, are fruitful contexts for IS emergence. Tudor et al. (2007) complement insights in fruitful contexts and state that fruitful contexts, beside the beneficial and supportive political climates, accommodate individuals and organizations motivated and capable of embracing the possible benefits of IS, and facilitative structures (economic, knowledge, relational, etc.) that can offer support and can assure the long-term continuity of the symbiotic system created.

Boons et al. (2011) and Boons and Spekkink (2012) state that in order for a context to be able to foster IS emergence and development, it needs a certain level of institutional capacity, i.e. knowledge, relations, and mobilization capacity. Spekkink (2013, pp. 343) explains that "*there should be a network of actors that trust each other and have some level of mutual understanding (relational resources), that have shared definitions of problems and solutions, possibly codified in plans or even strategic visions (knowledge resources), and that among them there are actors with sufficient power and resources to mobilize others for action (mobilization capacity)*." Focusing on contextual capacities that can foster and encourage IS emergence seem to be as yet under researched. Scholarly efforts concerned with the factors influencing IS emergence, appear most often to examine drivers and limitations (Tudor et al., 2007), critical factors and antecedents (Boons et al., 2011), enablers/challenges, as initial conditions for IS emergence (Boons et al., 2017). Examining these as characteristics of a geographical context invite a focus on specific capacities that the context has for fostering IS emergence.

Furthermore, identifying the enabling factors specific for IS emergence, can increase the understanding of IS dynamics, as well as the mechanisms and initial conditions that enable it. With a certain level of contextual capacity, enabling factors and initial conditions can be addressed and IS emergence dynamics can be shaped. Thus, in order for IS emergence to be encouraged there is a need for a deeper understanding of this specific phase of IS evolution: IS emergence, its process, dynamics, and the factors and mechanisms that enable it specifically. As IS emergence is context-dependent, it is necessary to develop contextually embedded knowledge for specific geographical areas and to examine their characteristics and the capacities they present for fostering IS emergence. The focus on the contextual (institutional) capacity to address factors enabling IS emergence accentuates the importance of doing contextualized research. This kind of research identifies context capacities for fostering IS emergence and the quantifies the capacities that the context needs to acquire. Moreover, contextualized knowledge could inspire the design of specific actions for addressing the missing capacities and shape capacity building initiatives for further IS emergence.

2.3 RESEARCH QUESTION(S), OBJECTIVES, AND CONTRIBUTIONS

In connecting the gap between the IS literature and IS emergence in practice, e.g. in the port industrial area in Aalborg East, the need for IS emergence to be encouraged in such contexts, contextual characteristics is identified. Building on the insights from IS dynamics, an initial conceptualization of the IS emergence process is developed. Moreover, experiences from other contexts provide inspiration and enrich the initial conceptualization of IS emergence and enlarge the understanding of IS emergence in port industrial areas. The currently unfolding IS-aiming initiative in Aalborg East port industrial area, Environment^{++}, and its embedded facilitation process, Sustainable Synergies project, present an opportunity for collecting real-time insights on IS emergence processes, mechanisms, and factors that enable IS emergence within this specific context. Contextual research into the IS emergence in Aalborg East port industrial area aims to raise awareness of port industrial areas' characteristics, the dynamics of IS emergence within these, and ways to further encourage the IS emergence and development.

Through conceptual development and empirical studies, the present research aims at enriching the scientific understanding of industrial symbiosis emergence and of specific factors that can facilitate it. Likewise, the research seeks to provide insights in contextual characteristics of port industrial areas as factors fostering IS emergence. Similar to achieving a scholarly aim, this research aims at empowering the practice of IS emergence in Aalborg East port industrial area through collecting inputs from the on-going IS-aiming initiative, Environment^{++}, and providing inputs for further IS emergence.

The following main question guided this research:

How can industrial symbiosis emerge and what factors can facilitate the industrial symbiosis emergence in Aalborg East port industrial area?

To elucidate the research question, an embedded case strategy is adopted, where the IS emergence process in Aalborg East port industrial area is used as the main case, while other secondary cases contribute to enriching the empirical findings and to conceptualizing IS emergence in port industrial areas. By applying a case study strategy for this research, five objectives were formulated following recommendations by Saunders, Lewis, & Thornhill (2016, pp. 44-45):

1. To explore and analyze the process through which IS emerges
2. To develop a conceptualization of IS emergence
3. To identify the specific factors that can enable IS emergence
4. To identify the contextual characteristics and capacities that Aalborg East port industrial area presents for fostering IS
5. To identify how IS emergence can be further facilitated in Aalborg East port industrial area

To address the research objectives, the following research sub-questions (RSQ) are raised: Two research sub-questions (RSQ 1 & RSQ 2) refer to the scholarly conceptualization of IS emergence and factors that enable it, and two research sub-questions (RSQ 3 & RSQ 4) examine the practice of IS emergence in port industrial areas.

RSQ 1: How can industrial symbiosis emerge?

RSQ 2: What are the factors that can facilitate industrial symbiosis emergence?

RSQ 3: What are the specific contextual characteristics and capacity of Aalborg East port industrial area that can facilitate IS emergence?

RSQ 4: How can the IS emergence be further facilitated in Aalborg East port industrial area?

Further guiding questions arose along the research process as it unfolded following a flexible research design approach (Robson & McCartan, 2016), i.e. evolving from the gaps identified in the IS literature and the interests and possibilities provided by the Environment^{++} initiative in Aalborg East port industrial area. For instance, questions such as the ones presented in Table 3 guided the research during the PhD project:

Table 3: Guiding questions for research.

Level of enquiry	Guiding questions
Conceptual	• How can IS emergence be defined? • What are IS emergence characteristics, boundaries and dynamics?
Port industrial areas	• How does IS emerge in port industrial areas? • What factors can enable and facilitate industrial symbiosis emergence in general and in in port industrial areas specifically? • What characteristics do port industrial areas present that foster IS emergence? • What role can ports play in enabling IS emergence?
Aalborg East port industrial area	• What characteristics does the IS emergence in Aalborg East port industrial area present? • Who is involved in IS emergence process and how does IS emergence unfold at Aalborg East port industrial area? • What are the capacities of Aalborg East port industrial area for facilitating IS emergence? • What can the role of Port of Aalborg be in fostering IS emergence in Aalborg East port industrial area? • How can IS emergence be further encouraged in Aalborg East port industrial area?

Delimiting IS emergence from IS development and providing a conceptualization of IS emergence, sets specific focus on this exact phase of IS evolution, on its particularities and characteristics, and raises attention on specific factors that could foster it. Emphasizing IS emergence and factors enabling it, elucidates particular factors to be addressed through facilitative processes encouraging a practical application of IS initiation and thus encouraging IS emergence.

By exploring real-time and on-going IS emergence within Aalborg East port industrial area, new insights on IS dynamics from a port industrial area context are created constituting an important input to the field of IS: these provide a deeper understanding on how IS emerges and develops, and an understanding of evolutionary paths within such specific contexts. Connecting these to the necessity of studying the initial conditions that enable IS emergence in specific contexts, as proposed by Boons et al. (2017), creates a better understanding of the IS dynamics and the contextual factors that trigger them. By that, it encourages IS emergence in contexts with similar characteristics. Understanding the specific characteristics and capacities present in port industrial areas, provide important inputs to the practice, in the form of the significant capacities to be activated through facilitative processes for further IS emergence in such contexts.

3 THEORETICAL FRAMEWORK

The insights from IS literature point at several groups of factors that can be perceived as enablers for IS emergence: geospatial, technical, economic, human and organizational, informational, institutional, and social factors. Such groups of factors refer to contextual characteristics that can enable IS emergence and development within a particular context. Furthermore, the literature points at the need for a specific institutional capacity to be present for IS to emerge and develop.

However, the literature does not refer to factors specific for IS emergence, but rather to factors for IS initiation and development. Moreover, the literature is also scarce on presenting factors, contextual characteristics, and institutional capacity that port industrial areas have for enabling IS emergence.

As specified in the research objectives (section 2.3.), there is a need for establishing a frame of reference in regards to the existing knowledge on factors enabling IS emergence and development. Furthermore, insights within the institutional capacity as a theoretical framework can lead to a deeper understanding of the factors and mechanisms that enable IS emergence in port industrial areas.

The following sections aim, thus, at establishing the theoretical frame of reference for understanding the factors facilitating IS emergence.

3.1 FACTORS ENABLING INDUSTRIAL SYMBIOSIS EMERGENCE

IS emergence and development is found dependent, among other things, on the national and general development of international experiences with applying IS as a strategy for achieving sustainable development, remediation of urban, industrial, and environmental challenges, and the span of its benefits for society, industry, and environment (Elabras Veiga & Magrini 2009; Velenturf, 2016a; Spekkink, 2015; Madsen et al., 2015).

The IS literature presents local characteristics of specific contexts that are expected to have a larger influence on IS emergence and development (Costa & Ferrão, 2010; Boons et al, 2017). Such characteristics set specific geospatial, technical, economic, human and organizational, informational, institutional, and social conditions from which IS can emerge and develop. The following sets focus on these and refers to these as contextual factors that shape the context's capacity for enabling IS emergence and development. Understanding these, even though they refer to both IS emergence and development, can contribute to a better understanding of which characteristics and capacities port industrial areas can have for enabling IS emergence and development.

The pool of organizations gathered within a geographical area and the distance or proximity among these (Velenturf, 2016a) characterize the **geospatial conditions** of a context for fostering IS emergence. The proximity among organizations within a specific geographical area is referred as to the co-location of organizations within a defined physical context (Mirata, 2005). The co-location of organizations implies a small geographical distance among these, which can facilitate organizations taking advantage of the agglomeration economies (Chertow & Ehrenfeld, 2012; Chertow, Ashton, & Espinosa, 2008). First, the availability of a critical mass of diverse organizations can provide a large pool of (available or needed) resources. These can be amounts of specific by-products, waste materials, energy, and water (Madsen et al., 2015; Van Beers, Bossilkov, & Lund 2009; Taddeo, Simboli, & Morgante, 2012), and financial, human, informational, knowledge, etc. resources *"as different companies have different needs and different things to offer"* (Madsen et al., 2015, p. 859). The presence of a large industrial diversity and a large pool of resources can present opportunities through which new companies are attracted to the site (Ashton, 2009), increasing the potential for new symbiotic relations (Qu, Liu, Nayak, & Li, 2015). Then, co-location provides the possibility for reduced resource transportation costs within symbiotic connections (Park et al., 2016) and encouraging an economic impact and the viability of symbiotic exchanges (van Beers et al., 2009).

The presence of possibilities for sharing facilities, utilities, and infrastructure can increase the opportunities for new synergistic flow formation (Walls & Paquin, 2015) among existing and new organizations (van Beers et al., 2009). Scholars within the IS field often refer to the availability of infrastructure that enables the connections among various organizations as the **technical factors** within a context that enable IS emergence and development in that specific area (Velenturf, 2016a; Mirata, 2005). Availability of infrastructure such as cables, pipelines, roads, railways, etc. provide a technical base for IS development (Park et al., 2016). Technical conditions enabling IS emergence and development can also refer to the availability of technologies and equipment that can facilitate the transferability of resources from one organization to another, enabling symbiotic connections (Mirata, 2005). Mature technologies and availability of experience within this context can minimize the resistance to their implementation and encourage organizations in their development and use of symbiotic relations. Technical conditions can also refer to the availability of sharing infrastructures such as databases or resource banks (Cutaia et al., 2015). Databases can function as platforms for information sharing on resource availability or need within a context (Wang et al., 2017) and can "allow for automatic input-output matching" (Cutaia et al., 2015, p. 1523).

Geographical proximity of co-located organizations can facilitate taking advantage of the **economic factors** within a specific context. These can offer access to new market opportunities (Chertow & Ehrenfeld, 2012), access to common or shared disposal sites (Chertow et al., 2008), and can generate economic gains as expected benefits. The expected economic benefits are mentioned as the key to IS emergence and development within the IS literature (Behera et al., 2012; Ashton & Bain, 2012). Once the organizations are able to see the economic value in the potential synergies, they can get more motivated and their interest in and engagement with symbiosis can increase (Velenturf, 2016a; Paquin, Tilleman, & Howard-Grenville, 2014). Economic benefits from symbiotic connections, i.e. the economic advantages from the small transportation costs within a geographical area, are only a few of the economic factors that are presented as being able to encourage IS emergence and development. Scholars, mentioning the economic conditions important to IS emergence and development, refer also to the prices for input-resources, the fees that can incentivize organizations to enter symbiotic relations, the size of investment necessary to be made for the development of a specific symbiotic relationship, etc. (Mirata, 2005). These, however, are found to be more dependent on international developments.

Geographical proximity and co-location of organizations is found to be able to facilitate communication across potential symbiotic partners and actors across sectors (Tudor et al., 2007), including knowledge and information sharing on various possibilities and industrial activities. **Communication and sharing of knowledge** among actors and across sectors are perceived as one of the important factors that can facilitate the IS emergence and development. These, within a specific geographical context, allow for generation and accumulation of a complex system of knowledge (Chertow et al., 2008), generation of shared values and norms among actors, and formulation of a common vision (Spekkink, 2013). Furthermore, the communication and information sharing across organizations within the context can facilitate cognitive proximity among actors (Velenturf, 2016a). Cognitive proximity includes the formation of common frames of references and conceptualization of symbiotic relationships, formation of various (market and technical) competences and of a shared trust and culture among potential partners. Velenturf (2016a) specifies further that cognitive proximity is necessary to enable communication and sharing of knowledge and experiences across the geographical area, while a diversity of frames of references can trigger innovations and new forms of IS.

The presence of a multitude and various organizations within a geographical site, presupposes existence of a tradition and culture for collaboration. Such collaboration culture can involve multiple (e.g. business, social, etc.) interactions among potential partners where information, experience, knowledge, contacts, etc. are shared. Through such interactions, certain degrees of trust among organizations form pointing at the **social conditions** for IS emergence and development. Social conditions within a context can point at the presence of a specific degree of embeddedness. Embeddedness, applied to the industrial ecology field by Boons and Howard-Greenville (2009), comprises the social, cultural, cognitive, structural, political, etc. aspects supporting the emergence of IS. The social embeddedness refers to 'nontechnical' factors (Paquin et al, 2014, p. 277) that can shape the collaborations between companies and organizations. These can include, beside the inter-organizational and inter-personal trust (Panyathonakun, Tantayanon, Tingsabhat, &

Charmondusit, 2013; Valentine, 2016; Veleva, Todorova, Lowitt, Angus, & Neely, 2015), the relationships created based on social interactions such as friendships, kinships, and professional acquaintances among organizations (Velenturf, 2016a). Measuring the social embeddedness is still a contested area, but agreement exist that these provide a positive contribution to IS emergence and development within a particular context. The social interactions provide possibilities for knowledge, information sharing, the formation of a shared and short mental distance (Ashton, 2008; Ashton & Bain, 2012; Branson, 2016), and convergence of actors' interests (Elabras Veiga & Magrini 2009). These can also create a sense of community and mutual interest and a desire for cooperation and collaboration (Panyathonakun et al., 2013).

There is however a disagreement among IS researchers regarding the extent to which geographical proximity is a prerequisite to the IS emergence and development. Jensen, Basson, Hellawell, Bailey, & Leach (2011), by quantifying geographical proximity of synergies facilitated by the United Kingdom's National Industrial Symbiosis Programme in their first five years of operation, provides quantitative evidence for symbiotic linkages forming across larger distances and not only among co-located companies. Branson (2016), by re-constructing the Kalundborg symbiosis, refutes the idea of geographical proximity being a prerequisite of IS emergence and development. Thus, while geographical proximity seems to facilitate shorter transportation distances of resources, knowledge, information and experience sharing, and social relations creation, it seems to be insufficient. A focus on larger geographical areas, their resources, and their conditions might present greater potential for IS emergence and development.

Human and organizational factors are presented in the IS literature as shaping the contextual conditions**.** Perceiving the IS as a social and organizational construct, Cohen-Rosenthal (2000) advances the human dimension as one that determines the creation of effective symbiotic connections at the practical level. Knowledge, information, experience sharing, and other factors can provide the means for identifying synergistic potential and formation of a fruitful context for IS emergence and development, "*but these do not link them: decisions by people do*" (Cohen-Rosenthal, 2000, p. 246). In this context, people are understood as individual and organizational actors. The importance and criticality of the human dimension are externalized through the role of "*individual champions*" (Hewes & Lyons, 2008) who focus on creating humanistic, social connections among various organizations leading to IS emergence and development. Walls and Paquin (2015), developing a review and synthesis of the antecedents, consequences, lubricants, and limiters of industrial symbiosis and focusing on organizational factors, mention that few are the studies focusing on the individual-actor level. They acknowledge the role of individuals as "*champions*" that have the ability and energy to trigger IS emergence and development within a geographical context. Furthermore, they accentuate the role of individuals' IS cognition and skill sets, their experience, their values, orientations, motivations, and preferences, as antecedents for IS emergence. Moreover, the actors' capacities, their reactions to each other, their involvement in IS-aiming processes, and their interactions are presented as organizational factors that can influence IS emergence and development within a context.

Regarding the contextual conditions related to organizational characteristics, Qu et al. (2015) and Behera et al. (2012) refer to the importance of environmentally minded managers and robust managerial practices for the emergence of IS. They stress the role of "*instituting environmental norms*" (Qu et al., 2015, p. 335) and anchoring environmental thinking and practices deeper into their organizations by adopting a pro-active strategy and considering the "*the company's perceptions of issues, needs, resources, and opportunities*" (Behera et al., 2012, p. 111); all this, while keeping the usual organizational habits. Moreover, organizational resources and characteristics can drive IS emergence and development. The attitudes and flexibility of individuals within an organization (Velenturf, 2016a), their willingness and openness for collaborations (Panyathanakun et al., 2013), organizational values and norms that support environmental contributions, and an organizational culture that supports a collaborative spirit are critical organizational factors that can characterize a fruitful context fostering IS emergence and development (Mirata, 2005; Valentine, 2016).

The IS literature is rich in presenting **institutional factors** as conditions to IS emergence and development. These refer to the policies, policy instruments (i.e. taxes, fees, subsidies, etc.), standards, laws and regulations, and the political support for symbiotic initiatives (Mirata, 2005; Park et al., 2018). Yap and Devlin (2017) complement these by arguing for the importance of market forces, the state with regulative power, the civil society with civil regulations, cultural norms, and informal authority groups, for the interfirm collaborations. Multiple examples exist where these are both beneficial and/or restrictive for symbiotic relationships development (Mannino et al., 2015). For example, the availability of financial incentives and support for synergistic relationships offered by governmental bodies or other public agencies, together with availability of supportive (e.g. environmental) regulations (Wu, Qi, & Wang, 2016; Elabras Veiga & Magrini, 2009), can provide support for technological innovations and solutions (Zhu, Geng, Sarkis, & Lai, 2014). Furthermore, a politically supportive environment could enable IS emergence and development (Costa & Ferrão, 2010). Branson (2016, p. 4350) mentions that "*what enables or inhibits industrial symbiosis is not distance, as such, but the commercial and political factors that are associated with location*."

In connection to the IS emergence and development, the **time** dimension is an important factor to consider. It has been found important especially in relation to the creation of the human, organizational, and the institutional capacity aspects such as flexibility, familiarity, awareness of IS benefits, knowledge exchange, and trust between actors. *"[IS exchanges] don't tend to drop out by one visit, you need to put in a lot of time and effort, follow[ing] up meetings and bringing in other members, so* *it takes longer to nurture*" (Paquin & Howard - Grenville, 2012, p.89). As IS emergence and development are perceived as unfolding through multi-actor engagement, it takes time "*to ensure sustainable outcomes for all parties involved*" (van Beers et al., 2009, p.377).

Boons and Spekkink (2012) emphasize the role of **institutional capacity** within a context for IS emergence and development. They present how institutional capacity, i.e. not only the political and regulatory frameworks, but also the knowledge the actors have, the relations among these, and the existence of actors with the ability to mobilize the resources and capacity available in that specific geographical context, can affect the actors' decisions and motivations, and the opportunities they see for symbiotic relations. Institutional capacity can thus refer 1) to the knowledge, information and experience sharing (informational conditions), 2) to the collaboration culture existing within a context or developed through further collaborative processes (social and relational conditions), and 3) to the existence of 'change actors' such as bridging actors, facilitators, and coordinators, and specific facilitative processes and platforms for actors' interactions (mobilization conditions) as contextual conditions conducive to IS emergence and development.

Scholars within IS literature refer to (institutional, network, organizational, and individual) actors as able to play a multitude of roles and functions in the process of IS emergence and development. As mentioned above, both individuals and organizations can be ***champions***. These are actors that "*possess deep understanding of the local society and culture…and have proven… industrial innovation*" (Behera et al., 2012, p. 104). Furthermore, actors can be within a bridging position functioning as ***bridging actors***. These are a shared contact for the other organizations and possible symbiotic partners on which these are dependent (Velenturf, 2016a, p. 125). The presence of bridging actors, together with the common ground developed through participation in different events building capacity for IS emergence, are found to be two important dimensions of the collaborative capacity needed by the actors within a context for fostering IS emergence and development (Spekkink & Boons, 2016). Despite of the multitude of important roles and functions, the ***coordinative and facilitative function*** seems to be the most important one among the actors. Individuals (Velenturf, 2016a; Qu, et al., 2015), organizations (Spekkink, 2015; Panyathanakun, et al., 2013; Taddeo et al., 2012; Madsen et al., 2015; Baas, 2011), and networks or interconnected structures of actors (Wang et al., 2017; Farel, Charrière, Thevenet, & Yune, 2016) can play the role of facilitators. These can monitor the process of emergence (Paquin & Howard-Grenville, 2012; 2013) and "*follow through the implementation processes and end-results*" (Panyathanakun et al., 2013, p. 75). They are often "*responsible for coordinating the exchanges*" (Spekkink, 2013, p. 354), as well as coordination of stakeholders' communication and their engagement in different activities that promote IS emergence and development. Facilitators can provide incubation platforms that accommodate engagement activities, deliver various support to potential symbiotic partners, attract funding (Velenturf, 2016a;

Madsen et al., 2015), and build actors' capacity for IS (Sharib & Halog, 2017; Valentine, 2016; Baas, 2011).

Originating in collaborative governance and first introduced to IS field by Boons et al. (2011), institutional capacity theory proves to be relevant for interpreting and understanding the research findings regarding the factors that need to be in place within a context so that IS can emerge. By using the institutional capacity theory to interpret the research findings, an understanding of contextual conditions enabling IS emergence in port industrial areas is shaped. Thus, a focus on institutional structures that can accommodate IS-aiming initiatives is gained. The next section discusses this in detail.

3.2 INSTITUTIONAL CAPACITY AND FACILITATION DYNAMIC

3.2.1 Institutional capacity

An increasing body of research within IS literature focuses on the institutional capacity that can support and foster IS emergence and development (Boons et al., 2011; Boons & Spekkink, 2012; Spekkink, 2013; 2015; Wang et al., 2017; Abreu & Ceglia, 2018). Introduced by Boons et al. (2011) and Boons and Spekkink (2012), institutional capacity theory seems to be promising when explaining the driving forces for IS emergence and development. Within IS literature, the institutional capacity is defined as the collective capacity of actors to address specific challenges and find collective solutions for IS emergence and development (Boons et al., 2011). The IS literature concerned with institutional theory application to IS emergence and development refer to Healey and colleagues' work (Healey, 1998; Healey, de Magalhaes, Madanipour, & Pendlebury, 2003) originating in the collaborative governance literature. However, for a deeper understanding of the institutional capacity and its role and effect on IS emergence and development, a look at the meanings of 'institutional' and 'capacity' are necessary.

In order to understand *institutional capacity*, it is necessary to understand what *institutional* refers to and what *capacity* is. Originating within institutional theory, *institutional* refers to the institutions existing within a context. What an institution is, then, differs according to the various approaches of institutional theory (Peters, 2012). Peters (2012) however identifies four specific features common for most of the approaches to institutions:

1) Institutions present a structural feature of society that can be formal (ex. an established entity with statutes and defined rules) or informal (e.g. a network, a partnership, etc.). An institution involves groups of individuals engaged in "*patterned interactions*" (Peters, 2012, p. 19) that take place with regularity.

2) An institution requires regularity and stability over time. Loose interactions among actors and individuals do not make an institution. By contrary, repeated interactions at the same time and place shape institutions. Even though institutions are characterized by stability, these tend to be subject to (incremental or disruptive) change over time, and thus flexibility of institutional members is necessary.
3) Institutions are shaped by individuals and, at the same time, the individuals' behavior is shaped by institutions. An institution poses some form of constraint (formal or informal) on individuals, shaping their norms, values, rationales, and behavior.
4) For an organization to be considered an institution, there must be "*some sense of shared values and meaning among the members of an institution"* (Peters, 2012, p. 20).

Thus, putting it simply, institutions can be defined as societal structures that take the form of a specific type of (formal or informal) collective organizations. These are formed by regular interactions among institutions' members which are individuals. Individual members shape institutions with their shared values, norms, meanings, and behaviors, while institutions shape these back.

Capacity, in its turn, is described as the knowledge, skills, and abilities of institutional members that shape the institution's behavior "*so that the [institutional] organization can efficiently meet its goals*" (Ku & Yuen – Tsang, 2011, p. 470). Such abilities and skills can be diverse: these can encompass "*human, scientific, technological, organizational, institutional, and resource capabilities"* and/or *"the ability to evaluate and address crucial questions*" (Ku & Yuen – Tsang, 2011, p. 470).

The *institutional capacity* then refers to the presence of an enabling environment that has various resources, skills, and abilities to evaluate and address common challenges and issues. Institutional capacity, focusing on strengths rather than problems and limitation (Ku & Yuen – Tsang, 2011), implies focusing on the positive qualities of a context that can deliver a beneficial nexus for sustainable regional development (Amin & Thrift, 1994), social well-being, and environmental healthiness (Healey, 1998).

For a context to be fruitful Amin and Thrift (1994) propose that numerous civic associations, a high level of interactions among various social groups, coalitions that are formed across individual interests, and a strong sense of collective purpose must exist. Thus, a fruitful institutional 'soil' for sustainable regional development must include various institutions shaped by the interactions among actors that transcend individual interests and build on shared values, norms, and a shared vision (Healey, 1998). Such contexts, to be fruitful for IS emergence and development, should contain relevant organizations (networks, partnerships, etc.) of facilitating actors and of firms engaged directly in symbiotic exchanges, with the ability to address the challenges and issues related to IS emergence and development through various types of interactions (Wang et al., 2017). Spekkink (2013, p. 343) complements this view and explains that for a context to be able to foster IS emergence and development "*there should be a network of actors that trust each other and have some level of mutual understanding (relational resources), that have shared definitions of problems and solutions, possibly codified in plans or even strategic visions (knowledge resources), and that among them there are actors with sufficient power and resources to mobilize others for action (mobilization capacity)*." Building on Healey (1998) and Healey et al. (2003), Spekkink mentions further that institutional capacity thus has three dimensions: the knowledge, relational, and mobilization capacity.

The presence of knowledge resources builds on the availability and accessibility of information on by-products, surplus heating, etc. as 'available residues' and potential local uses for IS emergence and development (Wang et al., 2017). Healey et al. (2003) refer to the *range of* (formalized, tacit, experiential, etc.) *knowledge* to which actors have access and the actors' *shared frames of reference,* which is their collective conceptualization of issues, problems, and opportunities as elements of knowledge capacity. The access to various kind of knowledge shapes the actors' understandings of challenges and issues and helps them develop shared visions on possible solutions, which in their turn shape the conceptualization of issues and the design of interventions. The "*existence of a common alignment between [the understandings of] problems and solutions… shape the capacity of collective action based on quality of knowledge and experience*" (Abreu & Ceglia, 2018, p. 100).

Relational resources manifest through networked relationships among various actors within a context working to find common solutions. Relational resources build from the *range* of actors involved in a process that connects within interconnections to create specific network *morphology*. Such networks are integrated within the context to various degrees. The extent of *integration* within a context shapes the *power relation* among actors and the location of the *power to act* (Healey et al., 2003, p. 65). The range of actors are those actors that potentially can be involved in finding solutions for IS emergence and development. The range and number of actors involved define the network size, which in turn defines the network's morphology by impacting the network's density and connectivity (Doménech & Davies, 2011).The network morphology and quality of relations among actors facilitate the exchange of information, knowledge, and experience and the creation of social relationships based on trust (Healey, 1998; Ashton, 2008; Wang et al., 2017). Such relationships present high possibilities for collaboration and capacity for collective action (Abreu & Ceglia, 2018).

The knowledge and relational dimensions are the 'reservoir of capacities' and will mostly lead to fruitful results if the context presents mobilization capacity to activate their potential (Healey et al., 2003). Mobilization capacity builds on knowledge and relational resources that are mobilized through programs and projects as *arenas* for actors' interactions, the *opportunity structures* provided by different arenas, networks, projects, etc. that engage actors using a *repertoire* of mobilization techniques, such as workshops, specific meetings, and other kind of activities that are used to develop and sustain momentum and develop a shared vision and mission. The presence of *change agents* at different stages of actors' mobilization is critical for knowledge, information, and experience sharing and relationship creation (Healey et al., 2003, p. 65). Change agents are (private, public, community) actors with the ability to activate and engage relevant firms and other actors in the development of symbiotic linkages (Wang et al., 2017).

Referring to how institutions are created in the first place, the literature points at the institutionalization process through which specific norms, rules, and values are created through regular interactions among actors. Engaging actors in continuous and regular interactions develop shared norms, values, and rules (Spekkink, 2013; Abreu & Ceglia, 2018). Sharing norms and values facilitate creation of a shared vision and alignment of the actors' scope of action, which in turn provides the actors with stability (Abreu & Ceglia, 2018) leading to creation of institutions to support, foster, and build capacity for IS emergence.

3.2.2 Facilitation as mobilization capacity

The capacity for collective action for IS emergence and development is based on the engagement of various actors in regular interactions facilitated by (formal or/and informal) institutions with "a robust management and structure" (Behera et al., 2012). These permit the creation of quality relations and the formation of a dense network morphology, that facilitates the exchange of knowledge, information, and experience, the formation of similar frames of reference, and that lead to the emergence of strong collaborations among various actors. Among these there must exist specific actors with enough resources to mobilize the network and with knowledge that provides opportunity structures and supports interactions among actors within various mobilization arenas and through various mobilization techniques. These can act as champions (Hewes & Lyons, 2008), orchestrators (Paquin & Howard–Grenville, 2013), facilitators, and coordinators (Park et al., 2018). Active participation shapes the change actors and makes the exchanges happen (Boons & Spekkink, 2012; Abreu & Ceglia, 2018). Actors, who are participating in different arenas, can act as bridges and mobilizers of institutional capacity in both such arenas (Spekkink, 2015). Boons and Spekkink (2012), analyzing the process of IS emergence and development, find that mobilization capacity might be the most important factor that affects the opportunity set from which actors can choose their actions.

Connecting the mobilization capacity to the IS dynamics (Boons et al., 2017), it appears that each dynamic presents variate levels of mobilization. Self-organization implies self-mobilization of industrial actors to form symbiotic relationships driven mostly by economic interests (Chertow & Ehrenfeld, 2012). Within such a dynamic, the change actors can then each be a self-organized symbiotic partner or the partner that takes initiative to such relations. While the trust between actors is engrained and the self-organization processes lead to long-lasting networks, often it takes long time for a network to emerge (Paquin & Howard-Grenville, 2012). The facilitation dynamic can be thought to be the most fruitful and promising dynamic of IS emergence and development (Doménech et al., 2019).

Facilitation is a *middle-out* (Costa & Ferrão, 2010) dynamic, which combines self-organization (i.e. bottom-up approaches) with planned activities (i.e. top-down approaches) in a balanced manner (Park et al., 2016; Paquin & Howard-Grenville, 2012). Facilitation supposes the presence of a facilitator, coordinator, and/or orchestrator (Paquin & Howard Grenville, 2012; 2013; Mirata, 2004) that provides specific support and 'handholding' to companies (Velenturf, 2016a). Such actors function then as change actors that activate and mobilize the existing institutional capacity (Boons & Spekkink, 2012).

Facilitation dynamics seem to propose processes and platforms where actors can be engaged, and their knowledge capacity can be activated. Healey (1998) refers to the (local) knowledge resources as mobilized through regular interactions, from participating in local initiatives, interactions, taking part in collaborative networks and partnerships, and participating in meetings and events where a convergence of the different 'social worlds' and knowledge of empirical facts and "theories" used to explain and give meaning to actors take place (Healey, 1998, p. 1540). In contexts where facilitative structures exist, knowledge and relations can be mobilized to deliver pursued objectives and results.

Knowledge and relationships can be activated through various mobilization techniques or facilitative activities. For example, Paquin and Howard-Grenville (2012), exploring the longitudinal emergence and development of IS through the NISP Programme, identify three types of facilitative activities: *conversation* (through which actors involved exchange knowledge, information, and experience)*, connection* (through which actors explore possible relationships) *and co-creation* (through which actors explore ways to organize for symbiotic linkages). These emphasize the role of a facilitative body to encourage self-organization among participating actors by providing common interaction spaces and coordinating the knowledge exchange, relationship creation, and emergence of symbiotic linkages.

Velenturf (2016b), building on the case of resource innovations in the Humber region (UK), proposes to divide facilitative activities into *strategic* and *operational* activities. Spekkink (2015) identifies nine types of activities that can mobilize and activate the institutional capacity, strengthening existing knowledge and relations and building new ones. Some of these can be categorized as strategic and others as operational and thus complement the activities presented by Velenturf (2016b).

Table 4 presents these as adapted from Velenturf (2016b) and Spekkink (2015). As it can be read from the Table 4, IS emergence and development is enabled by strategic activities that imply developing a common ground, creating a common vision, converging actors' interests, and building stronger relationships that lead to a fruitful institutional (i.e. regulative, political, economic, etc.) environment. Sun et al. (2017) call these "institutional anchoring", as these aim at stimulating social interactions and activating and mobilizing existing knowledge and relational capacity, but also promoting the area.

The operational activities target mostly the activation and mobilization of actors' knowledge and relational capacities to lead directly to initiation of symbiotic linkages. These aim at providing managerial support to companies (Sun et al., 2017) by assisting them with feasibility calculations, symbiotic business idea development, attracting funding and marketing, and communicating the benefits obtained. Facilitative operational actions seek to manage the relationships among potential symbiotic partners, by matchmaking them and facilitating communication and collaboration among them.

Table 4: Strategic and operational facilitative actions. Adapted from Velenturf (2016b, Figure 3) and Spekkink (2015).

Facilitative actions	
Strategic	• *Establishing new organizations* within the boundaries of a regional industrial system • *Lobbying activities* through which actors aim at influencing the political, economic, etc. context attracting financial resources, and supportive policy and regulations, thus shaping a fruitful institutional context • *Strategic visioning* activities through which actors articulate shared interests, goals and strategies, identify skills and infrastructure needed, represent contextual interests, foster a democratic process of actors' involvement, etc. • *Activities generating (academic, commercial) knowledge* and facilitating research and feasibility studies
Operational	• *Orientation and planning activities* through which actors explore issues of common concern and steps to be taken with the aim of developing symbiotic relationships • Activities providing *support to business organizations* through which facilitators assists with attracting funding, marketing, business development, handholding • *Research activities* that focus on identifying the technical, economic or organizational feasibility of symbiotic solutions, guide research direction for the corporate benefit, etc. • *Network management* activities that focus on matching companies, signposting, facilitate collaborations and network formation, etc. • *Declaration and implementation activities* through which actors express their desire of joining a symbiotic relation and start implement these • *Communication and facilitation of information* exchange through which actors influence the opportunities other actors see, assist and advise corporate environmental management systems, link companies with the relevant information, etc.

While self-organization of IS can still occur parallel with or as a part of facilitation processes (Paquin and Howard-Grenville, 2012), facilitation can 'uncover' (Chertow & Ehrenfeld, 2012) the self-organized symbiotic networks and the institutional capacity available within a context. Within such (facilitative) processes, institutional (knowledge, relational, and mobilization) capacity is not only mobilized but also continuously built (Spekkink, 2013). Actors acquire new knowledge and information, develop new relationships, or strengthen the existing ones and "*shape the institutional capacity available to them in the future*" (Spekkink, 2015, p. 136). Building institutional capacity is interlinked with mobilization of existing capacity as the institutional capacity if found to be fluid or boundaryless, i.e. institutional capacity built in one process (not necessarily targeting IS initiation) can be mobilized in another (which can be directed towards IS initiation) and vice versa. Moreover, facilitation can start to develop the existing IS network towards regional learning and a sustainable industrial district (Baas and Boons, 2004).

Various processes and projects can serve as arenas for building actors' capacity and shaping the common ground for their actions (Spekkink & Boons, 2016). Thus, it is impossible to define when and where institutional capacity initially was built and from where it originates. What is maybe most important is that institutional capacity is mobilized and built in the same time through the continuous interactions and dialogues among various actors across sectors. Interactions among actors building their capacity can be both intentionally and unintentionally directed towards IS emergence and development.

Institutional capacity building is then a face-to-face and interactive process, based on various practices that unfold through long-term and continuous dialogues (Boons et al, 2011). Within institutional theory, capacity building is described as processes that focus on recognizing and identifying local context's strengths instead of problems and issues and building further on those, empowering the relevant actors to bring about change. Capacity building is usually designed to bring change through various and continuous interactions. Through these, actors share and build new knowledge, skills, and other resources that are needed to achieve shared visions. (Spekkink, 2013; 2015) Capacity building can take place in collaborative organizations such as networks and partnerships. These can act as institutions or as mechanisms for managing and addressing challenges and issues, overcoming the collective action challenges and making sense of the strengths of a context. (Ku & Yuen-Tsang, 2011). Within these, participatory methods through which a multitude of actors are engaged are applied (Ku & Yuen-Tsang, 2011) and long-term collaborations among actors from different sectors can take shape (Spekkink, 2016). Long-term collaboration implies the cooperation among a multitude of actors and formation of collaborative networks and partnerships, referred by Wang et al. (2017, p. 1573) as to the "*IS coordination network*." An IS coordination network is the compilation of various organizations (e.g. government departments, environmental services companies, academic institutions, etc.) that work together by taking formal and informal actions, implementing various activities projects and initiatives to exchange information, and stimulating mutual understanding and by these activities form a common ground and build institutional capacity of actors and contexts that foster and promote inter-firm symbiotic networks in a region (Wang et al., 2017).

As expressed by Chertow and Ehrenfeld (2012, p. 21), facilitation pushes the industrial systems towards "*embeddedness and institutionalization*" through creation of institutions shaped by intentional collaborative networks and partnerships within which shared norms, visions, values, and social capital such as trust, mental, cognitive, and cultural proximity (Velenturf, 2016a) form to enable further IS emergence and development. Such collaborative entities could be an evolution of existing entities or entities newly created for the purpose of IS emergence and development support. These provide platforms for sharing knowledge, information, and experiences thereby creating commitment, new norms and relationships, and platforms for action. The rise of these explicit coordination structures, which

Spekkink (2016) argues take the form of collaborative networks and facilitate continuous interactions among actors, refer to collaborative governance structures that have potential to facilitate the emergence of collaborations such as IS. Such collaborative platforms and governance structures seem to have the potential of institutionalizing IS emergence even further in various structures within a given context.

Mobilization of existing capacity and the subsequent rise of collaborative structures, shared values, norms, and visions ask for a higher degree of commitment, responsibility, and reflexivity. Scott (2014) cites Selznick who affirms that the social commitments, which are formed and embedded in collaborative structures (such as network and partnerships) with a high degree of interdependence, are the source of stability and integration of action. Commitments made in collaborative networks become the shared norms according to which (individual and collective) actors behave. Such collaborations and subsequent commitment to shared norms can pose different degrees of responsibility: Responsibility to own interests, to others' interests, and for the process (of e.g. IS emergence). An increased commitment among actors entering such collaborative and coordinative structures suppose a higher degree of reflexivity that can ask for a revision of their own identity and roles within intentional and facilitative processes (Scott, 2014). In order to create and later maintain the shared norms, values, and visions there is a need for continuous interactions and constructive dialogue among the actors that build on collaborative routines (Peters, 2011).

4 METHODOLOGICAL REFLECTIONS

This chapter provides a general overview of the research design and research process and approach followed by reflections on the choices of specific methods used for the data collection and analysis, and the use of theory. Methodological choices are presented in a larger perspective and the implications for theoretical and empirical field are discussed. Reflectivity on researcher role and identity was an integrated part of the research process and reflections on these are inserted.

4.1 RESEARCH DESIGN

As specified in section 2.3, the aim of the present research is to provide a better understanding of the IS emergence phase and identify specific factors enabling it in port industrial areas. To reach this aim, a synthesis is developed by gradually building upon the academic articles developed during the PhD project and the insights from the IS emergence process in Aalborg East port industrial area. Figure 4 visualizes the research design, which also explains the architecture of the synthesis.

The Figure 4 shows that each chapter in the synthesis of results follows a specific purpose and builds around a specific academic outcome. This is either a published or under review article, or a non-submitted study (as is the case of IS emergence through the Sustainable Synergies project in Aalborg East port industrial area). By using a specific research strategy and methods, these contribute to a particular research objective formulated in section 2.3. The findings from each research outcome, feed into discussions (presented in chapters 5 – 8) related to one or more research sub-questions. By doing this, each chapter contributes to answering the overall research question.

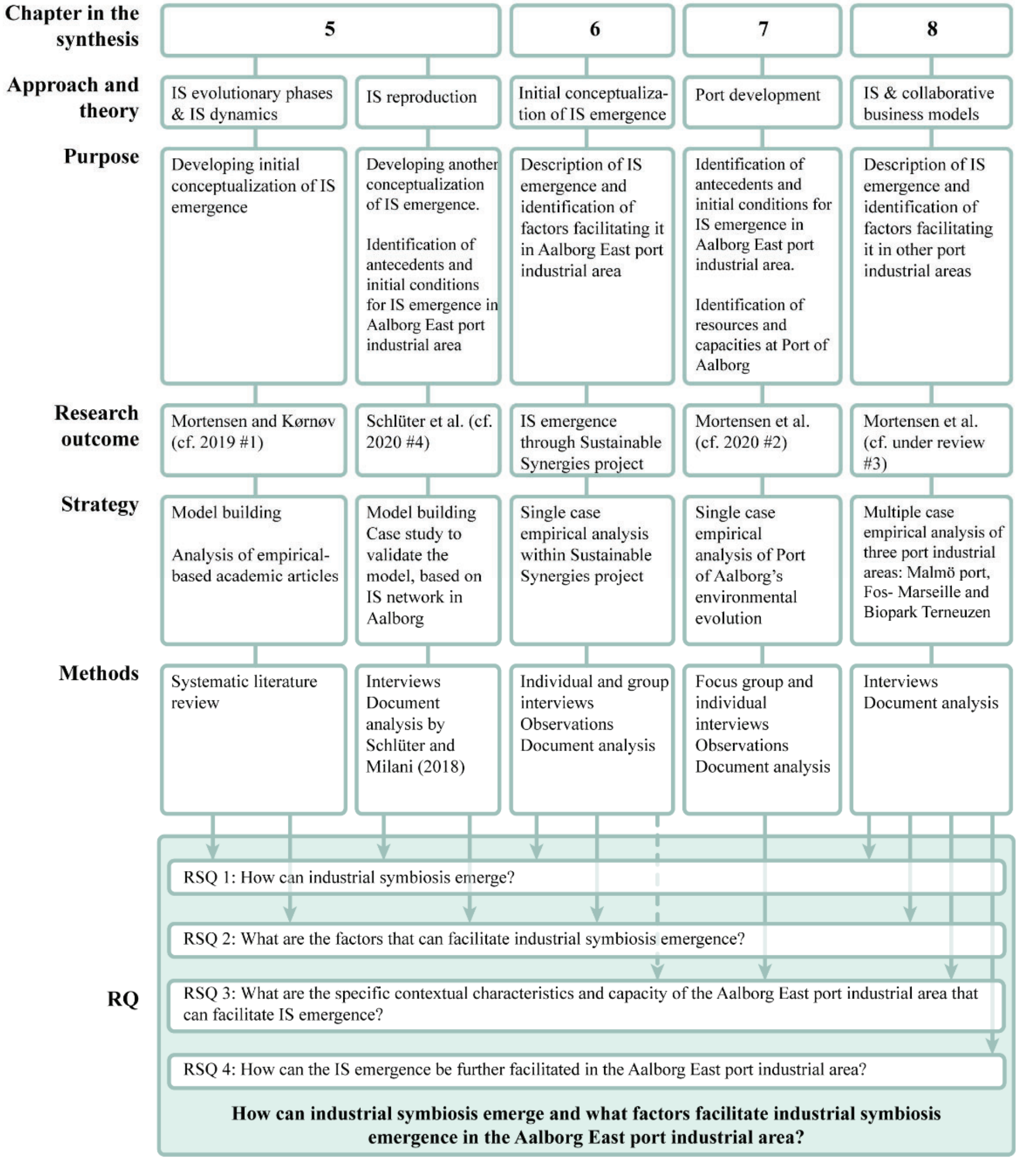

Figure 4: Research design. Developed by the author.

4.2 A CASE STUDY RESEARCH STRATEGY

The present research follows a case study strategy as also specified in the previous section 4.1. The case study strategy is recognized as a relevant real-world research strategy (Robson & McCartan, 2016). Case study is especially relevant in producing contextual knowledge (Flyvbjerg, 2006) that encourages and provides opportunity for initial theoretical ideas generation (Jaccard & Jacoby, 2010). Moreover, the case study is an appropriate research strategy for the empirical investigation of contemporary and ongoing phenomena, individuals, group, event, etc. within a real-life context, where data can be collected on the go and where respondents can present retrospective data (Yin, 2018). As the present research seeks to study the contemporary phenomenon of IS emergence and factors enabling it within the real-life context of a port industrial area, case study seems to be an appropriate and relevant strategy.

Furthermore, the research makes use of an embedded case study design where the IS emergence process and factors enabling it are investigated in multiple subunits (Scholz & Tietje, 2011; Yin, 2014). The subunits are the studies effectuated along the PhD project, as visualized through arrows in the Figure 5.

Figure 5 shows how conceptual and empirical studies conducted along the PhD project focus on specific aspects elucidating the process through which symbiotic linkages emerge, the factors that facilitate IS emergence, the characteristics of port industrial areas, and the antecedents and initial conditions that enable IS emergence in port industrial areas. These contribute in various degrees to developing a conceptualization of the IS emergence process and to identifying factors through which this can be fostered in a real-life context. This thesis, then, binds the studies together, builds further on them by bringing insights from the Environment^{++} initiative, and returns to the "*larger unit of analysis*" (Yin, 2014, p. 55), which in this case is the IS emergence in Aalborg East port industrial area, providing answers to the main research question. By doing this, a unified scientific understanding of IS emergence is developed and contribution to practice of IS emergence in Aalborg East port industrial area through Environment^{++} initiative is made. Moreover, an example of how academic knowledge produced through this PhD project can be applied to inform the practice and enable further IS emergence in port industrial areas is provided. The force of example is used to create both a scientific contribution and a contribution to practice (Flyvbjerg, 2006) permitting a certain level of analytical generalization from case studies (Yin, 2018).

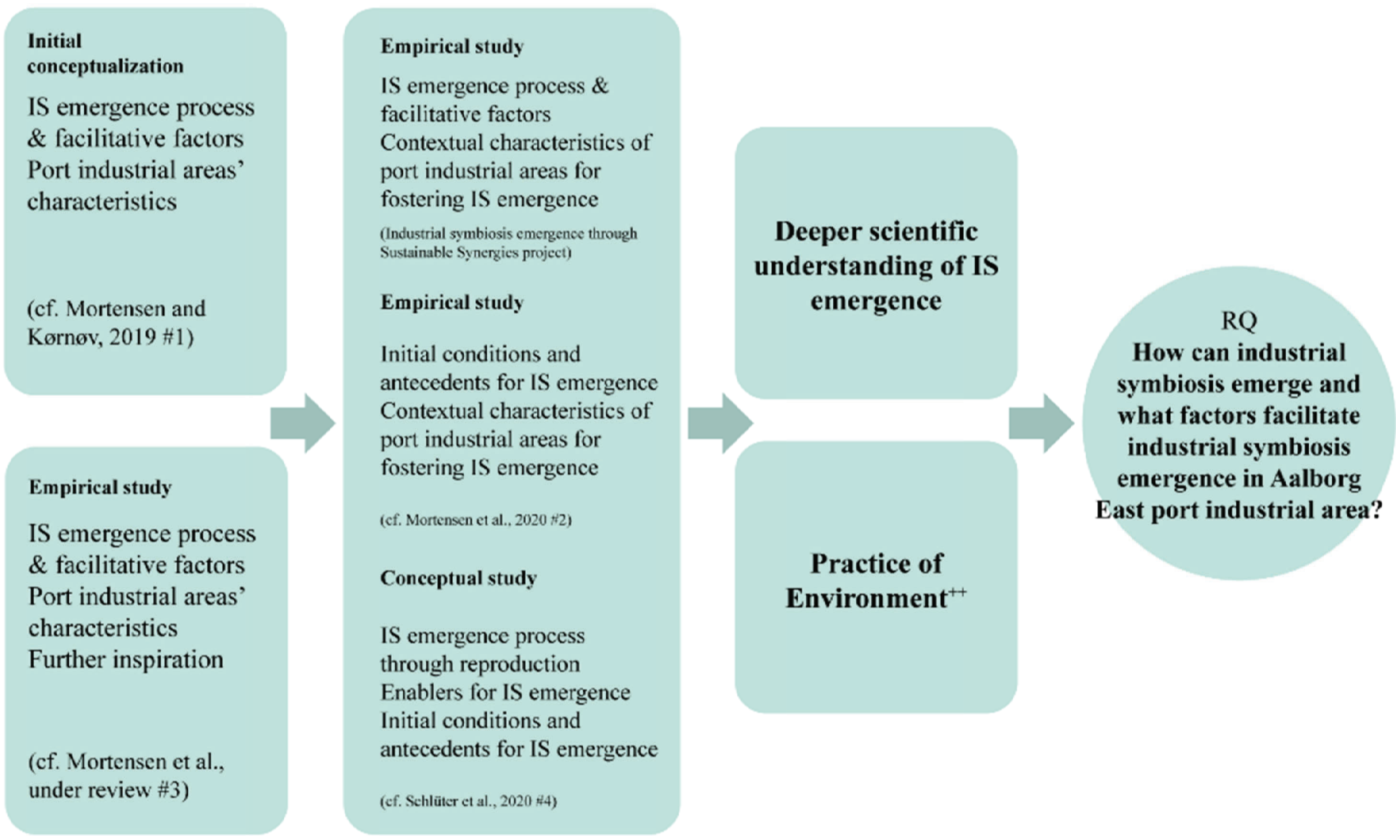

Figure 5: Representation of the embedded case and its sub-units. Developed by the author.

The process encouraging IS emergence in Aalborg East port industrial area is studied in the context of Environment++ and functions as the primary case for elucidating the IS emergence process and to identify the factors enabling it in a port industrial area, while the other cases are secondary. Figure 6 presents schematically the relationship among the different types of cases within this research.

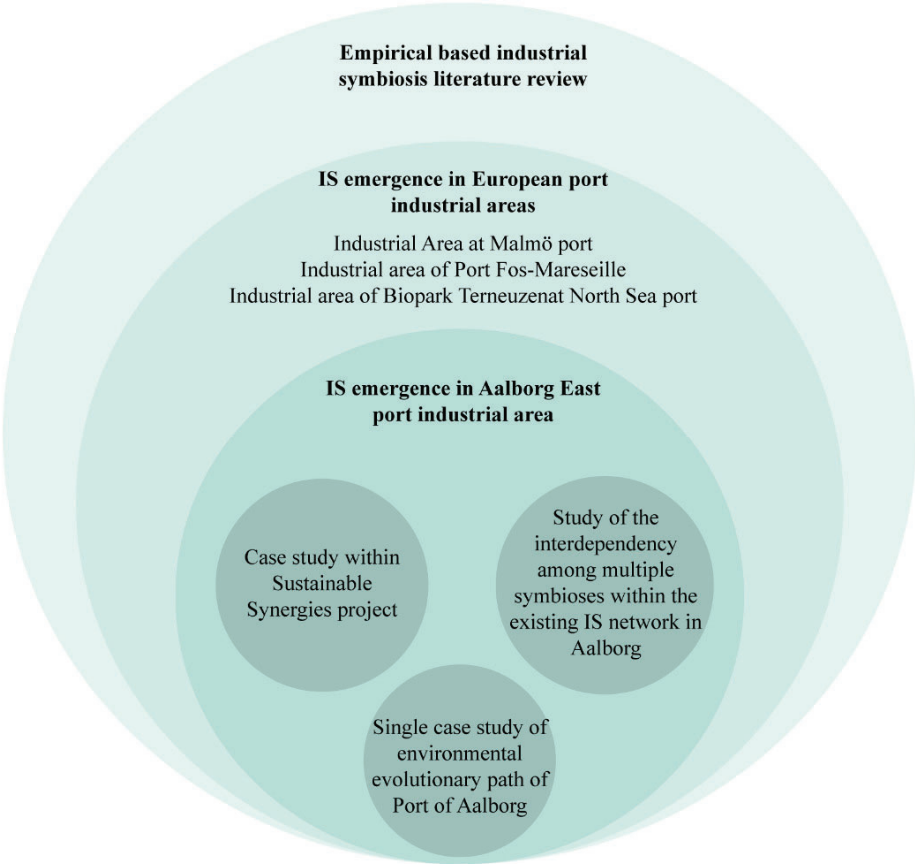

Figure 6: Relationship among the cases within this research. Developed by the author.

The secondary case studies each had their purpose. Starting deductively from the study of **empirical-based industrial symbiosis literature** by Mortensen and Kørnøv (cf. 2019 #1) the aim of developing an initial conceptualization of IS emergence and identifying enablers specific to this was pursued. The initial conceptualization served then as a conceptual framework for the study of the facilitative process within the Sustainable Synergies project, being enriched and further developed by this.

The purpose of studying the **IS emergence in European port industrial areas** was to analyze the IS emergence and factors facilitating it in three other port industrial areas, for informing the Environment^{++} initiative and complementing the conceptualization of IS emergence. The three port industrial areas were selected through a process of 'purposeful sampling' (Patton, 2002) or by a strategic selection of cases (Flyvbjerg, 2006). The aim was to assure the selection of a maximum variation in cases (Flyvbjerg, 2006), which permitted the study of different approaches to facilitated IS emergence and different degrees of IS implementation process and experience. By applying this strategy of case selection, the authors (i.e. cf. Mortensen et al., under review #3) sought to achieve a great amount of knowledge (Flyvbjerg, 2006) on IS emergence processes at different stages of development and of factors encouraging these in port industrial areas. Moreover, it was sought to minimize the 'frequent surprises' (Yin, 2009a) connected to availability, quality of interviews, and relevance of data for the overall research question. This knowledge permitted obtaining wider insights into and a deeper understanding of the IS emergence within such contexts, informing Environment^{++}, and complementing the initial conceptualization developed by Mortensen and Kørnøv (cf. 2019 #1).

The primary case of IS emergence in Aalborg East port industrial area makes use of three in-depth embedded subcases (Yin, 2014) to elucidate the facilitative process that took place within the Sustainable Synergies project, identify the specific factors that facilitated it, and identify the contextual characteristics that can further enable IS emergence in Aalborg East port industrial area: 1) the case study of symbiotic linkage emergence through facilitation within the Sustainable Synergies project, 2) the single case study of the environmental evolutionary path of Port of Aalborg, and 3) the case study of the interdependency among multiple symbioses within the existing IS network in Aalborg. These insights feed back into the Environment^{++} initiative and inform the further IS emergence process.

The case study within the Sustainable Synergies project. Sustainable Synergies is a two-year sub-project to Environment^{++} initiated in January 2017 and prolonged with finalization by end of June 2020 (Bæredygtige Synergier, 2019). Supported financially by the European Fund for Regional Development and administered by the Danish Business Authority through Structural Funds, it is managed by The Danish Center for Environmental Assessment (DCEA) at Aalborg University. The project is undertaken in a project consortium consisting of Aalborg University (AAU), the Port of Aalborg, and House of Energy[2]—with DCEA as project manager. The Sustainable

[2] House of Energy is the Danish energy cluster working for sustainable energy technologies along the entire value chain including the production, distribution, and delivery of energy to the consumer. The cluster connects a large number of relevant actors for the energy sector—businesses, researchers, utility companies, municipalities, investors, etc.—and engages them in a variety of activities such as conferences and networking events. (House of Energy, 2020)

Synergies project aims "…*to develop green business models*[3] *for 25 SMEs that are part of industrial symbiosis collaborations and thereby promote collaboration between SMEs to increase energy and resource efficiency and support local and regional growth in Northern Jutland"* (Project application, 2017). With participation in the project, it is expected that companies will become more energy and resource effective and that companies' competitive advantage will rise due to resource cost savings and by transforming waste into resources and/or innovations (i.e. developing new products, services, and markets). (COWI, 2019)

Being an ongoing project and aiming directly at facilitating IS emergence in the port industrial area, the Sustainable Synergies project permitted collection of first-hand insights by studying the facilitation process in real-time within the context of Aalborg East port industrial area. Part of the project served as a data collection site. The focus was on mapping the facilitative process and the enabling factors that contributed to the emergence of new symbiotic linkages. Therefore, the project's assessment of the symbiotic linkages' sustainability effects (COWI, 2019) and the final evaluation of the project were not considered.

The case study of environmental evolutionary path of Port of Aalborg applies a single case study strategy (Flyvbjerg, 2006) where the Port of Aalborg's environmental evolution is the case studied. The study contributes at elucidating the antecedents and initial conditions for IS emergence in Aalborg East port industrial area. Moreover, this single case study contributes to understanding the Aalborg East

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[3] 'Green business models' refer to the Danish Business Authority's definition which states that green business models are those business models that 'contribute to minimization of resource consumption in one or more stages of a company's business, i.e. in relation to suppliers, customers or in the production process itself. Typically, green business models include new types of collaborations with customers, suppliers or other agreements that support environmentally sound solutions' (Danish Business Authority, 2019).

In relation to Sustainable Synergies project several requirements were in place for the development of green business models. These should:

- Describe how the previously underutilized resources are utilized through new resource flows
- Describe (with an estimate) if and what investments where made in any equipment
- Describe the environmental impact calculated according to the Climate Compass (The facilitation team however, analyzed the sustainability of green business models developed through the systemic perspective of life cycle assessment and included more measurement parameters than those required by the funding program and required by the Climate Compass).
- Offer the company precise steps to take and explain how they influence their main business
- Be described within a document with a specific length that describes the model in detail and in a language that is clear for outsiders

port industrial area's characteristics and the Port of Aalborg's capacity as factors that can enable IS emergence.

The case of the interdependency among multiple symbioses within the existing IS network in Aalborg. Four interconnected symbioses from the existing IS network in Aalborg have served as specific cases for validating the IS reproduction model developed by Schlüter et al. (cf. 2020 #4). The purpose of this embedded sub-case was to validate any new conceptualization of IS emergence (i.e. through reproduction) and to get insights of antecedents and initial conditions for IS emergence in Aalborg East port industrial area. By that, enrichment of the initial IS emergence conceptualization developed by Mortensen and Kørnøv (cf. 2019 #1) was sought.

4.3 REFLECTIONS ON DATA COLLECTION METHODS

Case study strategies are not limited to single type of data (Yin, 2009a). By contrary, they rather call for a combination or triangulation of data collection methods. Figure 7 presents an overview of the methods used in relation to the study to which they contributed and led to answering the research questions.

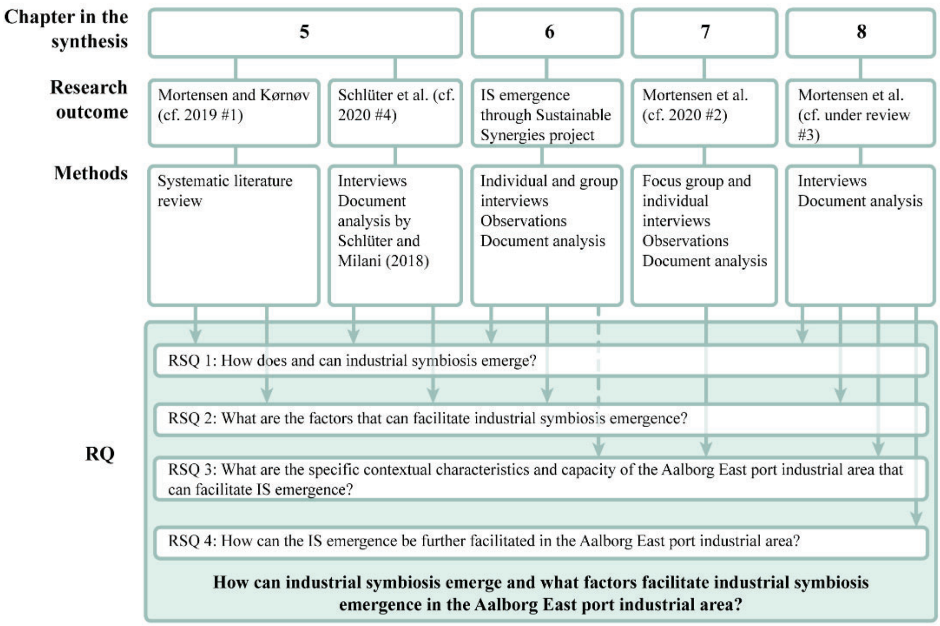

Figure 7: Overview of data collection methods. Developed by the author.

As Figure 7 shows, methods such as document analysis, interviews, and observations are primarily used for data collection. Yin (2018) mentioned such methods as crucial sources of evidence within a case study research and adequate real-time research methodologies (Brundin, 2007). The specific methods used in the studies are presented in the specific articles (sections 5.1.; 5.2.; 7.1.; and 8.1.) and the study presented in chapter 6.

The PhD project was an integrated part of Environment^{++}, which shaped the overall context of this research in Aalborg East port industrial area. As described in section 2.1.2. Environment^{++} incorporated several sub-projects, among which part of the Sustainable Synergies project constituted data collection sites for the research on IS emergence in Aalborg East port industrial area. Despite a systematic data collection from the Sustainable Synergies project, following and understanding the development of Environment^{++} was necessary. This is because it presented the overall framework within which IS emergence in Aalborg East port industrial area unfolded and that permitted the IS emergence process to be set in a larger context. This in its turn permitted better understanding of IS emergence and the factors that can facilitate it in the area.

The interplays of engagement-distance and insider-outsider positioning described in section 4.14. had implications and shaped my research design, strategy, and the choice of methods within the process. The insider position created a possibility for participant observations, facilitated the access to archival data and key actors in the process, and permitted a view into the IS emergence process in Aalborg East port industrial area from the inside-out.

The following sections present methodological reflections across studies and address the methodological background for the discussions presented in chapters 5 - 8.

Archival data and document analysis. Annual reports, company presentations, strategy documents such as the sustainability strategy and development plan for 2050, and research reports on clusters and networks in port industrial areas provided insight into the Port of Aalborg organizational development and the focus on catalyzing industrial symbiosis development at the port and its hinterland. Furthermore, a series of articles in the port's magazine TransPort, the Environment^{++} homepage, notes from the meetings in which I participated served as data sources for understanding the process around IS emergence. In addition, a series of academic articles developed along the last decade on Port of Aalborg and IS initiation processes in Aalborg East, and articles from newspapers, with the specific descriptions of specific symbioses emerging through the Sustainable Synergies project (also to be found on the homepage of the project) provided input on the IS emergence process in general and specific input to understand symbiotic linkages emergence through the Sustainable Synergies project.

Individual, group, and focus group interviews. Interview is an important method when doing case studies on real-life contexts (Yin, 2014). It was therefore an integrated part of this research as a data collection method for four out of the five studies developed during this PhD.

For developing the study presented by Mortensen et al. (cf. under review #3), two semi-structured individual interviews and two group interviews were held with port representatives, municipality representatives, and researchers who participated in the IS emergence process in the different port contexts. Interviews were a secondary data collection method for this study, complementing the data collected from archival data and document analysis.

The data at the core of the study presented by Schlüter et al. (cf. 2020 #4) was collected by Schlüter and Milani (2018) while I participated at one interview.

For the study presented by Mortensen et al. (cf. 2020 #2), a focus group interview and an individual follow-up interview were held. Two group interviews were held with the researcher team functioning as the facilitation team for IS emergence through the Sustainable Synergies project. Moreover, I conducted and participated in nine formal semi-structured individual interviews with representatives from companies involved in the Sustainable Synergies project. I conducted four of them, and five were conducted by my colleagues while I was participant and observer.

Besides these, I had numerous informal discussions with various representatives from academia, the municipality, different business networks, business organizations in Aalborg East, and the Port of Aalborg. These were held during project meetings, network events, everyday conversations, status meetings, and department meetings. By interacting with various actors engaged in IS emergence in Aalborg East port industrial area I learned about IS emergence from various perspectives that permitted a better understanding of this and the larger context of Environment^{++}.

The duration of individual interviews lasted one to one-and-one-half hours, while the group and focus group interviews lasted two to three hours. Notes from each interview were taken. Each (individual, group, focus group) interview was recorded and then fully transcribed. Both notes and transcriptions were part of document analysis.

Making inferences based on data originating from interviews can pose limitations. First, it can be argued that limited respondents were interviewed for the study conducted by Mortensen et al. (cf. under review #3). Then, the formulation of questions in the interview guide could have been misinterpreted, and the interviewees would have formulated their answer based on what they thought they had to answer, thus presenting a subjective meaning (Yin, 2014). Moreover, biases related to difficulty recalling the exact course of events in a process could have presented inaccuracy to the data collection. The fact that interviews were not the primary data collection method, and that these were complemented by a triangulation of data sources, contributed to cross checking the data from interviews and complementing these with insights from observations and archival documents. Besides, the group interviews held with the researcher team managing the Sustainable Synergies project and facilitating IS emergence process (presented in section 6.1.2.) were held in real-time and had a reflexive character. This means that the data were collected as the project and the facilitation of symbiotic linkages' emergence unfolded in real-time and by that, respondents have provided fresh and spontaneous answers without rationalizing the happenings (Brundin, 2007). Moreover, the data were collected in several rounds with follow-up discussions that allowed the researcher group to "*signal agreement, suggest changes, disagree about the interpretations, supplement information, or clarify obscure points*" (Pessoa, Harper, Santos, & Gracino, 2019, p.3).

Interviews and group interviews as a sole technique or complementary data collection method can reduce the distance between the researcher and the researched which allow access to data that otherwise would not be possible to access, it brings the voices of various human respondents into the researched, it allows cross-referencing of various opinions and generating new views and ideas contributing to change generation. (Frey & Fontana, 1991)

Observations. Observation was another method applied to collect data on the study for Mortensen et al. (cf. 2020 #2) and of IS emergence in Aalborg East port industrial area. The latter offered the possibility to get deeper insights in the IS emergence process through the Sustainable Synergies project and the overall framework that Environment^{++} imposed on this. The observations had mostly an unstructured and informal character in order to observe a large range of aspects related to the process of IS emergence, actors' involvement, and their actions and roles. Minutes from specific meetings were taken and served later as observation notes.

Being immersed in the Environment^{++} initiative and the Sustainable Synergies project allowed a longitudinal approach to observations, which did not focus on mapping 'before' and 'after' situations, but rather to study the trends and developmental course of actions regarding the IS emergence in Aalborg East port industrial area over a longer period (Yin, 2011). Moreover, it allowed conducting mostly participant observations shifting among being a complete participant and a participant as observer (Bøllingtoft, 2007), as also showed in Figure 8. As such I participated at Sustainable Synergies internal project status meetings, project partner meetings, and engaged in informal conversations with the facilitation team from a total insider position. Regarding observations on Environment^{++}, I was taking part in internal port department meetings and partner meetings, and engaged in daily informal conversations with port employees interacting with them as colleagues.

	Complete insider		Complete outsider	
	Complete participant	Participant as observer	Participant as observer	Complete observer
Role	Interacts with field as naturally as possible, and becomes a member of the group.	Participates fully with the group under study, but researcher makes it clear that he is also undertak-ing research.	Identifies himself as a researcher and at-tempts to interact with the group. Does not participate in group activities and relies mostly on informants.	Observing from a distance. Is isolated from phenomena, allowed no direct contactor interplay.
Visibility	Covert	Overt	Overt	Overt
Advantage(s)	Informants more honest and natural.	Able to assume a stranger's role and ask questions from a position of igno-rance. Ability to establish an insider's identity-from a researcher's point of view.	Able to assume a stranger's role and ask questions from a position of ignorance.	Most closely approximates the traditional ideal of the 'objective' observer.
Disadvantage(s)	Risk of going native. The researcher might affect the area of study.	Risk of going native. Informants may shift attention to the re-search project itself rather than carrying on with their natural behav-ior. Friendship between researcher and informant (s).	Risk of going native (albeit to a lesser extent than the two former roles). Informants may shift attention to the research project itself rather than carrying on with their natural behavior. Possibility for misunderstand-ing the informant.	Possibility of ethnocentrism. Lack of richness and detail. Potential for misunderstanding and inaccuracy.

Figure 8: Continuum of observer roles. Adjusted from Bøllingtoft (2007, Table 16.2, p. 418).

In the periods when I acted mostly from an insider position, as described in section 4.4., my identity as researcher was weak and I conducted observations as a complete participant. In contrast, at times where I distanced myself from the practice field and engaged with mode 1 research[4], my identity as researcher became more present and this led to engaging with the practice field from the participant-as-observer position. This was mostly obvious when collecting data through the two group interviews with the facilitation team of the Sustainable Synergies project.

Shifting among these modes of conducting observations, is however, not without implications for the research conducted. Each position provided specific advantages and disadvantages for my research. By engaging with the practice field, I got access to data from the inside. This helped me understand what was really going on and create deep understandings of the IS emergence process and factors affecting it. In the same time, distancing myself from the research field and remaining more as a participant-as-observer gave me the possibility to see the process with a stranger's eyes, ask critical questions for data collection, and remain critical in relation to their analysis.

4.4 RESEARCH PROCESS AND THE RESEARCHER REFLEXIVITY

Research process as engaged scholarship. Considering my research approach in retrospect, I could characterize it as one that primarily resembles a mode 3 research (Kørnøv, Lyhne, Larsen, & Hansen, 2011) with an engaged scholarship approach (Van de Ven, 2007). To explain this, I should mention that I was actively involved in the processes of IS emergence in Aalborg East port industrial area due to the

[4] *Mode 1* research is perceived as discipline-based and intra-scientific knowledge production that is not necessarily rooted in "*experienced problems in specific contexts*" (Kørnøv et al., 2011, p. 206). Its character is mostly scientific, with limited relevance for society and low concern for changing the practice. The researcher within this mode of research decides alone on the research direction with no implication for practice.

Mode 2 research, in contrast, is a co-production of knowledge, between a researcher and societal actor(s), where the knowledge produced is a result of an interaction between science and practice with focus on producing change within a specific context. According to Kørnøv et al. (2011, p. 206) "*mode 2 research is validated by its relevance for practice*" while its frame and direction is externally decided.

Mode 3 research, much like mode 2, is an integration of science and practice "*closely linking to societal needs*" (Kørnøv et al., 2011, p. 207) and being strongly oriented towards producing change. The researcher, however, enjoys its autonomy determining research directions and being accountable, not to the milieu and the financial organization as in mode 2, but to "*the people and/or the environment affected*" (Kørnøv et al., 2011, p. 207) during the research process and its outcome. Despite the (time, money, knowledge) resource interdependency with its milieu, the researcher producing mode 3 research makes active choices regarding external influence on research topics and negotiates these with its external milieu, while also engaging actively and intervening in ongoing processes (Kørnøv et al., 2011).

integration of my PhD project within Environment^{++} initiative. The PhD project contributed to the process through infusing knowledge into practice and bringing new insights when needed. I engaged with the practice, while at times needing to distance myself from it to make sense of the data and reconsider my contribution to both academia and practice. I engaged with the practitioners' view and knowledge and played an active role that can be characterized as an engaged scholar (Van de Ven, 2007) or "*a change agent*" (Kørnøv et al., 2011). Such a role refers to a researcher "*being part of and influencing the field studied—without devaluing or compromising the traditional scholarship*" (Kørnøv et al., 2011, p. 225).

My research process was rather fluid, shifting between different degrees of engagement with and distancing from the research field and from practice. It was one characterized by the constant shifts among the three forms of engaged scholarship (Van de Ven, 2007): 1) basic science with stakeholder advice, 2) co-production of knowledge with collaborators, and 3) action/intervention research for a client. The research process began with the co-production of knowledge with collaborators (2). This resulted in the formulation of challenges of practice with IS emergence that informed the formulation of the research question. Then, while taking a change agent role, I engaged with action research inspired methodologies (3) inspired by 'research circles' (Hecksher, Thomsen, & Nordentoft, 2014) to interact with the research field and researcher team facilitating the IS emergence through the Sustainable Synergies project and Port of Aalborg representatives. These aimed at both knowledge production and practitioner empowerment. Inspired by action research, I held five meetings with port representatives involved in Environment^{++}. The researcher (i.e. me) facilitated the meetings, making sure all participants had a say. The meetings always started with a presentation of results of my last study or research and continued with discussions, exchange of opinions, knowledge, and experiences. Themes such as the IS emergence process, the role of ports in IS emergence, ports' capacity for fostering IS emergence served as subjects for discussions. These enriched my understanding of IS emergence in Aalborg East port industrial area and contributed to formulating the research focus.

Furthermore, continuous interactions with the researchers involved in both Environment^{++} and the Sustainable Synergies project took place at the university, project events, status meetings, etc. In the early stages of the project, I immersed in mode 3 research, being part of the facilitation team, contributing to the development of the initial screening method and collecting data from companies regarding their potential resources. Later in the process, I distanced myself from being part of the facilitation team, and instead, by engaging with mode 1 research (Kørnøv et al., 2011) (1), contributed to making sense of the data accumulated from the project. This was then injected back into the practice of IS emergence facilitation and of Environment^{++}.

The continuous interactions and meetings were a constructive method to bring practitioners (from both Port of Aalborg and the facilitation team) close to my research and generate both new knowledge and new ways of practice. These offered common spaces for reflections and sharing of existing knowledge.

Analyzing the research process, I found that the shifts among different modes of research had implications for my positionality, my identity as researcher, and the way I perceived the research process. The following elaborates on this.

Research process has implications for researcher positionality, identity, and engagement with respondents. In my view, a research process includes *doing* research and *being* a researcher (Cunliffe & Karunanayake, 2013). Along the research process, a researcher finds them self (at different degrees) interacting with the research field, research respondents, and their own approach, identities, and roles taken during the research process. A research process is thus the outcome of interactions between 1) the researcher, 2) the researched, and 3) the respondents, as also depicted in the Figure 9. As shown in the figure, the research process is the interplay between my own identity and role as a researcher and my approach to the researched, which is the IS emergence phenomenon and the facilitating factors. Interview respondents, practitioners, and other researchers that I collaborated with, met at conferences, etc. contributed to both my identity and role creation and to the understanding of the phenomenon studied.

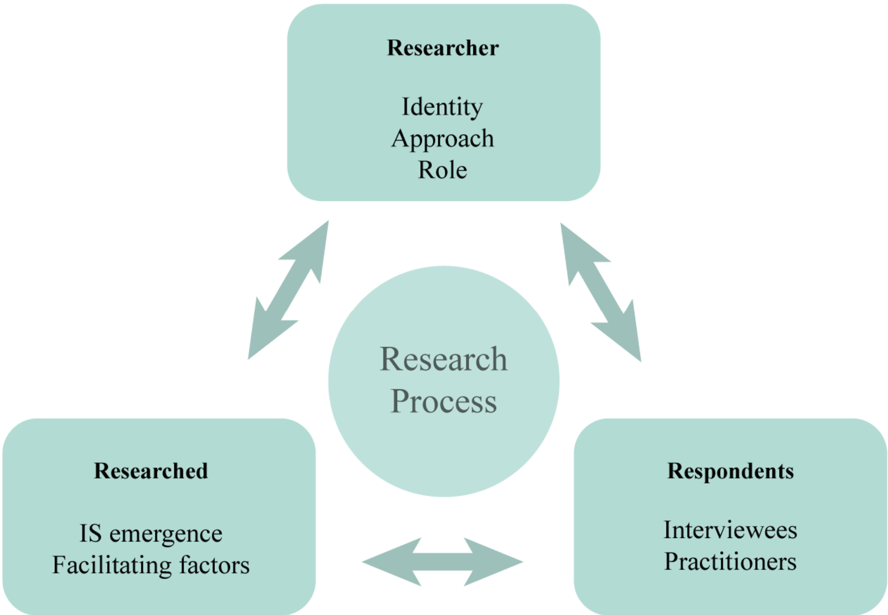

Figure 9: Research process—a result of interactions among research field, research respondents, and researcher identity. Developed by the author.

In this regard, the research process can be associated with 'working the hyphen' (Cunliffe & Karunanayake, 2013), which refers to the acting from *researcher–researched–respondents* relationships and transcending boundaries across 1) 'Engagement–Distance' approach, 2) 'Insiderness–Outsiderness' positionality, 3) 'Sameness–Difference' self-perception, and to 4) 'Activism–Neutrality' role of researcher (Cunliffe & Karunanayake, 2013).

Referring to the (1) "Engagement–Distance" interplay Cunliffe and Karunanayake (2013) mention the degree to which researchers get involved with their research and research field. Engagement and distance can, for example, refer to physical and emotional engagement with the research site and research respondents, which can have epistemological implications. Cunliffe and Karunanayake (2013) define the hyphen space between (2) "Insiderness–Outsiderness" as continuous shifts between researcher being external to the research site while mostly involved with what Kørnøv et al. (2011) calls Mode 1 research, and being actively engaged with the research field, having an ongoing role with interest in developing practical knowledge. The hyphen space of (3) "Sameness–Difference" relates to the way a researcher "*experiences and deals with differences and similarities between ourselves and others, identity differences embedded in culture, ethnicity, religion, class, education, symbolism (dress, hairstyle, carrying a notebook, video recorder), and language"* (Cunliffe & Karunanayake, 2013, p. 375). Referring to the role of researcher, Cunliffe and Karunanayake (2013) mention (4) the "Activism–Neutrality" of researchers. Researcher activism is expressed through the degree of researcher intervention in finding solutions to a societal problem and producing knowledge oriented towards social change. In this regard, doing action research and acting from inside-out of a research field is considered doing research with a high level of activism as the research is committed to produce change. Neutrality is then the opposite, and is in line with doing basic, Mode 1 research which does not aspire to produce change within a practice field.

Research process is the outcome of working the hyphen. The reflections on the research process as working the hyphen are summarized in the Figure 10.

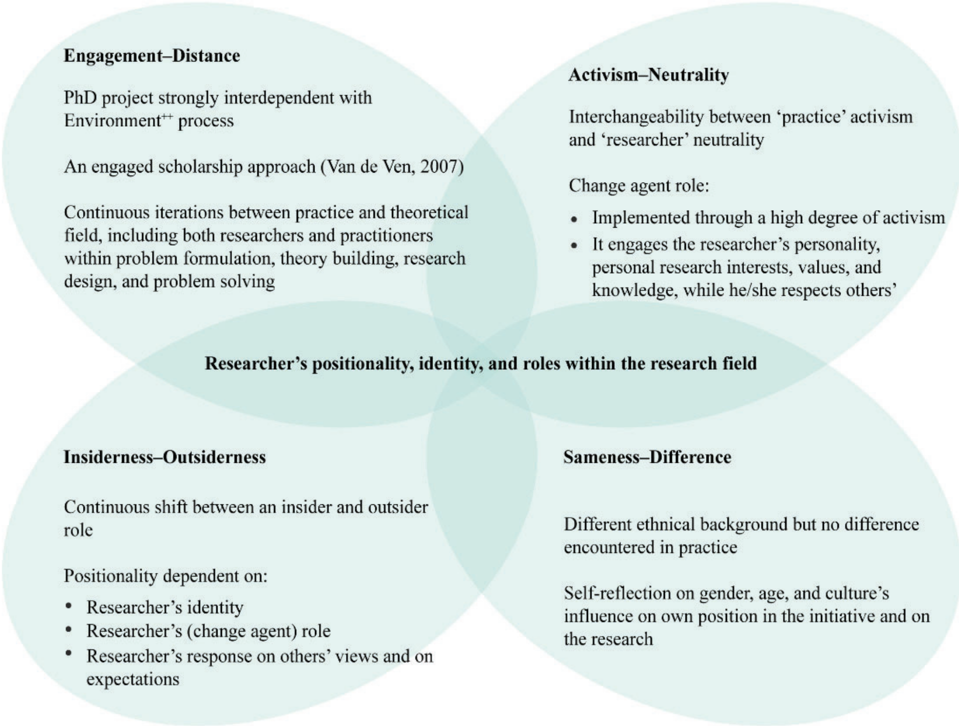

Figure 10: Research process as working the hyphen. Developed by the author inspired by Cunliffe and Karunanayake (2013, Figure 1, p. 372).

Engagement–Distance. Being an integrated part of the strategic IS-aiming initiative, Environment^{++}, I worked directly with academics and practitioners; problem formulation was strongly interconnected to challenges in practice. I conceptualized the challenges with IS emergence in practice as an ontological entity, (Jahn, Bergmann, & Keil, 2012; Wickson, Carew, & Russel, 2006), i.e. as something that exists in and originates from the real world, which was transformed into an object for scientific investigation and theory generation. IS was ontologically assumed to be a phenomenon that brings (environmental, economic, and social) benefits. The focus was then set on collecting knowledge that could create a better understanding of the phenomenon's emergence and of ways to bring it along (without further questioning its actual benefits and effects). For that, I worked 'up close' to the practitioners'[5] field

[5] The 'practitioners' here refer to both the Port of Aalborg employees and the researchers at DCEA who facilitated IS emergence in Aalborg East port industrial area through Sustainable Synergies project.

and ‘afar’ of it (Van de Ven, 2007), i.e. within theoretical understandings provided by the theoretical field of IS to formulate the research sub-questions and the theoretical framework provided by IS emergence and critical factors. My intention was to produce practical and applicable knowledge in a real-world context, while also contributing to the field of industrial symbiosis with understanding of its emergence. In this way I coped with the integration of theory and practice, which Van de Ven (2007) argues that engaged scholarship approach could facilitate. Exactly how this was done is presented in section 4.5.

Insiderness–Outsiderness & *Activism Neutrality*. During the PhD project I found myself engaging with insider–outsider positionality from which I had varying degrees of engagement with the practice field. At times, when Environment^{++} was at its beginning, the process had to be shaped and the knowledge on IS emergence had yet to be acquired and I engaged strongly in the ‘doing’ of the initiative, taking a higher degree of engagement and activism than other times by participating in project and partner meetings and contributing to organization of the initiative’s bootcamps. Similarly, I participated in the initial phase of Sustainable Synergies by contributing to development of the initial screening methodology, taking part at several screening interviews, and engaging in other project activities. At these times, I acted from an insider position to the process of IS emergence in Aalborg East port industrial area, acting more as a practitioner than a researcher, being one of the Environment^{++} team members. From this insider position I sought to contribute actively to the process of IS emergence in Aalborg East port industrial area and the research activity as a change agent was mostly oriented towards development of the initiative and thus producing change.

At times, though, I had to distance myself from the practice field and take a more neutral position in order to reflect on the experiences, challenges, and accumulated data and turned to other contexts for inspiration and empowerment of the practice in the Aalborg East port industrial area. At these times, I turned both to the theoretical field of IS and empirical cases of IS emergence in similar contexts to find answers on how IS could emerge and what factors affected the IS emergence. A conceptual study of various cases describing the coming about of IS within IS literature (resulting in the study by Mortensen and Kørnøv [cf. 2019 #1]) and an empirical study of IS emergence in other port industrial areas (resulting in the study by Mortensen et al. [cf. under review #3]) were effectuated. An initial conceptualization of IS emergence was developed and later enriched and further developed by the empirical studies. These studies could then inform both the IS field and the practice. The practice in Aalborg East port industrial area was enriched with inspiration from other IS emergence processes in port industrial contexts. While doing these studies I was somehow neutral to the process of Environment^{++} (even though I continued to follow it from distance, making observations and collecting notes on it).

By the end of the PhD project, I found the need to distance myself even more from the process of Environment^{++}, taking an outsider position without engaging further in the process (thus being neutral to it). This was in order to make sense of the research findings and to relate these to the current and future process of IS emergence in the Aalborg East port industrial area.

In this way, I shifted between an insider and outsider position in relation to the practice of IS emergence in the Aalborg East port industrial area to generate valid and relevant knowledge for both academia and practice. While being an insider, I sought a higher degree of involvement in the process than when taking an outsider position. From these positions I also dealt with the privileges and challenges that this role duality (i.e. shifting among being an insider and an outsider) (Coghlan, 2007) brought along.

Doing research from the inside of the practice field while being an insider meant that I could follow the process closely with access to the most internal details—I was granted access to the first-hand data, I knew the critical events taking place and the course of actions within Environment^{++}, I understood the practice language, I could engage in discussions at the same level with practitioners, and could raise questions about the misunderstood aspects. However, acting as an insider was not without disadvantages. Thinking that I understood the practitioners' language, I risked making assumptions and my own interpretations about practitioners' statements and did not to confront them with alternative "*re-framing*" (Coghlan, 2007, p. 297) of IS emergence. I also risked not being critical enough to practitioners' answers as we were connected with "*friendship*" relationships (Coghlan, 2007, p. 297).

By stepping out regularly from the practice and taking a more outsider position, I managed the challenges especially related to remaining critical to the data collected. To address this challenge, I shifted among physical places (alternating between university, the port environment, and other places), which created those needed 'breaks' from practice and provided environments that encouraged criticality. This detachment allowed me to stay critical of the data observed and was mostly necessary in the process of developing this thesis. Here, I located physically at a third organization (neither port or university) and tried to reflect on the findings from both articles and data from the IS emergence in the Aalborg East port industrial area (through Sustainable Synergies and Environment^{++}) from a neutral position.

Sameness – Difference. The interplay of engagement–distance and the positioning of insider–outsider roles raised reflections on my own identity, role, and positionality as a researcher in relation to degrees of activism and/or neutrality.

Prior to the PhD project, I was employed by the Port of Aalborg for half of a year to work within the Environment^{++} initiative. At the time the PhD project began, I remained employed by the port. However, I was collaborating strongly with DCEA. Even though I had the employer-employee relation to the Port of Aalborg, the connection to Environment^{++} and Sustainable Synergies project was stronger.

Throughout the PhD project, I saw myself as a "hybrid" between the port and DCEA; between practice and academia. Balancing this hybrid identity during the process was at times challenging and at times rewarding. Challenging and rewarding because, having insights into and understanding both contexts, I found myself often being the connecting line between the two. This feeling was strengthened by other's views of me. Sometimes I could feel that at the port I was "the researcher," while at the university I was "the port representative." While this could have had some down sides in some other situations, in my situation I felt it like a strength. I felt I got into the role of translating the knowledge and insights from one context to another. Facilitating knowledge flow among the main partners in the initiative was shaping my identity and role in both Environment^{++} and Sustainable Synergies.

Taking the role of change agent is anchored in the researcher's own personality and identity. Moreover, acting as a change agent is personally driven and engages researcher's own values, knowledge, and the acceptance of others' knowledge and values. (Kørnøv et al., 2011) Reflecting thus on motives, values, and knowledge that drive my own research is relevant here.

With a background in geography, environmental management, and sustainability science and having been employed in the project for half a year prior to the PhD project, I had a practice-oriented interest, besides the advancement of science. My interest was to contribute to the initiation of IS in Aalborg. This interest was, as specified above, anchored in the ontological assumption that IS is a strategy and tool that, when applied, can bring about sustainability. Thus, a desire to contribute to change drove my personal and scientific interests. The same values and beliefs could be perceived from the other actors' actions in practice. These seemed to have facilitated the actors' commitment degree and involvement in both Environment^{++} and my project. Representatives of the main partners in the Environment^{++} initiative (i.e. the port and DCEA) were highly interested and engaged in providing their views and inputs to the studies undertaken during my PhD project, enriching those with their knowledge and views of the world and anchoring this collaborative knowledge within their practice.

As an engaged scholar, I also had to make ethical considerations when reporting the data within the papers and this thesis. All through the research process, I respected the possibility of being an insider and having access to the phenomena researched from the inside the field. I therefore use the data with confidentiality for sensitive issues. Moreover, I respect the confidentiality of interviewees, as agreed, and do not present any names in the quotes included in this thesis. For non-sensitive issues, I chose to refer to the organizational actors that played or can play an important role in such processes. This is to assure a better understanding and inputs on who can contribute with what in the process of IS emergence in Aalborg East port industrial area.

In the research process, thus, I alternated between engaging with practice and engaging with the theoretical field of IS. Moreover, in the doing the research and reporting it (Saunders et al., 2016) in the developed academic articles, I also engaged with other theoretical perspectives that shaped the results of the present research. How exactly I engaged with the use of theory is explained in the following section.

4.5 REFLECTIONS ON THE USE OF THEORY

***How* and *what* within the research question**. Research that makes use of case study strategies can result in *exploratory*, *descriptive,* and/or *explanatory* research (Yin, 2014). Engaging with 'how' and 'what'-led research questions can point at all three types of studies. The main research question of this dissertation asks *how* industrial symbiosis can emerge in Aalborg East port industrial area and *what* factors can facilitate industrial symbiosis emergence in this area. Here, the 'how' and 'what' point at an explorative and descriptive approach to generating knowledge (Saunders et al., 2016).

The 'how' explores the IS emergence phenomenon as separate from IS development, focusing on its boundaries, characteristics, and the process that drives the emergence of symbiotic linkages. The 'what' permits identification and presentation the factors that, when set in connection to each other, can explain the coming about of symbiotic relationships. Identifying and presenting such factors, goes further than just describing these. These are viewed as variables necessary for enabling IS emergence as a phenomenon. The relation among the factors identified describe and explain to some degree the IS emergence process as these factors can be considered as 'causes' for the IS emergence process (Saunders et al., 2016). However, the research did not seek to explain 'why' such factors enable IS emergence. Thus, the research is not explanatory, in the sense of explaining reasons, but rather descripto-explanatory (Saunders et al., 2016), i.e. it presents the factors that can enable IS emergence and views these in relation to each other to describe the IS emergence process. Asking the 'how' then becomes a representation of the relationships among these factors, adding order to the conceptualization (Whetten 1989) of the IS emergence process.

Theory use. Answering the research question and seeking to enrich the aim of this research (which is to both bring a contribution to academia and practice), the research makes use of theory in various ways. Generally, research can engage with meta or grand theories, middle-range or general theories, and/or with substantive or specific theories (Saunders et al., 2016; Egholm, 2014) to provide cohesion, efficiency, and structure to research questions and design (Hitt & Smith, 2005, p.1). Grand theories are abstract and general worldviews that shape the ways one perceives the world. The middle-range theories are general theories that lack the capacity to change the way one thinks about the world (Saunders et al., 2016) and are used to describe models that explain specific elements of the phenomena studied (Egholm, 2014). Substantive theories are immediate theories that are used to describe and/or explain phenomena bound to specific time, place, problem, etc. (Saunders et al., 2016)

Kørnøv (2015), studying the use of theory in 502 articles on environmental impact assessment, develops eight categories describing the ways in which theory can be used in research pictured in Table 5.

Table 5: Categorization of use of theory by Kørnøv (2015, Table 1).

Use of Theory	Explanation
No explicit theory used	"Pure" empirical research.
Non-attached theory	Theories mentioned in the introduction or literature review, but without explicit evidence that the theory is used for any other purposes than to establish legitimacy or support the author's ideas.
Theory informing	Theories are used to focus and inform the design of the study.
Theories are used to focus and inform the design of the study.	Theories are brought in after the empirical findings are presented and used to interpret and discuss the findings.
Theory testing	Theories are used to develop hypotheses being tested through empirical analysis.
Theory development	Existing theories are modified or extended.
New theory development	New theory proposed — and possibly implemented in the research design.
"Pure" theory research	Discussion of and upon theories.

Using these categories to analyze the use of theory in this research, it can be stated that the present research makes use of theories in various ways as pictured in Table 6: It engages with both middle-range and substantive theory of IS, identifies the gaps within these, and, through bringing insights from IS emergence processes within empirical contexts of port industrial areas, informs and further develops these.

For instance, the two conceptual studies—Mortensen and Kørnøv (cf. 2019 #1) and Schlüter et al. (cf. 2020 #4)—engage with the substantive theory of IS to further develop this, bringing specific focus on IS emergence and factors that enable it. While Mortensen and Kørnøv (cf. 2019 #1) engage directly in theory development by building on existing knowledge of IS emergence and development from different contexts, Schlüter et al. (cf. 2020 #4) brings its contribution to theory by proposing a new dynamic explaining IS emergence and development. Both studies therefore engage with basic research (Jaccard and Jacoby, 2010; Kørnøv et al., 2011) and develop the existing theoretical perspective on IS emergence, contributing directly to the specific filed of IS. The empirical study of IS emergence through the Sustainable Synergy project uses the initial conceptualization developed by Mortensen and Kørnøv (cf. 2019 #1) and, by bringing fresh empirical data from real-time processes, tests and develops the initial conceptualization further by applying it to both study design and data interpretation.

Table 6: The use of theory in the studies.

Study	Theory used	Purpose of use
Mortensen and Kørnøv (cf. 2019 #1)	Substantive theory of IS	To enrich existing theory on IS emergence
Schlüter et al. (cf. 2020 #4)	Substantive theory of IS	To enrich existing theory on IS emergence
The study of IS emergence through the Sustainable Synergy project	Conceptualization of IS emergence by Mortensen and Kørnøv (cf. 2019 #1)	To enrich the initial conceptualization of IS emergence with empirical insights from specific context
Mortensen et al. (cf. 2020 #2)	Substantive theory of ports' development and roles	To focus and inform the design of the study and develop analytical framework
Mortensen et al (cf. under review #3)	Middle-range theory of collaborative business models Substantive theory of IS	To focus and inform the design of the study To understand and interpret IS emergence in port industrial areas
This thesis	Substantive theory of institutional capacity	To understand and interpret the findings across studies

Mortensen et al. (cf. 2020 #2) make use of the substantive and specific theories of ports' development and roles to focus and inform the design of the study and to develop the analytical framework used in the study. The study tests the existing theories about larger ports' development on a smaller port case: the case of Port of Aalborg. The idea was not to identify strengths and weaknesses in such theories, but rather to present avenues for how theory could be further developed. Thus, the study is theory informing.

The study conducted by Mortensen et al (cf. under review #3) made use of middle-range theory of collaborative business models, and the substantive and specific theory of IS to focus and inform the design of the study and the subsequent understanding of IS emergence in port industrial areas. IS is conceptualized as a collaborative business model that can come about as a result of a collaborative process among multiple stakeholders. Such conceptualization is scarce within the IS literature and few studies consider IS as a business model (Bocken, Short, Rana, & Evans, 2014; Boons & Lüdeke-Freund, 2013). Adopting such a theoretical lens (across disciplines) was rooted in the authors' belief that the IS field is best understood by addressing it through transdisciplinary collaborations, i.e. collaborations between researchers across disciplines and at the same time, between researchers and practitioners. By bringing theoretical insights from collaborative business models into the IS field, the study brings new perspectives on IS emergence by complementing the initial conceptualization developed by Mortensen and Kørnøv (cf. 2019 #1) and informs and enriches the existing theoretical insights within the IS field. Thus middle-range theory is used to inform the conceptualization of IS emergence and contribute to enriching the substantive theory of IS.

Building further on these studies and applying the knowledge acquired through these to the IS emergence process in Aalborg East port industrial area, the research within this thesis uses theoretical insights from institutional capacity theory to understand and interpret the research findings. Thus, the theory is used here for interpreting and discussing further insights in how IS emergence can be enabled in the specific context of the Aalborg East port industrial area. Choosing this theory was rooted in the desire to go from understanding the IS emergence process and factors that enable it in port industrial area (micro-perspective) to the important role of contexts' characteristics for fostering such processes (mezzo-perspective) and to identify further implications for practice and research (macro-perspective).

The engagement with theory points at the present research generating new insights into IS emergence processes, which enrich and expand the existing theory on IS emergence and development, thus generating new theoretical insights through generalizations from case studies (Flyvbjerg, 2006). Generalization from case study is done regarding IS emergence in the particular context of port industrial areas and not on IS emergence in general. The goal was to make analytical (and not statistical) generalizations (Yin, 2011; 2018) on IS emergence in port industrial areas based on empirical data from specific (multiple) contexts, among which the Aalborg East port industrial area was the main case area.

Empirical–theoretical relationship. Making use of various theoretical perspectives and in various ways, these affected the entire research process from informing the research design to interpretation of findings (Saunders et al, 2016).

As the aim of the present research, presented in section 2.3 is to bring contribution to both practice and academia, this research makes use not only of theories but also empirical data to both advance theoretical understanding of the IS emergence phenomenon, and to inform the practice. In pursuing the research aim, an interplay between theoretical perspectives and empirical data is applied, moving back and forth between the two, as undertaking research is understood as managing the balance between the use of theory and empirical data (Saunders et al., 2016). Theoretical aspects and empirical insights were closely interwoven throughout the research process, as also represented by Figure 11.

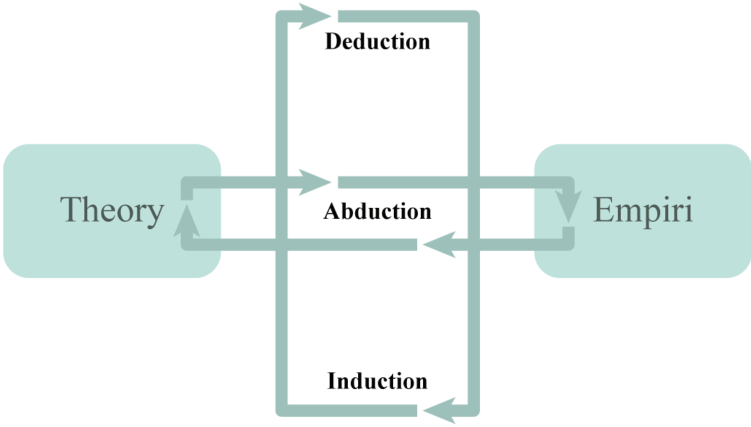

Figure 11:The use of theory and empirical data in the studies.

Figure 11 presents graphically the interplay between the use of theory and empirical data. However, variations in the use of empirical data and theories were identified across studies. The conceptual studies of Mortensen and Kørnøv (cf. 2019 #1) and Schlüter et al (cf. 2020 #4), aiming directly at enriching the existing theoretical perspectives on IS emergence, and thus contributing to the academia, were only indirectly engaging with empirical data. While Schlüter et al (cf. 2020 #4) uses empirical data from the existing IS network in Aalborg to validate the IS reproduction model, Mortensen and Kørnøv (cf. 2019 #1) collects data from empirical-based literature to enrich the IS emergence model with insights into factors that can enable such a process. The other three studies (cf. Mortensen et al., 2020 #2; Mortensen et al., under review #3; and the study of IS emergence through Sustainable Synergies project) engage directly with empirical data and build on these to inform the theoretical perspectives used and to enrich the understanding of IS emergence.

The interplay between theory and empirical data was operationalized through the abduction approach to research (Saunders et al., 2016), as also represented in Figure 11. Shifts between deduction and induction are to be found both at the study level and at the level of this thesis's research. The movement between theory and empirical data permitted combination of the deductive and inductive approach resulting in an abduction (Sunders et al., 2016). At the beginning of the PhD process, when I knew less about IS emergence, I turned my sights towards the substantive theory of IS and sought creation of a conceptual framework and model describing the IS emergence. This functioned then as a theoretical apparatus that provided initial insights, which helped with understanding the resulting empirical findings in the specific contexts of port industrial areas. Then, I returned to this theoretical apparatus and complemented it with other theoretical insights to design the other studies (deductive approach). In the same time, I also turned my gaze to the empirical data. I explored IS emergence processes in port industrial areas and sought identifying factors enabling IS emergence in these contexts. In this way, empirical data informed and developed the theoretical insights (inductive approach). This thesis gathers the generated theoretical insights, informed by the empirical research throughout this PhD project and feeds them back into the empirical field of IS emergence in the Aalborg East port industrial area (abductive approach).

By adopting an abductive approach to knowledge production, I managed to go deep within IS emergence conceptualization, identification, and understanding of specific factors driving it. Moreover, an abduction approach permitted faster understanding of IS emergence in empirical contexts, as the initial conceptualization provided already the needed 'lens.'

Simultaneously, using an abductive approach to knowledge generation had some limitations: I risked limiting my views and understanding to this original conceptualization of IS emergence processes and factors, and not being able to see other aspects emerging from real-life contexts. To address these limitations, I tried to adopt a semi-grounded approach to data collection from case studies, to include open-ended questions in the interviews in order to be able to get some new insights not covered by the theoretical framework. This was most obvious by the end of the PhD process where the semi-grounded approach to data collection was intentionally used in the case of IS emergence in the Aalborg East port industrial area. By this time, I became aware of the biases that theoretical understanding could put on my findings, and I strived to stay true to the case study and empirical data.

Research contribution to theory and practice. Having an abductive approach, implies the use of theory and empirical data in shaping both theoretical contribution and contribution to practice. The research develops both conceptual and empirical-based papers that feed into informing both theory and practice. Figure 12 presents how the studies developed throughout this PhD project feed into both theory and practice.

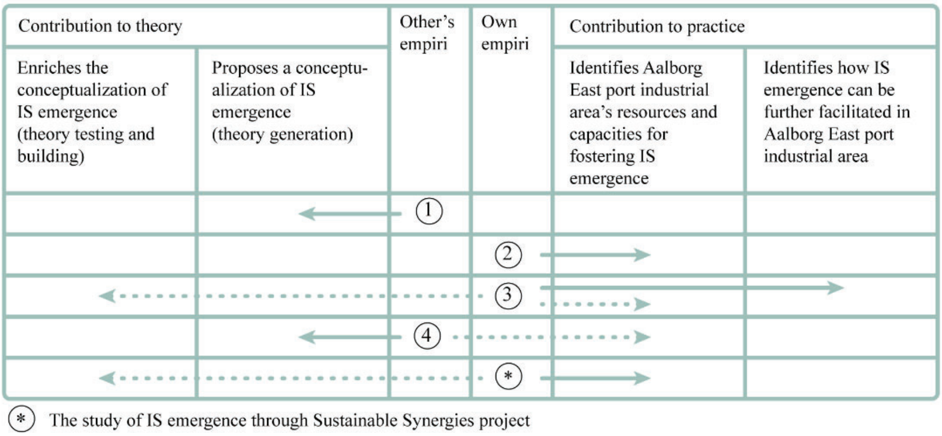

Figure 12: Research contribution to theory and practice.

As it can be seen from Figure 12, the developed studies make contributions to theory and practice in various degrees. The main contribution of the studies to theory and/or practice is represented by solid arrows, while a partial contribution (i.e. enriching the IS emergence conceptualization) is represented schematically by dotted arrows.

Contribution to theory. Figure 12 presents that the most obvious contribution to theory is made by the conceptual studies. These develop initial conceptualization of IS emergence, which is then enriched with empirical insights from the study of IS emergence through the Sustainable Synergies project in the Aalborg East port industrial area and the insights in IS emergence process from other port industrial areas presented by Mortensen et al. (cf. under review #3).

Mortensen and Kørnøv (cf. 2019 #1) build on existing literature on IS dynamics (Boons et al., 2017; Sun et al., 2017) to develop an initial understanding of IS emergence, conceptualizing it as the phase between pre-emergence and post-emergence. The pre-emergence is represented by the initial conditions as antecedents for and the unexploited potential of resource flows. The post-emergence is "*characterized through the formal establishment of synergistic ties, the physical implementation of IS and the IS development"* (p. 58). Moreover, the study identifies specific factors that enable IS emergence without focusing on IS development. As many studies within IS literature focus on both IS emergence and development simultaneously, this study makes a novel contribution by focusing specifically on the initial phase of IS development, identifying the boundaries of this phase and describing the processes and factors that enable IS emergence.

Schlüter et al. (cf. 2020 #4) brings a novel understanding of IS dynamics by identification of reproduction processes involved in IS emergence. The study adds the reproduction modes: budding, broadcast spawning, and brooding, and develops the IS reproduction model that permits researchers to understand how the interconnectedness among the existing and new symbiotic linkages can bring about IS. The reproduction dynamic complements the other IS dynamics (Boons et al., 2017; Sun et al., 2017) and proposes a new understanding of IS emergence. Moreover, focus is raised on the role of exogenous factors, the flow of knowledge, and the role of shared symbionts and facilitators for the development of symbiotic linkages, thus complementing the initial conceptualization developed by Mortensen and Kørnøv (cf. 2019 #1).

The immediate contribution to theory of both conceptual studies are the developed conceptual models: The IS emergence model (cf. Mortensen & Kørnøv, 2019 #1) and the IS reproduction model (cf. Schlüter et al., 2020 #4). While both models are described in the articles, the building of the models differs and necessitates attention here.

Building the models. Jaccard and Jacoby (2010) find that models are, among other things, theoretical expressions and symbolic representation of a conceptual system. In this sense, both models are graphical representation of the conceptualization of IS emergence. These representations, by themselves, do not constitute a theory or theoretical insights (Sutton & Staw, 1995), but are rather visual representations that "*clarify the author's thinking and increase the reader's comprehension*" (Whetten, 1989, p. 491). Accompanied by the written descriptions in the articles, these can provide theoretical traces (Sutton & Staw, 1995).

Inspired by biological science on plant emergence and coral reproduction, the models use analogy and metaphor as theory generation. Analogies and metaphors are a well-recognized heuristic for theory development (Jaccard and Jacoby, 2010). It is a method for theory development where "*the logic of another problem area [is transposed] to the logic of the area of interest*" (Jaccard & Jacoby, 2010, p. 52). In our case, the logic of seedling sprouting and coral reproduction is transposed to the logic of IS emergence. Using metaphors and analogies permit a grasp on hardly understandable phenomena "*by virtue of an analogy with a familiar situation*" (Gentner & Smith, 2012, p. 130).

Building the IS emergence model: The method for generating the IS emergence model was based on 1) generating the idea and 2) analytical scrutiny as proposed by Jaccard and Jacoby (2010). The initial idea of modeling IS emergence was generated with the use of creativity (Jaccard & Jacoby, 2010) where the authors went back to the roots of conceptualization of IS and dove deeper into the biological metaphor. The plant emergence example (Booth et al., 2003) was found to be the most relevant metaphor with capacity to explain the emergence phase of IS when connected to the practice and the IS literature on IS dynamics (Boons et al., 2017). Therefore, it was adopted for the development of the initial conceptualization of IS emergence. Using the metaphor of biological processes is at the core of the IS field. While older studies addressed and discussed this metaphor (Frosh & Gollopoulos, 1989) recent studies seem to have forgotten it. The model then can be said to rejuvenate the biological view on industrial systems and uses it creatively to explain the IS emergence process.

Empirical-based academic literature provides reality-based inputs for the model development. The IS emergence model is also enriched later in the research process by empirical evidence from IS emergence processes through the Sustainable Synergies project in the Aalborg East port industrial area. Thus, for analytical scrutiny, the IS emergence model draws on empirical-based literature and builds further on the conceptualization of IS dynamics by Boons et al. (2017) and Sun et al. (2017). Building on these with insights from plant emergence literature, specific (pre- and post-emergence) boundaries for IS emergence are identified that separate the conceptualization of IS emergence from IS development (which is marked by the physical establishment of the symbiotic linkage). Then specific characteristics that distinguish it from the other phases of IS evolution are identified and a definition of IS emergence is formulated.

The IS emergence model is a generic model, meaning that it builds and revolves around the IS emergence concept as a generalized *abstraction* (Jaccard & Jacoby, 2010) of reality. It depicts the initial conceptualization of IS emergence, where conceptualization is used to make sense of reality (Hitt & Smith, 2005). Modeling IS emergence then becomes a graphical representation of real-world process of the development of symbiotic relationships. However, it is not true reality, but rather a hypothetical reality, and the conceptual IS emergence model functions as a representation of this to help us understand it. (Jaccard & Jacoby, 2010) The IS emergence model makes sense of the process of 'IS emergence' as a real construct and a concept that encapsulates the activities and events that lead to the development of IS. Conceptualization provides then first insights into a deeper understanding of the emergence process. Understanding refers here to identifying the factors that explain what enables IS emergence, describing and organizing these according to three sub-phases of the model (i.e. awareness and interest in industrial symbiosis, reaching out and exploration of connections, and organizing). The aim of the IS emergence model is to explain and present ways in which IS emergence comes about by identifying specific facilitative factors. Such an understanding permits intentional encouragement of collaborative processes for IS emergence.

The IS emergence model conceptualizes *IS emergence as a process*, i.e. a sequence of events that unfold to lead towards enhanced relationships between (industrial) actors seeking IS establishment. Focusing on process, and the variables that drive the process, is a common heuristic for theoretical idea generation. Thinking in terms of variables is largely acknowledged as a strategy for theory development in social science (Jaccard & Jacoby, 2010). Thinking on variables refers to the factors that enable the IS emergence process, while thinking on process refers to the activities that take place, as a set of events unfolding over time for producing change (i.e. from non-emergence to emergence). Conceptualizing IS emergence in this way provides the possibility to shift the focus from the static understanding of factors driving IS emergence to the dynamic character of development, from *being* & *observing* IS into *becoming* & *developing* IS. In this way, IS is conceptualized as a dynamic phenomenon that is enabled by the factors as 'variables' that are not just 'momentary snapshots' (Jaccard & Jacoby, 2010, p. 55) but rather a set of factors that will affect the process at variate degrees and at different times.

Building IS reproduction model. Applying a biomimetic approach (Mak & Shu, 208) through analogic reasoning (Gentner & Smith, 2012) is taking inspiration from natural phenomena. Biological analogies are the most encountered direct ways of concept generation (Mak & Shu, 2008). As IS emergence has disparate conceptualizations within IS literature, a specific way to understand it is needed. Similar, to Mortensen and Kørnøv (cf. 2019 #1), Schlüter et al. (cf. 2020 #4) turned to biological processes to find a way of understanding the dynamics of emergence processes. Analogies are done as also mentioned by Schlüter et al. (cf. 2020 #4) from a 'source domain' (coral reproduction) to the "target domain" (IS emergence) (Gentner, 1983), thus the development of an IS reproduction model makes use of a cross-domain analogy, as the two domains are conceptually different (Mak & Shu, 2008).

The analogy and IS reproduction model generation steps are described with a great level of detail by Schlüter et al. (cf. 2020 #4), thus there is no need to include it here. The approach to building the IS reproduction model, corresponding to the three processes common for analogic thinking presented by Gentner & Smith (2012): 1) retrieval; 2) mapping, and 3) evaluation, however, needs attention and merits a description here.

<u>Retrieval process</u> refers to retrieving analogue situations by identifying the initial source domain that could be used to explain the target domain (IS emergence) (Gentner & Smith, 2012). Within this process, Schlüter et al. (cf. 2020 #4) followed the five-step strategy for biomimetic concept generation proposed by Vakili and Shu (2001) and adapted it to the industrial symbiosis field. First, the initial information sources of biological phenomena referring to 'symbioses' emergence' were explored. Finding out that the emergence processes of (general) biological symbioses didn't offer an attractive ground for analogy building to explain industrial symbiosis emergence, focus was shifted to 'emergence of life' and a new exploration of the biological literature began. The 'emergence' concept was identified to match the search. Then, other synonyms to 'emergence' were explored that could bridge the two (source and target) domains and 'reproductive mechanisms' were identified as a relevant ground for analogy building. Furthermore, a search for reproductive mechanisms followed and 'coral reproduction mechanisms' were identified as a relevant basis for analogy generation. Examining in detail the sources describing the coral reproduction mechanisms permitted development of a detailed overview of reproduction modes and processes.

Having retrieved the specific reproduction modes and processes from the source domain (i.e. coral reproduction), the next step in building the IS reproduction model was to map the coral reproduction modes into the IS domain explaining the IS emergence. Mapping, according to Gentner and Smith (2012, p. 131) is "*the core process of analogy*" development and consists, in our case, of finding how coral and IS reproduction are similar, and then developing inferences on IS emergence based on the coral reproduction mechanisms. Such a process required "*aligning the two situations based on their commonalities…and projecting inferences from the base to the target, according to this alignment*" (Gentner & Smith, 2012, p. 131).

Alignment was rather a creative process. Imagination and creativity played an important role in generating the analogy from coral reproduction to IS emergence. A heuristic based on imagination and creativity is an important mechanism for theory generation (Hitt & Smith, 2005; Jaccard & Jacoby, 2010). Moreover, systematicity and transparency (Gentner & Smith, 2012) were sought when mapping the mechanisms from coral reproduction to IS emergence processes, without making erroneous assumptions that what is true for coral reproduction is fully true for the industrial processes. Aligning the coral reproduction mechanisms with IS emergence was instead based on structural consistency (Gentner & Smith, 2012). Schlüter et al. (cf. 2020 #4) was specifically interested in the interconnectivity between an existing industrial symbiosis and the emergence of a new one. Therefore, mapping the reproduction process between the two domains had this aspect as criterion for alignment. The authors examined how the old and new emerging coral organisms were connected and dependent on each other within each reproductive mode (budding, broadcast spawning, and brooding) identified. Then, the "interconnectivity of organisms" analogy was transposed one-by-one to the IS filed, where the interconnectivity between existing and new industrial symbioses was identified. Aligning interconnectivity between two entities from the source domain (coral reproduction) into the target domain (IS emergence) resulted in an overview of IS reproduction modes that permitted creation of a larger picture on IS reproduction and then allowed inferences on the IS emergence process.

After aligning the two domains and developing the inferences within the target domain, it is common to evaluate the analogies and its inferences (Gentner & Smith, 2012). Schlüter et al. (cf. 2020 #4) make use of empirical cases from the existing IS network in Aalborg to evaluate the model through validation and illustration. Criteria such as factual correctness, adaptability, and contribution of the analogy to the IS field were explored. The authors conclude that "*the developed conceptual model has proven useful to highlight characteristics of connectivity and dependence between symbioses*" (p. 13).

Contribution to practice. The contribution to practice, as represented in Figure 12, is mostly brought about by the three empirical studies: the study of IS emergence through the Sustainable Synergies project, Mortensen et al. (cf. 2020 #2), and Mortensen et al. (cf. under review #3).

The study of IS emergence through the Sustainable Synergies project makes use of empirical data collected from the same context of the Aalborg East port industrial area. It collects insights from an on-going project where the findings function then as lessons learned and can be used in designing further projects aiming at IS emergence in the area. The study feeds directly into the further process of IS emergence in the same context by also informing the practice about the facilitation capacity that exists and has been built through the Sustainable Synergies project in the Aalborg East port industrial area. Moreover, the study presents the capacities that the facilitator must have to be able to facilitate IS emergence, and by that it informs the practice about the professional and personal profile of a facilitation body of a future IS-aiming process.

Mortensen et al. (cf. 2020 #2) collects data from the same empirical context as the practice it informs, thus a direct contribution to this is made. The study unfolds the environmental evolution of the Port of Aalborg and presents the environmental actions that were required. By focusing on past actions, the study collects insights into the capacity that accumulated over the last decade at the Port of Aalborg and that permitted the port to engage more proactively with IS emergence through the Environment^{++} initiative. Moreover, the study of environmental evolution made the Port of Aalborg aware of its evolutionary path, its strengths, (geographical, infrastructural, and institutional) resources and capacities that the port has and that can be mobilized to bring IS emergence about. Focusing on environmental evolution through analyzing the ports actions set focus on the initial conditions and antecedents for the actions the port has undertaken for fostering IS emergence. The study enriches the understanding of IS emergence in the Aalborg East port industrial area by emphasizing initial conditions. Using a similar perspective, the current actions can be perceived as the foundation upon which the port builds its actions and initiatives of tomorrow, as these build (institutional) capacity that can be activated in future processes.

Making use of empirical data collected from other port industrial areas *Mortensen et al. (cf. under review #3)* brings empirical insights in other IS emergence processes in port industrial areas. The insights obtained enrich the understanding of IS emergence and the initial conceptualization of IS emergence developed by Mortensen and Kørnøv (cf. 2019 #1) by identifying collaborative structures such as networks, partnerships, and platforms as important factors facilitating IS emergence. Moreover, the study's findings point also at the various roles that actors might take within IS emergence processes in port industrial areas, among which the role of ports is underlined. Obtaining such insights informs then the practice in Aalborg by presenting a way for understanding the collaborative structures supporting IS emergence in the Aalborg East port industrial area and inspiring further development of these.

All in all, the research within this thesis makes a novel contribution to the IS research field by delimiting IS emergence from IS development and setting focus on the processes and factors that enable it. Moreover, it brings empirical insights from novel contexts—port industrial areas—into the IS literature and emphasizes the resources and capacities that might exist in these areas for fostering and facilitating IS emergence. The research finds that port industrial areas present significant resources that permit them to be natural habitats for IS emergence. Furthermore, by adding theoretical perspectives from institutional capacity theory and adding empirical evidence from facilitation processes in real-world contexts, insights into how IS emergence might be fostered in contexts with similar characteristics as port industrial areas are presented.

By uncovering the resources and capacities that brought the Port of Aalborg to engage with current IS-aiming initiative, Environment^{++}, and identifying the role that the port took and the roles that it can take in further IS-aiming processes, the present research, brings its contribution to practice of IS emergence in Aalborg east port industrial area. The research points as well to roles that other actors can play in present and future initiatives aiming at IS emergence. Furthermore, the research identifies the capacities, skills, and tasks of a facilitation body and provides inspiration to practice and others involved in similar processes for how the available resources and capacities can be mobilized in collaborative structures that can support further IS emergence.

The next chapters present the research findings highlighting details on how these contribute to both IS emergence conceptualization and the process and factors enabling it in practice.

PART 2

Research findings and discussion

5 CONCEPTUALIZING INDUSTRIAL SYMBIOSIS EMERGENCE: PROCESS AND FACILITATIVE FACTORS

As described in section 2.2, a rich body of research addresses the factors influencing IS emergence and development as drivers and barriers, as enablers and challenges. Around the world, many initiatives have been taken for encouraging IS emergence by addressing some of these factors (see e.g. Park et al., 2016; Park et al., 2018; Sharib & Halog, 2017; Wu et al., 2016; Doménech et al., 2019). These all take different approaches, dependent on the characteristics and capacities that each context presents. Research on IS emergence and development dynamics tries to bridge the gap of differentiations among approaches to IS emergence and development by providing inputs on the ways and processes through which these can be encouraged (e.g. facilitation, self-organization, pilot programs, anchoring, etc.). However, the IS literature points to the need for a better understanding of IS emergence, as different from IS development, as well as the identification of factors that foster IS emergence specifically. Furthermore, contextualized research is encouraged to help identify the contextual characteristics that can encourage IS emergence.

Following the aim and objectives of this research as presented in section 2.3, this chapter aims to develop an initial understanding of IS emergence and the factors enabling it. To achieve this aim, Mortensen and Kørnøv (cf. 2019 #1) make use of IS literature describing IS dynamics and the biological metaphor of plant emergence to develop the initial conceptualization of IS emergence. Conceptualizing IS emergence as "*the dynamic (social) process between pre-emergence and post-emergence phases, where actors are engaged in processes of building awareness and interest in IS, reaching out to new possible partners through interactions that encourage the exploration of new possible connections, and organizing new symbiotic ties*" (p. 58), the authors develop the IS emergence model. A systematic literature review of 33 empirical-based articles is performed to identify the factors critical for each sub-phase of the IS emergence model and to obtain initial insights into factors enabling IS emergence in general.

Then, using analogy with the biological processes of coral reproduction, Schlüter et al (cf. 2020 #4) develop a complementary conceptualization of IS emergence. The authors identified several coral reproduction modes that were then transposed through analogy to IS emergence, based on the influence of the existing symbiotic linkages on the emergence of new ones and developed the IS reproduction model. The model conceptualizes IS emergence as a reproduction process that arises from a pre-emergence phase where an existing symbiotic tie influences a new emerging symbiosis and goes through various reproduction modes, such as budding, broadcast spawning, and brooding, to evolve further by staying attached to the previous symbiosis or by budding off before settling. In this process, the emerging symbiosis could clone itself. A post-emergence phase follows where the newly emerged symbiosis can further reproduce to form a colony or to form separate colony divisions. Empirical cases from the existing IS network in Aalborg are used to validate and illustrate the model.

Through conceptualizing IS emergence first as a collaborative process and then as a result of interconnectivity among symbiotic linkages, a more elaborate understanding of IS emergence is obtained. Section 5.3. describes how exactly the two conceptualizations inform and complement each other. Thereby, the results of both studies feed directly into answering the first and second research sub-questions, as presented in Figure 13 Besides contributing to a deeper understanding of IS emergence, Schlüter et al. (cf. 2020 #4), by using empirical cases of existing symbioses in Aalborg to validate the IS reproduction model, present relevant initial insights into the contextual characteristics as initial conditions for the actual, real-time IS emergence process in the Aalborg East port industrial area.

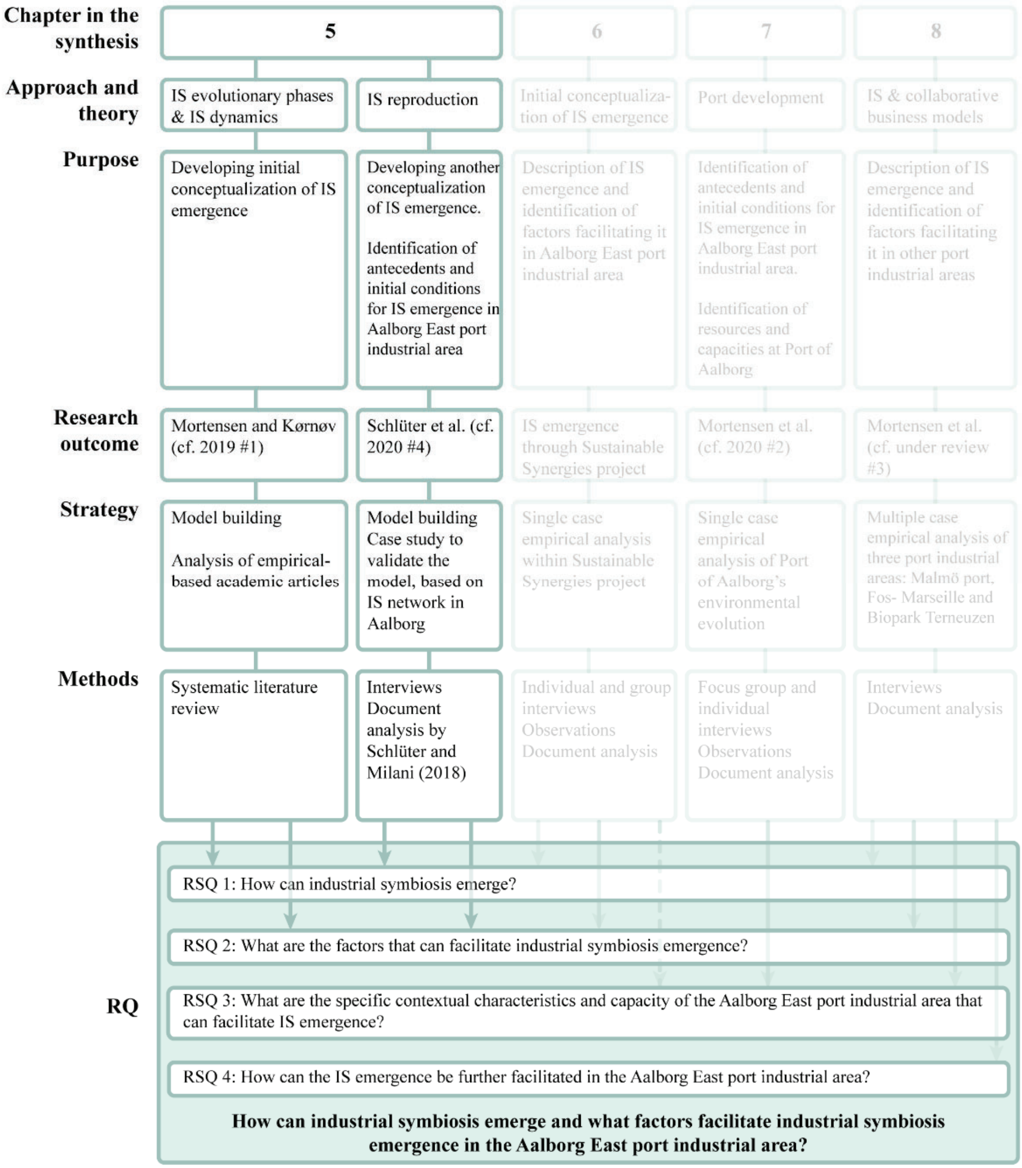

Figure 13: Chapter 5th's contribution to research question (s).

5.1 INITIAL CONCEPTUALIZATION

This section contains article #1:

Critical factors for industrial symbiosis emergence process

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Review

Critical factors for industrial symbiosis emergence process

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Industrial symbiosis is increasingly acknowledged as a strategic tool for the realization of industrial ecology and implementation of circular economy. Recently, industrial symbiosis literature was enriched with views and discussions on dynamics, focusing on the process and dynamic character of industrial symbiosis development. However, little attention is given specifically to the emergence of industrial symbiosis, in contrast to its development. In addition, no holistic picture exists envisioning the process through which initial ties come about and the critical factors fuelling this process. The aim of this paper is to set focus on and promote a better understanding of industrial symbiosis emergence as the earliest phase of its development. This study explores two aspects of the industrial symbiosis emergence: the process through which initial ties emerge and the critical factors influencing the transition between phases in the process. Based on an in-depth and systematic review of the existing empirically-based literature and by using a rigorous and iterative content analysis, three key (iterative)phases are identified: 1) awareness and interest in industrial symbiosis, 2) reaching out and exploration of (connections, and 3) organizing. Furthermore, five groups of critical factors (contextual conditions, actors, actors' roles, actors' characteristics, and actors' activities) are identified to influence the emergence process in different degrees at different times in the process.

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Contents

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1. Introduction

As plants grow from seeds planted in a soil with complex soil processes among different agents (e.g. sun, energy, and water) and other existing environmental factors, industrial symbiosis (IS) emerges likewise through complex dynamic processes among a multitude of critical factors, before evolving over time and space.

Inspired by the biological mutualistic relationships (Boucher, 1985; Bronstein, 2001), industrial symbiosis reflects symbiotic connections among traditionally unconnected organizations. These are based on resources (material, energy, water, etc.) exchange, transaction or sharing (References). IS is acknowledged as being able to reduce the industrial material and energy loss (Domenech, n.d.), increase businesses' economic performance (Verguts et al., 2016), improve the ecological footprints of industrial processes (Boons et al., 2017), and foster eco-innovation (Lombardi and Laybourn, 2012), creating added value for the actors involved (Domenech, n.d.). At EU level, IS has been recognized as a means to implement circular economy (EU Commission, 2011, 2014; Horizon, 2020, 2015) and in 2012 was noted as being 'one of the top priority areas' by the European Resource Efficiency Platform (EREP, 2014) triggering in this way the transition toward sustainable business development.

One of the most cited examples of an IS network is Kalundborg eco-industrial park in Denmark. However, examples can be found all over the world. A classic example from the Aalborg region in Denmark is, for example, the cement company Aalborg Portland delivering chalk slurry to the North Jutland power plant, which is used in the flue gas cleaning and returned as gypsum (NBEN, 2016; Sacchi and Ramsheva, 2017). Such successful examples are difficult to duplicate: A deep understanding of the processes through which IS emerges and the factors that trigger these processes is needed.

Recently, Boons et al. (2017) have conducted process-oriented research presenting dynamics through which IS comes about. Sun et al. (2017) continue this line of thought and add to the dynamics discussion. However, these studies identify common patterns of IS development without having a specific focus on the initial emergence of ties. The abundant literature on drivers, barriers, challenges, and enablers influencing IS development in general do not specifically focus on the emergence of initial synergistic ties but focus generally on IS development after the initial synergistic ties are created (Walls and Paquin, 2015; Yu et al., 2014a). Furthermore, there is a need to define the emergence of IS in contrast to its development and further evolution, as many of the existing studies address the phases of IS development and explore their boundaries, structures, and characteristics without systematic attention to the specific initial phase (Chertow, 2007; Doménech and Davis, 2011; Chertow and Ehrenfeld, 2012; Paquin and Howard-Grenville, 2012). As the transition to sustainable business development calls for a deliberate and intentional 'planning' of new sustainable businesses based on IS models, a deeper understanding of the specific phase of emergence can help facilitation and initiation of more IS networks.

- This paper aims to fill this gap identified in the literature and makes the following contributions: It focuses on the initial phase of creating synergistic ties.
- It draws the boundaries of the emergence phase, defines its process, and builds a conceptual model incorporating pre-emergence, emergence, and post-emergence of IS.
- It identifies critical factors specific for this initial phase.

This paper is the first to focus precisely on and provide a definition of the specific phase of emergence. This kind of focus is novel in the IS literature and is therefore an important contribution. Furthermore, by using a systematic literature review, this study not only takes stock of the evolution of IS literature, it also uses the empirical knowledge that has been produced over the years to move the IS field further towards a deeper understanding of the emergence process and critical factors triggering it. The paper is thus original in its way of encouraging a new theoretical understanding of the emergence process of initial synergistic ties.

2. Industrial symbiosis emergence process: A conceptual framework

2.1. Defining industrial symbiosis emergence boundaries

Questioning the boundaries of IS emergence, inspiration can be taken from terminology referring to IS processes and the literature on plant germination in biology. Within IS literature, processes through which IS occurs are explored, and different phases of IS evolution are proposed. Chertow (2007), building on the theoretical perspectives of Boons and Berends (2001) and Baas and Boons (2004), explores the emergence of industrial symbiotic exchanges and proposes that a 'period of initial self-organization' occurs as the initial phase of IS coming about, before IS discovery. Chertow and Ehrenfeld (2012) stress the serendipitous (self-organizing) mechanisms leading to the sprouting phase of IS ties. Paquin and Howard-Grenville (2012) mention the 'pre-network development' through intentional interventions aiming at platform creation for the subsequent 'early network development' phase. All these phases are based on specific processes of coming about (i.e., self-organizing or facilitation). Doménech and Davis (2011, p. 288) use the term ‘emergence phase’ to describe the initial phase of IS coming about. They define IS emergence as the initial phase of IS evolution, which occurs before it is established and developed and where ‘initial ties are developed and some straightforward cooperation opportunities [are] explored’. In defining the emergence of initial ties, Spekkink and Boons (2016, p. 613) refer to the phase ‘*before* the start of a [synergistic] collaborative process’, which is before the establishment of any bilateral connections, or ‘collaborations’. Initial ties emerge from the unexploited potentials of resource flows, which exist in every local context. Initial conditions and antecedents must also be in place. However, these can be created through the collaborative process before the establishment of any synergistic ties (Boons et al., 2017; Spekkink and Boons, 2016).

Inspired by biological terminology related to the emergence of plants, two main phases can be identified: *pre-emergence* and *emergence*. Pre-emergence, or germination, ‘means that the seed is physically active, and the embryo is undergoing mitosis to produce a shoot and/or root’, and emergence ‘refers to the appearance of a shoot above the soil or a root from the seed’ (Booth et al., 2003, p. 95). Thus, the plant's *pre-emergence* supposes the presence of a seed and specific soil factors, agents, and resource flows creating the possibilities for the seed's germination. The plant's *emergence* supposes the process of interaction among different factors and agents leading to the plant's sprouting above the ground. This moment can signal a post-emergence, where the plant grows and develops. Biologically, the post-emergence phase, or establishment, ‘is generally considered to occur once a seedling no longer depends on seed reserves …. , i.e. it is photosynthetically independent’ (Booth et al., 2003, p. 95).

Building on IS literature and the biological terminology, we can thus identify an initial phase of the creation of synergistic ties that we call *industrial symbiosis emergence*. We define this phase as a dynamic process between pre-emergence (i.e. the existing initial conditions and antecedents and unexploited potentials for synergistic ties) and a post-emergence process (i.e., formal establishment of collaborative synergies, physical implementation, and the start of the IS network development). The IS emergence phase is thus defined by the authors as: *the dynamic (social) process between pre-emergence and post-emergence phases, i.e., building on existing specific factors, agents, and unexploited potentials for synergistic ties, and aiming to establish synergistic relations between at least two organizations.*

2.2. Determining industrial symbiosis emergence process

Spekkink and Boons (2016) indicate that within such an initial phase, many sequences of events occur (self-organized or coordinated) and later constitute ‘the building blocks’ of initial symbiotic ties. A multitude of actors are engaged in projects, where common issues, themes and subjects could be addressed in an institutional capacity development process (i.e., knowledge, relational and mobilization capacity creation) (Spekkink, 2013, 2015). Thus, paving the way for the establishment of new IS ties.

The process-oriented approach introduced by Boons et al. (2017) proposes seven IS dynamics that unfold through a specific order of event sequences: self-organization, organizational boundary change, facilitation-brokerage, facilitation-collective learning, pilot facilitation and dissemination, governmental planning, and eco-cluster development. Sun et al. (2017) identify an eighth dynamic: anchoring. Here, a collaborative process unfolds, engaging a multitude of actors, and a large palette of events and activities for increasing actors' capacities take place. This can be considered a convergence between the self-organization dynamic and the facilitated one proposed by Boons et al. (2017). These IS dynamics refer to the IS development in general, including the emergence phase as addressed in this article. The IS dynamics proposed by Boons et al. (2017) and Sun et al. (2017) are based on (common) typical sequences of events unfolding in the IS development process in different contexts. A closer look at these helped us identify only the events characterizing the initial phase: IS emergence. First, we identified patterns and coded the events in six event groups, as seen in Table 1. Then, the activities relating to a firm's integration into its geographical and market location were labelled as pre-emergence events, characterized through the identification of initial conditions and antecedents addressing the unexplored potentials for IS. Furthermore, it was observed that all event sequences tend to end with the ‘contract - closed’ activities. We interpret this as representing the end of the emergence phase and the start of a post-emergence one, where IS network creation and development occur. Lastly, events such as ‘generating and raising awareness and interest in IS benefits’, ‘partner search’, and ‘organizing for initial ties’ are in between pre- and post-emergence events. This observation encouraged us to define the events taking place in the emergence phase, defined in this article as follows: a) events generating, raising, and/or presenting awareness and interest; b) reaching out events; c) exploration of connections events; d) events for organizing and final decision-making.

In considering these events further and connecting them to the extant literature, we conclude that the actors involved in the IS emergence process pass through a number of sub-processes:

1. *Awareness of and interest in IS* and its benefits are created through anchoring and institutional capacity-building activities (Boons et al., 2017; Sun et al., 2017).
2. *Reaching out* for IS potentials occurs through a strategic appliance of IS for regional development (Baas and Boons, 2004), where the concept of IS is translated into the local context and multiple stakeholders are engaged to explore new industrial possibilities and symbiotic connections (Boons and Spekkink, 2012).
3. *Organization* of new relations and a definition of rules occurs, potentially leading to formal agreements and contracts.

2.3. Building the conceptual model of industrial symbiosis emergence

In summing up the above definition of IS emergence boundaries and the determination of its process (sections 2.1 and 2.2), we can thus define the IS emergence phase as: *the dynamic (social) process between pre-emergence and post-emergence phases, where actors are engaged in processes of building awareness and interest in IS, reaching out to new possible partners through interactions that encourage the exploration of new possible connections, and organizing new symbiotic ties.*

Fig. 1 visualizes this definition and proposes a general conceptual model for studying IS emergence process.

The pre-emergence phase (with initial conditions and antecedents, and unexploited potentials of resource flows for IS) and the post-emergence phase (characterized through the formal establishment of synergistic ties, the physical implementation of IS, and the IS development) are out of the scope of this study and are therefore not considered further. The reason for including them in the model is to show the position of the emergence phase in relation to the pre and post phases. In this way, a more precise definition of the IS emergence phase is achieved.

The three groups of events are visualized as three phases of the IS emergence process. Notwithstanding the easily assumed chronological order (from ‘*awareness and interest in IS*’ to ‘*reaching out*

Table 1
Events within IS dynamics. Adapted from Boons et al. (2017) and Sun et al. (2017).

Events	Event groups
Firm integrates vertically in one location Firm is split up into legally separate entities Actor creates market facilitation mechanism	Events generating potentials
Firms expect benefits from symbiotic exchanges Local actors engage in collective learning Anchoring activities provide an important role for IS emergence	Events generating, raising, and/or presenting awareness and interest
Actor aims for regional economic (re)development Actor pics up IS concept and translates it Concept is translated to local context Actor communicates best practices to other clusters Stakeholders are activated to shape development agenda Anchoring activities provide an important role for IS emergence	Reaching out events
Partner search Actor selects cluster of firms to test concept Stakeholders are activated to shape development agenda Symbiotic exchanges are explored as part of agenda Anchoring activities provide an important role for IS emergence	Exploration of connections events
Actor selects cluster of firms to test concept Actor evaluates results Actor develops rules, monitoring, and sanctioning	Events for organizing and final decision-making
Contract - closed	Establishment events

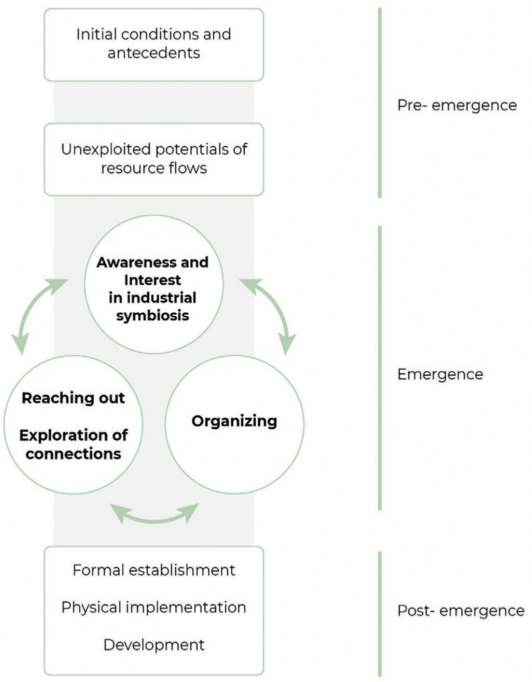

Fig. 1. Conceptual model for IS emergence process. The three phases are intentionally not visualized chronologically, as the characterising events do not happen necessarily chronologically, but rather simultaneously or at different order than chronologically. The arrows in the model represent the dynamism among the phases.

and exploration of connections', to '*organizing*'), these phases are intentionally not visualized chronologically. This is because the characterising events do not necessarily occur chronologically, they can also occur simultaneously or in a different order. As mentioned by Phaal et al. (2011, p. 218) 'it can be difficult to define exactly when an industry begins' because 'the process is not linear, …but instead there are many iterations and interactions between different factors [and actors]'. The emergence process of IS, just as it is presented by Boons et al. (2017) and Sun et al. (2017), is a dynamic one supported and fed by the interactions occurring often simultaneously at different levels leading to the different dynamics. We fully acknowledge the dynamism of IS emergence and do not claim a linear reading of the model. Instead, we consider the phases within the model as complementary steps to IS emergence, and in the model we represent this dynamism and iterative movement between and among phases with arrows.

In the following, we describe each phase of the IS emergence process as perceived by the authors based on the literature described in sections 2.1 and 2.2.

Acquiring knowledge and acknowledging potentials instead of challenges and risks can lead to raising awareness and generating interest in the initiation of new businesses or improvement of a business' own processes. Then comes the meaning creation. Here, the idea of a new business potential is born. The possible partners who can support the new idea can be either known or unknown. Often, this occurs at the individual or organizational level. We call it the *internal level*, since awareness and interest are held only by the individual or the organization itself (i.e., idea holders). We acknowledge that the awareness of a new possibility can be born at the collective level. This can, for example be during network activities and conversations or communications between different actors; or at a third party that can act as a facilitator, coordinator or broker. The common theme here is that during this phase the idea stays at its developer(s') level (individual or organizational) and does not move outside this boundary; thus, no action is taken.

When idea holders begin to act upon their new idea by sharing it (e.g., talking about it with actors other than idea holders) or when actors engage in collaborative processes where common ideas are studied (e.g., new ties and practical arrangements to support these) new ideas are explored. Here, the process leaves the internal level to unfold at an external level (i.e., at a relational, interpersonal, or inter-organizational level). Here, multiple (simultaneous) activities and interactions take place, through which institutional capacity is built and new connections are explored. We call this phase the ‘reaching out and exploration of connections’.

When initial contact to new potential partners is established through exploration of connections events, business ideas develop, and the new business models can be formulated. At this point, feasibility studies for such business models can be calculated. No formal arrangements, such as contracts, are made at this point and no physical infrastructural constructions are started. The IS emergence process undergoes the phase we call ‘organizing’, leading to the establishment phase, which is out of this study's scope.

Having identified the phases within the IS emergence process, the question becomes: What happens within these phases and what drives the transition between these? The answer to this question is found by addressing empirical-based IS literature from different contexts and identifying the critical factors affecting the IS emergence process.

3. Methodology

3.1. Defining the scope of the research

The research draws on empirical literature on IS and eco-industrial parks (EIP), as these concepts are often used interchangeably. EIPs are defined as a group of companies collocated at an industrial site among which IS is practiced (Elabras Veiga and Magrini, 2009; Ashton and Bain, 2012). The geographical scale of the empirical studies included spans 16 countries, as pictured in Table 2.

This article does not consider geographically specific contextual factors encouraging specific dynamics (Boons et al., 2017) but instead addresses general/universal critical factors encouraging the emergence of the very first symbiotic relations that mark the start of an IS network development. This is done in an attempt to focus on general parameters that must be considered when intentionally aiming for IS emergence in specific contexts. However, one must be aware of the limitations hereof. The model presented is not a normative one that must be followed literally. It is expected that when applying the model to a specific geographical context, the particularity of that specific context will have to be identified and incorporated in the model, since this study does not take account of cultural, political and institutional aspects of each specific context. Furthermore, this study only included academic literature in the systematic review; therefore, we might have missed insights and inputs on critical factors important from the practitioners’ point of view. These could be incorporated when applying the model to a specific geographical context.

By exploring the complexity of the IS emergence process and its critical factors and by proposing a general model, we aim to create a better theoretical understanding of the IS emergence phase. Awareness and knowledge of the emergence process and the critical factors, their properties, characteristics, and the possible (inter) actions between these could help to make the first informed steps towards strategic (i.e., intentional) IS network implementation.

Table 2
Overview of the articles included in the literature review and their geographical scope.

The Netherlands	Boons and Spekkink (2012) Spekkink (2015) Spekkink (2013) Baas (2011)
Denmark	Madsen et al. (2015) Branson (2016) Valentine (2016)
United Kingdom	Velenturf (2016a) Velenturf (2016b) Paquin and Howard-Grenville (2012) Paquin and Howard-Grenville (2013) Paquin and Howard-Grenville, 2009
Italy	Mannino et al. (2015) Cutaia et al. (2015) Taddeo et al. (2012)
Portugal	Costa and Ferrão (2010)
Sweden	Baas (2011)
USA	Hewes and Lyons (2008) Ashton (2009)
South Korea	Behera et al. (2012) Park et al. (2016)
China	Wang et al., 2016 Yu et al. (2014a) Ying et al., 2015 Zhu et al., 2014 Wu et al. (2016)
Australia	van Beers et al. (2007) van Beers et al. (2009)
Japan	Van Berkel et al., 2009
Thailand	Panyathanakun et al. (2013)
Malaysia	Sharib and Halog (2017)
India	Ashton and Bain (2012)
Brazil	Elabras Veiga and Magrini (2009)
Ukraine	Hewes and Lyons (2008)
19 cases worldwide	Farel et al. (2016)

3.2. The systematic literature review

Methodologically, the study is based on an in-depth and systematic review of existing empirically based literature. The overall aim of the literature review was to create an overview of factors critical for the phases of the IS emergence process. What we call ‘critical factors’, the IS and EIP literature calls ‘drivers’, ‘challenges’, enablers’, ‘barriers’, etc., and what we identified as the process of IS emergence is included in the literature under IS ‘development’, ‘evolution’, ‘facilitation’, ‘design’, ‘planning’, etc. Therefore, the literature search comprised academic peer-reviewed articles in English concerned with these aspects. All other literature, such as reports, books, conference proceedings, and open-source articles, were excluded.

The literature review was carried out in two steps: 1) A preliminary literature review of articles written in the period 2000–2017, and 2) A systematic literature review of articles from 2007 and later.

The reason for choosing firstly the period 2000–2017 was to create a larger overview over the field of IS and the themes related to emergence of IS. The use of the year 2000 as a lower limit was due to it being the year that research concerned with industrial ecology ‘became more established in the field’ (Boons and Howard-Grenville, 2009, p. 11). The establishment of the International Society for Industrial Ecology in 2001 and the peer-reviewed journal *Progress in Industrial Ecology* in 2004 have set the basis for a multitude of articles in the field. Limiting the final article selection for the systematic literature review to 2007–2017 was based on the preliminary results of the first step, which showed a richer core of literature based on empirical analysis after 2007 and richer literature available based on ‘uncovering’ IS, as described by Chertow (2007).

Step 1: The articles for the systematic literature review were collected through a search of the Web of Science and Wiley Online Library database. The original search query codes where a combination of the aspects in focus describing *the critical factors* and *IS emergence*: drivers, barriers, enablers and challenges, development, evolution, facilitation and planning, within literature on industrial symbiosis and eco-industrial park. Some examples of original search query codes are:

'industrial symbiosis AND enablers', 'industrial symbiosis AND eco-industrial park AND drivers AND barriers', 'Industrial symbiosis development', 'Industrial symbiosis AND planning', 'Eco-industrial park AND development', 'Drivers for industrial symbiosis development'. After a combination of the results from multiple topic search queries a list of 295 articles were found relevant, having some of these terms in their titles, keywords, or abstracts. These articles have then passed through an iterative manual review process (i.e., an assessment of abstracts, conceptual content, and citations used) through which 99 relevant articles were identified.

Step 2: During the second step the 99 articles within the period 2000–2017 were undergoing a new iterative review process. This time only articles from 2007 and later, based on empirical data (study cases) worldwide and describing the evolution/development/implementation of IS within a country or sector (e.g., forestry, iron) were considered. Following these inclusion criteria, a list of 33 articles was identified as relevant and formed the final body of articles for the literature review. The Table 2 provides an overview of the articles included and their geographical scope.

3.3. Data collection and analysis

The academic articles selected were reviewed using a rigorous and iterative manual process for data collection and content analysis as described by Elo and Kyngäs (2008). The aim of the data collection and content analysis was to identify specific factors critical for the phases of the IS emergence process.

The data collection and analysis involved the following steps:

1. *Preparation phase.* Pieces of text presenting critical factors referring to specific phases in the conceptual model of IS emergence were retrieved as quotes and later served as 'units of analysis'. In this process, only data that referred to the phases in the model were selected.
2. *Open coding.* Specific notes and headings on the critical factor(s) presented in the text and the specific phase of the IS emergence process it belonged to were added to each piece of text. The headings and notes were then collected and grouped into preliminary groups based on their meaning and belonging to the specific phase. In this way, several groups of specific factors per specific phase were created.
3. *Category generation.* The openly coded groups were further analysed and, through interpretation, grouped into broader higher-order categories per specific phase. Content analysis was applied to qualitative data in an inductive way, i.e. specific categories were derived from data by moving from specific 'analysis units' to general categories. Five categories of critical factors were identified: contextual conditions, actors, actors' roles, actors' activities, and actors' characteristics. The actors are those involved in different collaborative processes leading to IS emergence, where different roles are shaped through actors' characteristics and activities. Contextual conditions are the initial conditions or the antecedents in the form of physical and institutional conditions accommodating the IS emergence process. Each of these categories included smaller categories describing the factors critical for each phase. An overview of these categories is presented in Appendix A.

4. Results: critical factors for the IS emergence process

The composition and combination of specific factors included within the identified groups of critical factors (contextual conditions, actors, actors' roles, actors' characteristics, and actors' actions) differ from one phase to another ('awareness and interest creation', 'reaching out and exploration of connections', and 'organizing'). Fig. 2 summarizes the critical factors specific for each phase and the following sections describe each category in detail.

4.1. Phase 1: awareness and interest in industrial symbiosis

The collaborative, co-creational processes, also described by Spekkink and Boons (2016) as preceding the collaborative process, can create an awareness of and interest in the economic and environmental benefits generated through IS relations.

4.1.1. Contextual conditions

Based on the literature review, awareness and interest in IS can be created through technical and social infrastructure promoting the IS consideration and facilitating the good IS examples. *Policy* is a very important factor when it comes to generating awareness of IS possibilities and interest in gaining its benefits. As Velenturf (2016a, p. 121) puts it: 'the innovation process [started] in response to a change in the legislative or market context which created a problem and/or opportunity for a waste resource flow'.

Funding, financial support (Park et al., 2016), financial incentives, investments (Spekkink, 2013), and the availability of financial policies such as 'green investment tax credits, innovation grants' (Valentine, 2016, p. 76) raise companies' awareness of IS, awaken interest in IS, and drive their motivation for developing IS relations. 'Financial incentives could also be employed to encourage the corporate entities … [and] to begin to participate' (Valentine, 2016, p. 76). The financial incentives and support are found to come mostly from governments and other public bodies, such as municipalities (Wu et al., 2016; Park et al., 2016; Elabras Veiga and Magrini, 2009). The financial support was offered either directly to the companies involved in the process of IS emergence (Yu et al., 2014b; Wu et al., 2016) or to other actors, such as research and education institutions and other public entities, to facilitate the participative process for IS emergence (Velenturf, 2016b).

Awareness and interest in IS can depend on the *timing* and *history* of collaborations in a region (Baas, 2011). The existing relationships and the history and habits of collaboration can influence the establishment of new collaborations (Panyathanakun et al., 2013). Paquin et al. (2014, p. 277) mention that 'the difficulty of actually implementing potentially high-value exchanges … can stem from … past relationships, or an inability to leverage existing relationships in new ways'. The character of the existing relationships can affect the degree of awareness of IS possibilities and thereby influence the interest of companies in the IS benefits. As Baas (2011, p. 438) explains: 'Past and ongoing initiatives have resulted in the expanded consciousness that clean technology and industrial symbiosis can provide a synergy mode for innovative approaches beyond the adaptive capacity of single organizations'. Thus, history of collaborations can affect the actors' 'timescales for acknowledgement, information and application of the [IS] concept' (Baas, 2011, p. 438).

4.1.2. Actors

Within this first phase, the *research and education institutions* are found to be the most critical and are key stakeholders (Behera et al., 2012). They are generally considered crucial actors for the participatory/collaborative processes aimed at IS initiation (Park et al., 2016; Velenturf, 2016a; Panyathanakun et al., 2013; Behera et al., 2012; Elabras Veiga and Magrini, 2009; Spekkink, 2013; Taddeo et al., 2012). Generally, their role is seen partly as contributing to or playing the role of a facilitator or coordinator (Costa and Ferrão, 2010) by being able to 'feed valid information into the eco-

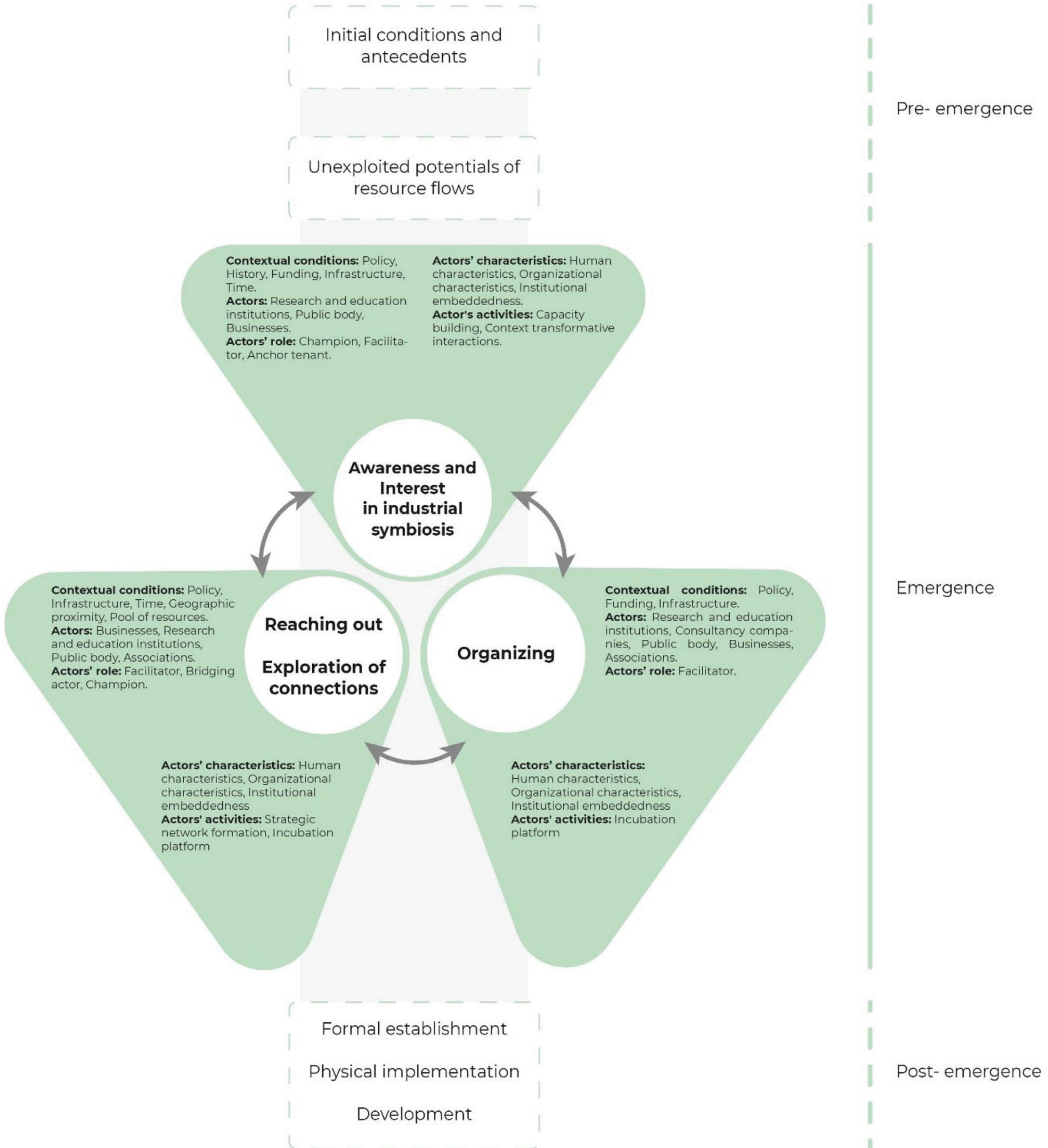

Fig. 2. IS emergence model: Process and critical factors influencing the transition between phases.

network and collaboration process, thereby overcoming impediments to successful collaboration caused by misunderstandings and asymmetric information among stakeholders' (Panyathanakun et al., 2013, p. 75) and partly as a champion (Behera et al., 2012). Within this phase, they support activities of knowledge sharing and dissemination, as well as knowledge capacity building (Panyathanakun et al., 2013; Costa and Ferrão, 2010).

The *public bodies* category of actor is one of the most cited that is important for IS emergence. This group contains national, regional, and local public entities such as governmental agencies (Costa and Ferrão, 2010; Panyathanakun et al., 2013; van Beers et al., 2009; Wang et al., 2016; Baas, 2011; Zhu et al., 2014; Park et al., 2016; Yu et al., 2014b; Elabras Veiga and Magrini, 2009), regional governments (Taddeo et al., 2012; Elabras Veiga and Magrini, 2009) and local governments (Park et al., 2016; Behera et al., 2012; Elabras Veiga and Magrini, 2009) such as municipalities (Hewes and Lyons, 2008; Baas, 2011), other kinds of local authorities (Velenturf, 2016a; Taddeo et al., 2012), and public agencies (Elabras Veiga and Magrini, 2009). Being involved in the collaborative processes from the early phases, public bodies are also those who can 'seed the innovation process' into a local context by providing support to companies, access to specialized knowledge, and incentives encouraging engagement, as well as promoting symbiotic thinking among other actors (Valentine, 2016).

Businesses are found playing different roles, as described in section 4.1.3. and being able to contribute to the implementation and 'dissemination of IS activities within a region' (Baas, 2011, p. 435).

4.1.3. Actors' roles

Businesses can play the role of an *anchor tenant*. The definition of anchor tenants found in the literature is similar to Chertow's (2007) conceptualization (i.e. a large company or power plant offering a large pool of material flows as IS potential). This can be a major firm (Valentine, 2016) or a somewhat industrial pole of a region (Cutaia et al., 2015) representing 'heavy process industries' (van Beers et al., 2007, p. 57) 'that can easily solve the curtailment of steam through in-house solutions' (Valentine, 2016, p. 72). Such companies, with their production streams, can get a number of by-products and need a number of resources. These can present a major source for symbiotic relations emergence. These actors are perceived as making a 'considerable impact at the regional level' (Costa and Ferrão, 2010, p. 987). Knowledge and awareness of their potential could inspire other actors to initiate IS relations.

Besides the identified groups of actor roles, such as anchor tenants and champions, the most quoted group of actor roles are those with the characteristics of a *facilitator* or a *coordinator*. The palette of who these actors can be is found to be large and 'colourful'. The literature reviewed presents examples of individuals being facilitators (Velenturf, 2016a; Qu et al., 2015), of organizations being facilitators (Spekkink, 2015; Panyathanakun et al., 2013; Taddeo et al., 2012; Madsen et al., 2015; Baas, 2011), or even networks or interconnected structures of actors playing the role of facilitator or coordinator (Wang et al., 2016; Farel et al., 2016). Such actors have been called 'more formal structures' (Valentine, 2016), 'facilitators and coordinating entities' (Mannino et al., 2015), 'change agent' (Baas, 2011), 'supervisory body' (Park et al., 2016, p. 37), 'a central organization' (Madsen et al., 2015), 'a shared contact' (Velenturf, 2016a), 'project group' (Spekkink, 2015, p. 139), 'a coordination structure' (Farel et al., 2016, p. 101003-6), Coordinator (Sharib and Halog, 2017, p. 1107; Paquin and Howard-Grenville, 2012), 'IS coordination network' (Wang et al., 2016, p. 1577), or 'network orchestrator' (Paquin and Howard-Grenville, 2013, p. 1648). In the initial phase of the IS emergence process, the role of facilitator or coordinator is summarized many times as the activation of 'the exchange of knowledge and relational resources' among business companies, public bodies, and other actors through different kinds of interactions organized (Wang et al., 2016, p. 1580). At this phase, facilitators must have a high degree of personal enthusiasm (Wang et al., 2016), involvement (Hewes and Lyons, 2008), and 'expertise to coordinate business-networking' (Wang et al., 2016, p. 1577). They are responsible for building actors' capacity (knowledge, relational, mobilization, personal, etc.) for IS emergence (Sharib and Halog, 2017; Velenturf, 2016b; Valentine, 2016; Paquin and Howard-Grenville, 2012; Baas, 2011; Qu et al., 2015; Yu et al., 2014b).

At this phase, actors such as public bodies, businesses, and universities can play important roles as facilitators and *champions* for other organizations (Hewes and Lyons, 2008).

4.1.4. Actors' characteristics

Specific *human characteristics* are found to be critical in the process of IS emergence. Generally, the actors involved in collaborative/participatory processes for IS initiation must be willing and interested in discussing existing challenges and possibilities and in collaborating with other actors (Cutaia et al., 2015; Valentine, 2016). The importance of an environmental mindset, spirit, and awareness, together with a symbiotic joined-up thinking and strategic thinking is accentuated in the literature (Valentine, 2016; Velenturf, 2016b). Within this first phase, it is the participants' opinions, perceptions, and understanding of IS that counts (Panyathanakun et al., 2013; Madsen et al., 2015). Madsen et al. (2015, p. 860) state that 'academics mainly focused on IS as "end of pipe" activity, where the practitioner considered the true potential of IS to be in process improvement, innovation, knowledge transfer and culture change', and these differences can create challenges in IS emergence. It is also found that actors' economic motivation is the largest motivation driving actors' involvement in IS (Ashton and Bain, 2012). There are however different motivations that are driving the IS emergence process at different times. During this phase, the experience and knowledge of other cases of successful IS implementation (Park et al., 2016) provoking an (economic, environmental, etc.) expectation and desired benefits from symbiotic synergies are crucial (Ashton, 2009; Paquin et al., 2014; Farel et al., 2016; Van Berkel et al., 2009; Branson, 2016; Behera et al., 2012). The same is the existent market mechanisms and policy incentives encouraging IS relationships (Velenturf, 2016a). Furthermore, existing and pressing challenges and needs (e.g., resource scarcity, environmental pollution, the availability of (considerable) amounts of waste streams, and exchange potential) can be a motivational factor during the awareness and interest creation (Ashton, 2009; Valentine, 2016; Paquin et al., 2014; Farel et al., 2016).

During this initial phase, the awareness, interest, and understanding of, for instance, contextual factors such as policy, regulation, but also IS and a recognition of the need for symbiotic thinking as a way to fight environmental pollution and resource scarcity, is fostered (Wu et al., 2016; Van Berkel et al., 2009). The personnel of an organization are a key factor within *organizational characteristics* when fostering awareness and interest in IS (Wang et al., 2016; van Beers et al., 2009). Fostering a different mindset and closed-loop thinking through knowledge sharing in organizations (Valentine, 2016) can also support and increase the organizational interest in IS. Velenturf (2016b, p.160) suggests that 'knowledge of policy and regulation as well as markets and industrial processes supported a more flexible attitude towards potential economic developments'.

Institutional embeddedness presents the 'nontechnical (e.g., norms, trust, and communication) factors influencing IS development' (Paquin et al., 2014, p. 277). It comprises the interorganizational aspects supporting the emergence of IS (e.g., cultural, cognitive, and structural aspects). Developing embeddedness by cultivating trust during the IS emergence process and developing a supportive (cultural) context for IS emergence is of critical importance (Costa and Ferrão, 2010; Paquin et al., 2014). During the initial phase where awareness and interest is cultivated through capacity building activities, knowledge and familiarity with the concept is addressed (Elabras Veiga and Magrini, 2009), and an early cultivation of a strategic vision is necessary. In the process of awareness creation, it is necessary to accentuate the IS characteristics such as the need for fostering a higher degree of cooperation among companies and a chance and need to develop new social relationships and apply a collaborative behaviour (Wang et al., 2016; Elabras Veiga and Magrini, 2009). Regarding the role of social relations, Hewes and Lyons (2008, p. 1335) mention that 'with social relationships, we are empowering each other [and that] construction of social relationships is key to the development of

EIPs', while Boons and Spekkink (2012) stress that relational capacity alone is not enough, there is a need for mobilization of relationships and using them to benefit IS emergence.

4.1.5. Actors' activities

Human and organizational characteristics, institutional embeddedness, and raising awareness via knowledge and information sharing could be built through capacity building events combined with context transformative activities.

Capacity building activities are mentioned in the literature as supporting IS emergence (Elabras Veiga and Magrini, 2009), mostly by contributing to the formation of a potential network of stakeholders with a large potential for fostering IS relations. The network develops through 'information exchange between industries co-located in a region' (Panyathanakun et al., 2013, p. 76), '[the] exchange [of] their visions on problems and solutions' (Spekkink, 2015, p. 143), 'sharing of ideas [and] knowledge exchange [on each other's processes, by-products, plans, visions, regulatory changes, etc.], [shared] willingness, and trust among parties' (Panyathanakun et al., 2013, p. 75), and by 'communicat[ing] the value' of IS (Paquin and Howard-Grenville, 2012, p. 87) among each other. Through these activities, an increase of environmental awareness among actors takes place (Qu et al., 2015, p. 336), improving motivation (Panyathanakun et al., 2013) and 'maintain[ing] and strengthen[ing] relationship[s]' among network members (Spekkink, 2015, p. 143), increasing in this way the knowledge and relational capacity (Boons and Spekkink, 2012; Spekkink, 2013, 2015). The role of facilitator or coordinator in organizing such activities and monitoring their outcomes during subsequent transitional phases is crucial.

Costa and Ferrão (2010, p. 985) write that 'a spontaneous emergence of IS can be triggered and further developed by a dynamic process of … interventions that can transform the context'. Stakeholder interventions are dynamic processes taking place at different levels, and they can shape the social, economic, cognitive, etc. contexts. A 'continuous dialogue … engaging public bodies' (Velenturf, 2016a), shaping the 'community-industry' (Panyathanakun et al., 2013) and government-industry relationships (Costa and Ferrão, 2010) is found to be the most *context transformative intervention*.

4.2. Phase 2: Reaching out and exploration of connections

4.2.1. Contextual conditions

Ashton (2009) suggests that initiation and implementation of IS was often driven by a *change in the existing regulation*. Therefore, engagement of public authorities, responsible for permitting and regulating in the participatory processes where exploration of connections take place, is crucial. Velenturf (2016a, p. 122) adds that 'continued interaction with regulator(s) [can contribute] to solve the regulatory issues' in the way of IS emergence.

Infrastructure is found to be critical, especially within this phase. In this paper, infrastructure includes technology, equipment, databases, and platforms for stakeholder interactions (Paquin et al., 2014; van Beers et al., 2009; Zhu et al., 2014; Van Berkel et al., 2009; van Beers et al., 2007; Spekkink, 2015; Valentine, 2016; Cutaia et al., 2015; Wang et al., 2016). Specific interactions' platforms or 'more formal structures to provide opportunities for interaction' (Valentine, 2016, p. 69) are found to be the most critical infrastructure within this phase.

There is an overall agreement among researchers that 'building industrial symbiosis requires *time*' (Qu et al., 2015), since building the 'IS [network] is a long-term process' (Elabras Veiga and Magrini, 2009) that needs 'bringing in other members' (Paquin and Howard-Grenville, 2012, p. 89) and developing trust among them. And 'trust might take time to build' (Madsen et al., 2015, p.859; Hewes and Lyons, 2008). Referring to *time* within this phase, the literature specifies that 'the stakeholder engagement processes' (van Beers et al., 2009, p. 377), the institutional capacity (i.e. the knowledge capacity), the relationship creation and the mobilization capacity (Boons and Spekkink, 2012, p. 67), and the trust among the potential partners can take time.

Geographical proximity is a factor identified in the IS literature, with no agreement on what role it plays in IS emergence (Jensen et al., 2011). The systematic review of this study has found that being geographically close can influence the type and number of synergies developed (van Beers et al., 2007). Paquin and Howard-Grenville (2013, p. 1649) suggest that 'proximity enables knowledge flow and innovation' among stakeholders from different sectors. When different potential relations are explored, the 'transportation and transaction costs' (Park et al., 2016, p. 35) can be important factors to be considered, together with financial aspects related to them (Branson, 2016). However, researchers currently have different views on this subject. van Beers et al. (2009, p. 370) mention that 'transportation costs will have a limited impact on the economic viability of a reuse opportunity'. We suppose that it depends on the context and the actors involved in the process of IS emergence.

The knowledge of each other's *pool of resources* (e.g. money, time, knowledge, the 'amount of by-product a company can supply and the amount another company is capable of handling or willing to accept' (Madsen et al., 2015, p. 859)), is found important. Madsen et al. (2015, p. 859) continue that 'often companies don't know what their neighbour is doing', which impedes them in contacting each other. During this phase, different scenarios with specific amounts of resources available can be studied. According to Valentine (2016, p. 73), there is a need for 'a resource flow that another member could utilize in an advantageous way', because otherwise it will be difficult to create IS connections. With regard to the resource security at this stage, it is 'in particular [the] confidence that resources with the right qualities would be supplied' (Velenturf, 2016a, p. 126) that is a high priority. Richness or scarcity of other kinds of resources, such as natural resources, i.e. 'including—but not limited to—iron ore, bauxite, gold, nickel, mineral sands, diamonds, natural gas, oil, and coal' (van Beers et al., 2007, p. 57), the 'geographical position' (Taddeo et al., 2012, p. 24), and 'the tropical climate … land and fresh water' (Ashton, 2009, p. 237) can have an overall importance for the emergence of IS.

4.2.2. Actors

Research and education institutions within this phase can contribute to the 'local coordination [of] activities', to 'the uncovering of IS kernels', to 'the monitoring and disseminating information on the developments' (Costa and Ferrão, 2010, p. 991), and can act as a strategic advisor for the collaborative process and contribute to knowledge development, sharing 'and dissemination of knowledge about the different projects that the actors were engaged in' (Spekkink, 2013, p. 352), complementing other involved actors' capabilities and raising knowledge participants' capacity (Panyathanakun et al., 2013; Costa and Ferrão, 2010) along the collaborative process.

Public bodies are considered an important component of the participatory process (Behera et al., 2012; Baas, 2011). Their role spans from coordinator and facilitator of the collaborative processes, facilitating the contact between different agents and assuming a more central role, to a champion in the development of symbiotic relations (Park et al., 2016; Costa and Ferrão, 2010), funding body (Baas, 2011), to a consulting body on planning and technical issues (Park et al., 2016), to a catalyst body for the development (Valentine, 2016) and at last to simple participants in the collaborative processes for IS emergence. They can 'develop a strong change management position by building trust between the different strategic platform member' (Baas, 2011, p. 436). By being more aware of local conditions, public bodies could 'provide a bridge between national government and business' (Costa and Ferrão, 2010, p. 991) and provide funds to research and education institutions (Park et al., 2016). Being either a coordinator themselves or part of a coordinator network (Wang et al., 2016), public bodies can influence the 'co-produced solutions' and 'co-decide about the innovation' that can happen (Velenturf, 2016a, p. 128) at the same time as being involved 'in building up the institutional environment for IS' by issuing regulation promoting IS (Yu et al., 2014b, p. 471) or encouraging companies through environmental licensing or permitting for IS thinking (Elabras Veiga and Magrini, 2009).

Businesses can become dominant and decisive for the symbiosis created by engaging themselves in coordination activities (Farel et al., 2016) and playing the role of *champions*, as described by Hewes and Lyons (2008).

The group of *associations* embrace a large variety of organizations representing a group of stakeholders' interests, e.g. industry representatives (Madsen et al., 2015; Panyathanakun et al., 2013), environmental organizations (Taddeo et al., 2012; Baas, 2011), or other organizations and associations (Velenturf, 2016a; Sharib and Halog, 2017) such as labour representatives (Taddeo et al., 2012) or 'expertise centres' (Baas, 2011, p. 436). Their role as a participant in the participatory process of IS initiation and playing an active role within a coordination body of such processes is largely acknowledged (van Beers et al., 2009; Baas, 2011; Spekkink, 2013; Taddeo et al., 2012; Velenturf, 2016a; Sharib and Halog, 2017). Panyuathonakun et al. (2013) specify that they are 'critical to the successful coordination of efforts by participating industries in support of EIE formation' as they can be mediators who want 'to foster positive interactions between member companies, government, and the broader community' (van Beers et al., 2007, p. 58). Furthermore, this group of actors 'might be a good way of finding partners' (Madsen et al., 2015, p. 859).

4.2.3. Actors' roles

Bridging actors are shared contacts that 'can ease the process for the companies' (Velenturf, 2016a) or can push an idea forward to companies, public bodies, and other actors. Even though this study found the role of bridging actors to be greater in the second phase of the IS emergence process, we acknowledge their role as introducing ideas and pushing them forward in other actors' awareness and in awakening their interest. In this initial phase, bridging actors can play the role of a champion. The role of *bridging actors* is crucial at this phase, since it is acknowledged that they play a role in connecting partners to create symbiotic relations. 'It often takes one person, like a mayor, to push the idea', mentions Hewes and Lyons (2008, p. 1340). In this case, the mayor would be a bridging actor between the companies and a facilitative body. The bridging actors are closely related to *champions*. To put it briefly, a champion is a 'leader that stands out in … initiatives' (Spekkink, 2015, p. 139) and 'possess[es] deep understanding of the local society and culture and ha[s] proven track records of industrial innovation' (Behera et al., 2012, p. 104). The literature focuses on academic researchers, company managers, anchor organizations, business owners, or individuals with experience in the field of industrial ecology as champions (Behera et al., 2012; Baas, 2011; Hewes and Lyons, 2008). The champions are seen as very important for the success of IS emergence (Hewes and Lyons, 2008), as they can 'establish … connections between different projects and actors' (Spekkink, 2013, p. 155). One of the most cited articles regarding champions, by Hewes and Lyons (2008, pp. 1335–6, 1338), stresses that a champion is 'developing local support through a bottom-up approach … [and] develop[s] social relationships by establishing social systems that start with the code "bringing people together" … [and teach] the vision of industrial ecology'.

During this phase, *facilitators* are characterized by 'adopt[ing] more formal structures to provide opportunities for interaction' (Valentine, 2016. p .69). Facilitators coordinate stakeholders' communication, relations and exchanges (Sharib and Halog, 2017; Spekkink, 2013; Behera et al., 2012; Valentine, 2016; Behera et al., 2012, 2012; Taddeo et al., 2012; Yu et al., 2014b; Wang et al., 2016; Park et al., 2016). They also offer 'an incubation chamber for innovative ideas' (Spekkink, 2015, p. 139) 'delivering … specific innovation support' and '[a]ttracting funding into the region and cascading it through the governance system' (Velenturf, 2016b; Madsen et al., 2015). By doing this, facilitators take responsibility for the collaborative process and IS network formation. A high level of facilitator engagement is necessary (Velenturf, 2016a).

4.2.4. Actors' characteristics

During this second phase, it is the actors' active participation, as *human characteristics*, that is crucial (Boons and Spekkink, 2012). In order for IS institutional capacity (i.e. knowledge, relationships, and mobilization capacity) to be created, actors' agency is necessary in the form of willingness to actively invest their time and resources in developing new knowledge and new relationships (Valentine, 2016). Furthermore, Valentine (2016, p. 72) mentions that it is important to have trust and confidence that 'solutions can be found … within the network'.

The awareness and interest in IS relations created during the first phase can *motivate* participants to develop a specific logic and strategic view (Spekkink, 2015), thus encouraging them to engage in institutional capacity building.

During this phase, interactions that foster a cooperative culture (Ashton, 2009) occur. Here, the *organizational characteristics* exemplified such as the companies' interest in IS created or adopted IS up to that point, their previous environmental practices, and the willingness and commitment to support/adopt new organizational changes and (environmental) activities is of crucial importance (Paquin et al., 2014; Qu et al., 2015; Baas, 2011; Taddeo et al., 2012). In the processes of this second phase, the companies' need for confidentiality is accentuated (Madsen et al., 2015). In the same way are the organizational habits (van Beers et al., 2009). These can be critical for (not) developing new relationships.

Concerning the *institutional embeddedness* in the process of reaching out and exploration of connections a 'common culture and trust' is cultivated among the actors (Behera et al., 2012, p. 106) along the 'shared vision' (Spekkink, 2013, p. 354). Here, actors' activities and interactions are very important (Velenturf, 2016a). These activities can drive and develop the 'good cooperation and collaboration' (Panyathanakun et al., 2013, p. 75) among stakeholders. At this phase, the 'short mental distance' (Branson, 2016, p. 4351) is developed. This occurs through increasing social proximity (Velenturf, 2016a), i.e. familiarity with each other (Behera et al., 2012, p. 106) and familiarity 'with one another's products and processes' (Paquin et al., 2014), developing 'a shared conception of the high value of residual materials[,] … shared norms regarding waste issues[,] … shared cognitive framing and norms' (Ashton and Bain, 2012, p. 77). Social proximity can 'decrease the efforts required in building shared knowledge and understanding' (Velenturf, 2016a, p. 125) among the actors involved in the process of IS emergence.

4.2.5. Actors' activities

What drives actors aware of and interested in the IS potentials to consider spreading their idea to other possible partners is their participation in the strategic network formation activities encouraged by facilitators such as public bodies, research and education institutions, or even businesses themselves through business networks. According to the literature, a facilitator has the responsibility to form and monitor the *strategic network formation*, acquisition of knowledge and relationships, and formation of mobilization capacity. Activities such as on-site guidance, policy tours, periodical meetings, and face-to-face discussions (Wang et al., 2016), facilitation (Costa and Ferrão, 2010), and follow-up activities (Spekkink, 2015) could help monitor and guide the network formation.

The presence of a common incubation platform with events supporting the exploration of connection processes, such as networking events and workshops, are also found to be crucial in facilitating the processes of reaching out and the exploration of connections. Boons and Spekkink (2012) and Spekkink (2013, 2015) conclude that knowledge and relationship capacity developed through capacity building activities during first phase is not enough for IS to emerge. It is mobilization capacity that has the potential to generate change. The literature review has revealed that interactions nesting the mobilization capacity could refer to building an *incubation platform for IS emergence*. Behera et al. (2012, p. 111) mentions that 'a robust management structure, including a champion and supporting staff …, is mandatory to support' the IS emergence.

4.3. Phase 3: organizing

4.3.1. Contextual conditions

The role of *policy* is found to be high during this phase. Here, companies can perform feasibility studies and explore the compliance of the new business model with regard to existing regulations. Within these two last transition phases, policy is 'good for stimulating agreements and commitments' (Mannino et al., 2015).

The availability of *funding* such as 'access to [and availability of] investment subsidies' (Van Berkel et al., 2009, p. 1555), financial support (Zhu et al., 2014), tax laws (Panyathanakun et al., 2013), financial support through 'capital projects' (van Beers et al., 2007, p. 69), and other 'governmental financial support' (Zhu et al., 2014, p. 465) can increase the possibility of IS establishment. This is because it provides necessary financial resources for exploring the possible ways of organizing for IS. Funding is found to come mostly from public bodies entities (Zhu et al., 2014; Baas, 2011) or business actors such as ports (Spekkink, 2013). However, we believe that raising awareness and making companies understand the role of IS for their business development, and the role of a facilitator within IS emergence process, could contribute to raising funds from commercial companies for facilitators' work. Other contextual conditions such as geographical proximity and industrial diversity, are less important, but one should have an awareness of their possible importance.

Infrastructure in the form of technology available and its (economic, etc.) accessibility (Paquin et al., 2014; Velenturf, 2016a; Van Berkel et al., 2009; van Beers et al., 2007; Zhu et al., 2014; van Beers et al., 2009); databases, including resource flow information and specification (Velenturf, 2016a); databases and operating handbooks '[with] information about resources … collected using input-output tables' (Cutaia et al., 2015, p. 1523) are of crucial importance. These can help the organization to get an overview of resource flows.

4.3.2. Actors

Research and education institutions can contribute to the organization of different activities such as innovation forums to support the identification of the best way to organize the new synergies (Behera et al., 2012). Here, the *consultancy companies* can overtake research and education institutions and play a more important role. They can contribute with modelling and calculation of the new business models. The contribution of other actors, such as service providers and interest associations is as well crucial at this phase.

The role of *public bodies* in this third phase is also considered crucial. In particular, its role as regulator and as issuer of licenses and permits is of great importance (Velenturf, 2016a). At the same time, the role of a funding body, providing financial support for new symbiotic initiatives, is more accentuated in this late phase (Baas, 2011; Zhu et al., 2014). Overall, public bodies are an inevitable component of the innovation process leading to IS emergence (Velenturf, 2016a; Elabras Veiga and Magrini, 2009; Taddeo et al., 2012; Behera et al., 2012).

Business organizations and interest *associations* are also viewed as crucial in this phase. Businesses are mostly seen as those implementing IS and a force that through interventions can influence 'the social and economic context of the municipality' (Costa and Ferrão, 2010, p. 991). Their role in the participatory and collaborative processes for IS initiation, supporting other local actors, is increasingly recognized (Park et al., 2016; Panyathanakun et al., 2013; Behera et al., 2012; van Beers et al., 2009; Hewes and Lyons, 2008). Business actors such as ports, accommodating a large number of companies at its territory, can support IS emergence by funding infrastructural initiatives necessary for IS establishment (Spekkink, 2013). Their role is particularly crucial in the last two transition phases: exploration of connections and organizing.

Relevant support can be gained from the interest associations representing different business interests. Such associations contain a large pool of knowledge on companies and their data (Sharib and Halog, 2017), and they can 'foster positive interactions between member companies, government, and the broader community' (van Beers et al., 2007, p. 58).

4.3.3. Actors' roles

During this last phase, *facilitators* monitor the process of emergence (Paquin and Howard-Grenville, 2012, 2013) and 'follow … the implementation processes and end-results' (Panyathanakun et al., 2013, p. 75). The roles fulfilled by such actors depend on the actions taken at different times in the process of IS emergence. and can embrace the concept of a form of 'formal governance' as Velenturf (2016b, p. 166) describes it.

4.3.4. Actors' characteristics

With regard to the *human and organizational characteristics*, the most important factors mentioned are a symbiotic mindset, pro-active attitude, flexibility, high motivation, and willingness to open up for new relations. The actors' characteristics within this phase are similar to those in the previous phase. Especially the actors' agency in the form of willingness to actively invest their time and resources in developing new knowledge and new relationships is necessary (Valentine, 2016). Concerning organizational characteristics, it is mostly the mobilization capacity that is considered critical (Boons and Spekkink, 2012). An organizational pro-active attitude, flexibility, willingness for new ways of developing its business, openness, and willingness to exchange knowledge on company and production operations are critical Velenturf (2016b); (Panyathanakun et al., 2013). Companies with a 'unique sociocultural environment … [and] a collaborative spirit' (Valentine, 2016, p. 75), and those recognizing the value of the natural resources and concerned with 'continued access to vital resources' (van Beers et al., 2007, p. 61) can succeed in organizing and establishing IS relations.

During this last phase, specific (economic) considerations take place: business factors such as supply chains (Behera et al., 2012), the costs of new commercial transactions, the weighing up of operational and revenue costs against existing expenses and the benefits expected (Valentine, 2016; van Beers et al., 2007), and discussions about shared benefits among the actors occur (Behera et al., 2012). *Institutional embeddedness* is built through the 'consensus and alignment of actors' interests' (Panyathanakun et al., 2013, p.75). In order for that to happen, there is a need for openness between the possible resource partners (Velenturf, 2016a) and readiness for establishment and maintenance of confidentiality (van Beers et al., 2009). The 'feeling of confidence or trust in the collaboration, …was the prerequisite for negotiating a contract' (Velenturf, 2016a, p. 126).

4.3.5. Actors' activities

Activities that are relevant in this phase and encourage development of an *incubation platform for IS emergence* could consist of creating and offering a platform or specific interaction spaces. Within these 'potential participants could meet' (Paquin and Howard-Grenville, 2013, p. 1633), information on enterprise, resources and (by-) products could be exchanged (Qu et al., 2015; Cutaia et al., 2015), 'material flow analysis' (Qu et al., 2015), 'cost-benefit analysis' (van Beers et al., 2009), feasibility investigations and other relevant studies (Behera et al., 2012; Spekkink, 2015) could be done. Incubation platform activities could focus on formulating new business model proposals and contract negotiations (Behera et al., 2012). Other activities found relevant could be 'workshops on exploring technical possibilities' (Velenturf, 2015) and keeping operating handbooks (Cutaia et al., 2015). Furthermore, such an incubation platform could foster new joint projects (Madsen et al., 2015) offering financial support (Yu et al., 2014b; Panyathanaku et al., 2013) and lobbying for the spreading of an IS approach (Spekkink, 2015) through 'eco-town programs' (Van Berkel et al., 2009), 'town-hall meetings' (Costa and Ferrão, 2010), and other lobbying and staff-mobility events (Spekkink, 2015; van Beers et al., 2007).

5. Discussion and conclusion

This study's specific scientific value lies in the synthetization of the various understandings of the IS emergence process and suggests the possibility for moving the scholarly conceptual definition towards defining it as: *the dynamic (social) process between pre-emergence and post-emergence phases, where actors are engaged in processes of building awareness and interest in IS, reaching out to new possible partners through interactions that encourage the exploration of new possible connections, and organizing new symbiotic ties.* Following the discussion of IS as a dynamic process established through a range of dynamics (Boons et al., 2017; Sun et al., 2017), we propose a conceptual model for IS emergence that places the emergence phase between a pre-emergence phase (including the multitude of factors and agents within a geographical context and unexploited IS possibilities) and a post-emergence phase (including the formal establishment and implementation of IS and its further development). This is an attempt to produce context-free, universal knowledge on IS emergence. However, the geographical characteristics; the existing initial conditions in form of a range of industrial, public, educational, etc. agents; and the pool of unexploited resources characterising the pre-emergence phase play a crucial role for the dynamics of IS emergence (Farel et al., 2016). Therefore, we fully acknowledge the role of specific (institutional and geographical) context for IS emergence and call for a thorough consideration of the pre-emergence phase and specific contextual conditions, as advised by Boons et al. (2017), when considering intentionally encouraging IS emergence.

The three phases of the IS emergence process (i.e., the awareness and interest in IS, the reaching out and exploration of connections, and the organizing) are found to be characterized by specific factors. However, these should not be considered to be the only factors critical for the processual phases, nor should they be seen as specific to one particular dynamic, as described by Boons et al. (2017) and Sun et al. (2017). The combination and the degree of criticality will depend on, for instance, the specific pre-emergence factors, degree of interaction of different agents, contextual conditions, etc. It is relevant to investigate further the discussion within IS literature on antecedents and initial conditions and further research on this is highly recommended.

This review's high-impact outcomes and contribution to the IS field are related to the identification of new avenues for research. More focus on individuals and organizations within IS literature is recommended. The focus on human, organizational, and institutional capacities necessary for the IS emergence process provides evidence of the multiple social layers important for IS emergence: the individual level, the organizational level, and the institutional level. Among these three levels, individual capacities are less addressed. However, individual characteristics should not be underestimated, since 'systems make it possible, but *people* make it happen' (Hewes and Lyons, 2008, p. 1340). Thus, researchers are invited to focus on the groups of actors engaged in the emergence process, their specific roles, activities, and individual/organizational capacities. What individual and organizational capacities do actors activate within the process of IS emergence? How are these capacities built? Who is responsible for coordinating interactions among actors that foster capacity building, data collection, and the monitoring of the IS emergence process – public bodies, private companies, or research and educational institutions? These are only a few aspects strongly recommended for further research.

As the last high-impact outcome, the present study identifies the importance of having a platform or a space for interactions among actors to unfold and capacity for IS emergence to be built, stressing the findings of Cutaia et al. (2015). Such a platform provides a space for trial and error, encouraging a more experimental approach towards IS emergence. It is the space of interaction and collaboration across sectors. What collaborative models between public, private, and academic sectors are mostly recommended for high results of IS emergence? How is the value created within such collaborative processes that engage a multitude of actors and organizations in collaborations for IS emergence? These are only few aspects that further research is recommended on.

Studying the IS emergence process opens the possibility of perceiving IS through a more complex lens, acknowledging the importance of individuals, organizations and their capacity, and the need for a more experimental aspect in their interactions.

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Appendix A. Supplementary data

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5.2 DEVELOPING A COMPLEMENTARY CONCEPTUALIZATION

This section contains article #4:

Industrial symbiosis emergence and network development through reproduction

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Industrial symbiosis emergence and network development through reproduction

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ABSTRACT

Industrial symbiosis, the exchange of excess resources between traditionally separate industries, has received increasing attention in recent years as a means of realizing a circular economy. Research has focused on determining how industrial symbioses come about and develop. Characteristics and dynamics of their emergence as well as their development processes have been identified. However, within this field, little attention has been paid to the effect of relations and interdependence between symbioses in the emergence process. The present paper addresses this gap. Its objective is to determine how existing industrial symbioses influence the emergence of new ones and contribute to industrial symbiosis network development. In doing so, a conceptual model is built and presented, explaining the connection and dependence between existing and emerging industrial symbioses. The model is inspired by analogies with biological processes of reproduction, which are translated into industrial principles. Embedded in the model are the principal reproduction modes: budding, broadcast spawning, and brooding. To validate and illustrate the applicability of the model, the paper presents empirical cases selected from the industrial symbiosis network in Aalborg, Denmark. Based on findings of the case study, the model of industrial symbiosis reproduction is found to be a useful tool for gaining a new perspective on industrial symbiosis networks' development. The paper contributes to the understanding of industrial symbiosis emergence and network development processes by revealing the role of interconnectivity among existing and emerging industrial symbiotic linkages.

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1. Introduction

Industrial symbiosis (IS) involves the adoption of a collective approach between companies, in which excess materials, energy, water, or by-products are exchanged and incorporated into business processes. Besides representing an innovative way of increasing resource efficiency, IS is also increasingly seen as a means of realizing a circular economy (European Commission, 2014), a regenerative system in which resource input, waste, emissions, and energy leakage are minimized by slowing, narrowing, and closing material and energy loops (Geissdoerfer et al., 2017). IS is a tool to address the latter: The closing of resource and energy loops between companies in traditionally separate industries. In recent years, IS has proven to bring economic, environmental, and social sustainability benefits. Various European symbioses have led to greenhouse gas savings, landfill diversion, and savings of hazardous waste, as well as savings of virgin raw materials and water. Additionally, economic savings through avoided waste disposal and raw material acquisition costs have been achieved in many projects (Doménech et al., 2019). An improvement of the recycling of raw materials through IS is estimated to lead to savings of EUR 1.4×10^9 per year in the EU (European Commission, 2011). Because of these benefits, focus is directed towards understanding how IS emerges and develops. Much research has focused on understanding the emergence and development process (Yu et al., 2014). Researchers acknowledge the dynamic character of this process (Boons et al., 2014) and describe the growth of an industrial symbiosis network (ISN) as the multiplication of symbiotic linkages. Recently, investigations have addressed how ISN development can be facilitated (Park et al., 2018), how technology such as online information-sharing platforms can support the performance of ISNs (Fraccascia and Yazan, 2018), and how policy instruments can provide the conditions for IS to develop and flourish (Järvenpää et al., 2019).

How an existing IS linkage influences the emergence of new

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symbioses, however, received much less attention within IS literature. While there seems to be a common understanding that existing IS linkages can be beneficial for further IS emergence, for example through raising awareness of the benefits of successful IS implementation (Park et al., 2016), no in-depth research on the connection between existing and emerging IS has been conducted.

The present paper aims at filling this gap by shedding light on the effect and relevance of an existing IS linkage on another's emergence. The overall research objective is to enhance, empirically and conceptually, the understanding of reproduction of IS and is driven by the question, "*How does an ISN develop through connectivity or dependence between existing and emerging IS linkages?*" Connectivity refers here to a relationship in which the newly emerged symbiosis is linked or associated with a previously existing one, while dependence refers to a relationship where the new symbiosis relies on or is controlled by another existing symbiosis. The present study makes use of an analogy with processes of biological systems as a method to build a new model illustrating the connection and dependencies among existing and new IS linkages. The "process by which organisms replicate themselves" meaning multiplying by "making a copy, a likeness, and thereby providing for the continued existence of species" (Lambers, 2018) is defined by the biological term "reproduction." This term represents the core of the analogy. Based on analogic thinking, the present study refers to IS network growth through connections and dependencies among existing and new IS linkages as "reproduction" of IS. The model developed in this study embeds the principal reproduction modes: budding, broadcasting spawning, and brooding. A validation of the model is conducted through its application to empirical cases selected from the industrial symbiosis network in Aalborg, Denmark. Based on findings of the case study, the model of industrial symbiosis reproduction is found to be a useful tool for gaining novel perspectives on industrial symbiosis emergence and network development. The paper brings novelty and contributes in several ways. For IS researchers it presents a conceptual model that allows a clear identification of reproductive processes involved in IS emergence. Furthermore, it contributes to an articulation of the respective mode of reproduction encountered in the cases utilized. In addition, IS practitioners, such as governmental, academic, and industrial actors directly involved in the facilitation of IS, can benefit from the present paper through an enhanced understanding of how currently developed IS linkages can facilitate new IS emergence.

In the following, a brief review of existing IS literature relevant to this study (section 2) is presented. The biological principles for reproduction and their industrial analogies are then presented and explained (section 3), providing the background for building the IS reproduction model (section 4). A case study of a mature industrial symbiosis network applies, illustrates, and validates the model (section 5). The findings are discussed in relation to the IS reproduction model (section 6) and conclusions are presented (section 7).

2. Interconnectivity among existing and new symbiotic linkages: a literature review

Trying to understand emerging symbioses, Chertow (2007) marked the difference between *planned and self-organized symbioses*. While planned symbioses build on conscious efforts to attract and locate companies together, so they can exchange resources, self-organized symbioses emerge from extant "kernels of cooperation" seeking new developments that aim at "cost reduction, revenue enhancement, or business expansion". There are many networks that reflect the workings of both processes (Kilduff and Tsai, 2003) and area result of a combination between the two: planned and self-organized. Many IS develop through a "middle-out approach" (Costa and Ferrão, 2010) or through facilitation processes (Paquin and Howard-Grenville, 2012). These dynamics of IS emergence were found to shape the structural features of a developing ISN (Zhang and Chai, 2019).

To describe the development of an IS network, a *phase-logic* is proposed and considered by a number of researchers. Chertow (2007) introduced an ISN development process of three stages that starts with regional efficiency, continues with regional learning, and ends with a last stage, in which a sustainable industrial district is created. Later, Chertow and Ehrenfeld (2012) presented a three-stage complex adaptive system model ranging from sprouting to uncovering and finally embeddedness and institutionalization of the network.

The emergence of single IS linkages within the network is also viewed from a phase-perspective by many authors. Doménech and Davies (2011) identified different phases in cooperation between companies leading to effective IS exchanges and, more recently, Tao et al. (2019) presented a model with 5 stages classified from the perspective of the firms. Mortensen and Kørnøv (2019) synthetized various studies on IS emergence into a process model of three phases: pre-emergence, emergence, and post emergence. The pre-emergence includes the initial contextual conditions and the available (unused) resources that support the emergence of IS. The emergence phase is described as a process of three sub-phases. The actors (1) become aware of and interested in IS benefits and develop a symbiotic idea based on a business interest they might have, (2) they reach out to possible partners and explore the possibilities for symbiotic connections, and (3) they prepare for establishment of IS in an organizing phase. This marks the end of the emergence phase and the beginning of a post-emergence phase where the IS is physically established. The IS network develops from various IS emergence processes that lead to an accumulation of IS linkages.

An increasing body of recent research refers to capacities that are built within IS networks through existing symbioses and that encourage the emergence of new symbiotic linkages. Mortensen and Kørnøv (2019) find that individual, organizational, and institutional capacity is built in the process of IS emergence and development and that this forms the context encouraging emergence of new symbioses. By entering initial symbiotic linkages, individuals can get a pragmatic and proactive environmental spirit and awareness, as well as a willingness to contribute to new IS links. These capacities can be brought by individuals in various organizational contexts and contribute to increased organizational capacities. Organizations involved in or acquainted with IS are more likely to enter new IS linkages than those that are not involved in IS processes, as these organizations develop organizational capacities in the form of knowledge about possible partners and IS benefits, and experience with symbiotic linkages and relations to new partners (Zhu and Ruth, 2014), for example. An organizational capacity can also be related to the anchoring of environmental thinking and practices deeper into organizations and adopting pro-active strategies for considering the company's perceptions of issues, needs, resources, and opportunities (Behera et al., 2012). An accumulation of organizational capacities and the development of IS linkages leads to the building of an institutional capacity in a region. Institutional capacity, introduced by Boons and Spekkink (2012) to the research field of IS, builds on the knowledge and relational resources accumulated through the IS experience in the development of IS network and the mobilization capacity of the actors in the region. Abreu and Ceglia (2018) state that the more (often facilitative) IS processes are implemented, the more knowledge of IS and relational linkages are created. Furthermore, relational resources of organizations involved can increases as the coordination process advances. Organizations get to know new potential partners and enlarge their network of relationships. Increasing the knowledge and relational capacity can then activate the mobilization capacity in the region and encourage companies to enter new symbiotic linkages (Abreu and Ceglia, 2018).

Institutional capacity also refers to the shared views on IS, the common norms and visions for a region, and the mutual relationships based on trust. These create the context within which IS occurs and define the embeddedness of IS (Boons and Howard-Grenville, 2009). ISN development is dependent on cognitive, cultural, structural, political, spatial, and temporal embeddedness. First symbiotic linkages in an IS network can provide shared conceptions of waste and resources, shared conceptualization of issues (cognitive embeddedness), and initial (social) interactions from which a more complex symbiotic network structure can develop (structural embeddedness). These can establish political support for new symbioses (political embeddedness) within and/or outside the same geographic region (spatial embeddedness). Furthermore, the first symbiotic linkages in an IS network can provide a technical infrastructure, such as technology, equipment, databases, or shared facilities that are needed for material and energy flows (Vermeulen and Eilering, 2004) and can additionally encourage and ease new symbiosis emergence.

To summarize, the literature indicates that an existing involvement of organizational actors in IS linkages can build strong capacities, embeddedness, and technological infrastructure, functioning as critical factors that support further IS emergence and ISN development. These critical factors are expected to affect the relationship among an existing and a new symbiosis.

It can be challenging to determine to what degree a previous IS linkage contributed to the development of a specific factor and, in turn, how crucial this factor is compared to others for future IS emergence. Nevertheless, the contribution of an existing symbiosis to the factor as well as the factor's influence on the emergence of a new symbiosis can be either insignificant, contributing, or decisive. The more decisive the factor is on both ends, the more dependent on the old symbioses the new symbioses can be assumed to be during the emergence process. A continued dependence is assumed to be the case if the factor is also decisive for the existence of the new symbiosis after its emergence. And vice versa, if the factors are insignificant, then a higher degree of independency between the existing and new symbiosis is expected to exist.

The present paper builds on and complements the presented body of research referring to dynamics of IS emergence by shedding light on a neglected dynamic in the IS emergence process, namely the *reproduction* of existing IS. The reproduction of single linkages is assumed to be influenced by the characteristics of the ISN and the institutional contexts in which they are embedded. Thus, the study complements the research referring to knowledge, relational, and mobilization capacities created by existing IS linkages within ISN development and their effects on the emergence of new symbiotic linkages.

3. Methodology

The present paper builds a model used to identify and categorize modes through which existing IS linkages reproduce. The model is subsequently validated and illustrated through application to multiple cases. Underlying methodologies for both parts of the paper are presented in the following.

3.1. Building the model

Analogies with biological processes are viewed as an inspiration for typology, language, and model building in the present study.

The use of analogic thinking is common in the industrial ecology field. Industrial ecologists traditionally look at industries by analogy with biology and state that industrial systems should, like biological ecosystems, minimize waste and maximize the economical use of materials (Frosch, 1992). Industrial symbiosis, as part of industrial ecology, reflects the notion of biological symbiotic relationships in which at least two otherwise unrelated species exchange materials or energy and mimic ecosystems *"by transforming the waste of one firm into the valuable input of another"* (Desrochers, 2002, p. 1031).

Analogic thinking is also a well approved method of tying economics and ecology together (Hannon, 1997) and can be described as an art form useful to gain novel points of view about perplexing problems. Moreover, analogy building is a common tool used for generating models (Jaccard and Jacob, 2010). Results of this creative process can be both "novel (i.e., original, unexpected) and appropriate (i.e., useful, adaptive concerning task constraints)" (Sternberg and Lubart, 1999, p. 3).

Building the IS reproduction model through analogy followed the steps suggested by Vakili and Shu (2001) for biomimetic concept generation, while being adapted to fit an industrial rather than an engineering or design focus. Fig. 1 describes each of them in detail. Literature on biological symbioses was selected and narrowed down to literature on the development of biological symbiosis. Then, suitable terms bridging the biological and industrial fields were identified. To bridge the gap from the industrial term 'emergence', the search keywords 'creation' and 'development' were chosen. In the process of using these keywords, reproduction processes of organisms were identified as a more attractive ground for analogy building than the creation processes of actual biological symbioses. Thus, attention was given to reproduction processes of corals. More detail on these relevant biological phenomena was acquired as a last step of the model generation. Even though the steps behind the development of the model appear to be linear, several iterations among the steps were taking place.

Processes of coral reproduction (the base) were chosen to serve as a source of inspiration for the explanation and illustration of IS reproduction (the target). Corals and industrial symbioses do not share many object attributes, if any. Thus, the present analogy is predominantly a relational comparison: That both units of analysis (coral and IS) can generate another unit of its kind is the relational structure that applies in both domains. Analogy is used in this paper to highlight details of this relational commonality, independent of the objects in which those relations are embedded (Gentner et al., 1988). This is also in accordance with the structure-mapping theory by Gentner (1983) that defines an analogy as a mapping of knowledge from one domain (the base) into another (the target), which conveys that a system of relations that holds among the base objects also holds among the target objects.

A description of this analogic work is presented in section 4.1, where the biological reproduction processes are analogically connected to the industrial ones and the model is built. The translation from the biological to the industrial processes had to be conducted carefully, without using the "often erroneous logic that if things are alike in some sense, they are alike in others" (Ehrenfeld, 2003, p. 2). Creating law-like generalizations that promise higher power of prediction and less uncertainties is tempting but involves dangers. For example, Penrose (1952) already warned that explanations created through analogies reduce the value of plausible explanations of the behavior of firms. The model developed in the present paper should not undermine findings on the behavior of firms engaging in industrial symbiosis and leave room for, or even incorporate, these already gained insights. There is also a need for increased abstraction in the industrial compared to the design concept generation. The reason is that the aim is not to imitate

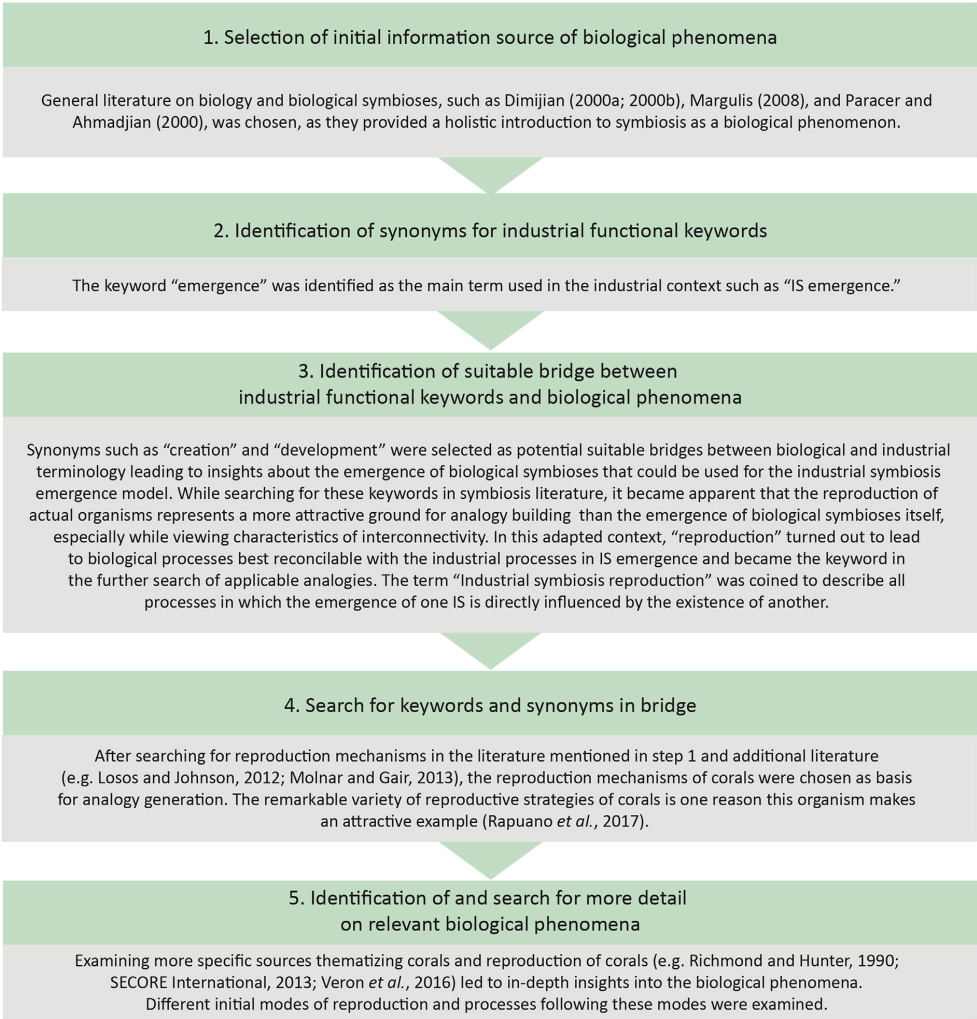

Fig. 1. Process of model building adapted from biomimetic concept generation steps by Vakili and Shu (2001). (Dimijian, 2000a; Dimijian, 2000b; Margulis, 2008; Molnar and Gair, 2013; Paracer and Ahmadjian, 2000; Rapuano et al., 2017).

intelligent designs and mechanisms from nature, but to get inspiration from biological processes—the concept should on no account assert the claim that IS emergence processes follow exactly the same laws as the selected biological ones or could be predicted in the same way. While building the model, industrial equivalents are thus sometimes close to the actual biological process from which the metaphor was derived and sometimes are more abstract or can even deviate from them.

3.2. Validating & illustrating the model

After building the model through the above-mentioned process, it was applied to multiple cases selected from the symbiosis network in Aalborg. In an iterative process, insights from this testing process were incorporated in the model to enhance its utility.

3.2.1. Case selection criteria

The IS network in Aalborg was selected as a case study based on two selection criteria: (1) the maturity of the system and (2) the diversity of the system. The maturity criterion describes that the IS network should involve a greater number of interconnecting links in order to have a wide range of resource links to frame into cases. The diversity criterion supposes that an IS network involves a variety of types of IS performing companies and a variety of resources being exchanged. These criteria were established to avoid testing and displaying the model on cases similar in the type of resource exchange and companies involved, which might prevent its application in more diverse contexts.

Regarding matureness, the Aalborg IS network started developing around 1950 and continuously grew in size, currently having over 18 established resource exchanges. Through IS-encouraging projects, several actors in Aalborg now consciously recognize and intentionally pursue network benefits, making Aalborg a rather mature symbiosis, which is currently transitioning from the stage of uncovering to the stage of embeddedness and institutionalization. Regarding diversity, the Aalborg IS network includes a variety of resource exchanges, such as heat, water, and liquids. Furthermore, companies from various sectors (such as energy, agriculture, and construction) in different parts of their supply chains are involved (e.g. suppliers, manufacturers, and wholesalers/distributers). There is also a mix of publicly and privately-owned companies involved in the symbiosis.

A strong body of empirical and historical data was expected to be necessary to apply the reproduction model and to identify and make sense of the reproduction mode at hand. The first linkages of the Aalborg ISN reached back far in time. Thus, the collection of trustworthy data, the application of the model, and the generation of useful insights was a bigger challenge than might be the case for younger IS networks or IS networks in which large parts of the emergence process have already been uncovered and where changes have been constantly tracked. Even though other mature and diverse symbiotic networks exist in the world, such as Kalundborg (Denmark), Kwinana (Australia), and Ulsan (Korea), deep insights into the historical development and complex data about relationships among symbiotic linkages were needed for the application of the model. Due to the availability of data and the closeness of researchers to the study field of Aalborg, this symbiotic network was identified as relevant for model application. Applying the model to other IS mature networks can be relevant for further development of the model.

3.2.2. Empirical data

The uncovering and mapping of the Aalborg symbiosis network was conducted over five months in 2018 (see Schlüter and Milani, 2018). Semi-structured interviews and research into grey literature were conducted not only to map the symbiosis, but also to make sense of its historical development. A focus was put on the involved actors, the historical context, and the conditions leading to emergence of new IS linkages. Data from this work was used in the analytic process of the present paper.

4. IS reproduction model

Prior to the model presentation, there is a need for describing the process of mapping knowledge from the base of the analogy, coral reproduction, to the target of the analogy, reproduction in the emergence process of IS. Explaining the analogic line of thinking provides a deeper understanding of the developed IS reproduction model.

4.1. From coral to IS reproduction

Coral reproduction, in some species, takes place in a circular order, following the stages of reproducing, settling, and growing larger. First, a colony releases gamete through broadcast spawning or brooding, embryos turn into ciliated planula larvae, settle and metamorphose. Then, the larvae grow into a juvenile polyp and engage in budding and colony forming. The newly developed colony starts the circle anew by releasing gamete clusters itself (Richmond and Hunter, 1990).

The reproduction mode called *budding* only occurs when the parent organism reaches a certain size (NOAA, 2011). In budding, a new organism develops from an outgrowth or bud of the parent polyp and remains attached as it grows (Veron et al., 2016). In some organisms such as hydra the new individual may separate to exist independently and *bud off* from parent polyps once it is mature (Losos and Johnson, 2012). Polyps, which budded off from their parent organism, *settle* to mature individually. The period of settlement is of exceptionally high mortality among corals (Barnes and Hughes, 1999). In most coral species, however, the buds *remain attached* after budding (Encyclopaedia Britannica, 2015).

Broadcast spawning describes the reproductive strategy of a mature coral releasing bundles of eggs. To compensate for the loss of offspring during the early developmental stages, significant quantities of gametes are released (SECORE International, 2013). The gametes have the capacity to undertake extended ocean voyages (Veron et al., 2016), which facilitates long-distance dispersion and thereby the creation of genetic links between one reef region and another. Larvae from broadcast spawning may reside as plankton in the water column for up to several weeks (SECORE International, 2013). Corals can create *clones* from embryos that have been dispersed in the water because coral embryos are able to reorganize their bodies to form anew. This means that when a coral embryo is damaged, it may end up turning into twins (Heyward and Negri, 2012).

A mode of reproduction similar to broadcast spawning is *brooding*. The difference is that eggs are fertilized, and embryos are maintained internally until they reach the larval stage of development (Foster and Gilmour, 2018). In the brooding mode of reproduction, usually relatively few and large larvae are released (SECORE International, 2016). In contrast to broadcast spawned larvae, brooded larvae are available for a much longer time and may be immediately ready for settlement after dispersion (SECORE International, 2013). In both broadcast spawning and brooding, the resulting larvae disperse, *settle* to the ocean floor, and attach to a hard surface (NOAA, 2011) before they form a new coral polyp (Combosch and Vollmer, 2013).

After settling and maturing, corals can engage in further processes. Corals can form further aggregates or colonies when the conditions are suitable (Encyclopaedia Britannica, 2015) through *extended budding* (Veron et al., 2016). The increase in size of colonies goes along with an immunity to risk of predation or mechanical damage (Barnes and Hughes, 1999). When coral colonies reach a certain size, they are described to engage in *further broadcast spawning or brooding* (Toh et al., 2013). However, due to stressful events such as coral bleaching, a *division of colonies* might take place. Single polyps may abandon their colony in a process called bail-out (Sammarco, 1982). Among certain reef-building corals, even an entire colony may branch off from the coral in a process called fragmentation, caused by external shocks such as a storm or boat grounding (Highsmith, 1982).

By translating these reproductive biological processes and applying them to the industrial system, several analogies could be established. Fig. 2 presents an overview of these.

As it can be seen, industrial symbiosis is interpreted to “reproduce” through different processes analogous to the biological reproduction of corals. Both the biological and the industrial processes were found to show a pre-emergence stage, with a baseline established by previously existing symbioses/organisms. The following biological phases of reproducing and settling are reminiscent of the IS emergence and establishment phase, as presented by Mortensen and Kørnøv (2019). A process of growing larger then follows in the development of corals. This is analogous to the post-emergence phase of industrial symbioses, in which an IS network can develop.

Looking closer at these phases, we can see that in the emergence phase, IS can emerge through the influence of existing symbiotic linkages with varying degrees of intention and dependence (budding, broadcast spawning, or brooding). In all three reproductive modes, actors make use of the knowledge, experience, relational, and mobilization capacity accumulated by the initial symbiosis to develop a new symbiotic linkage. When new

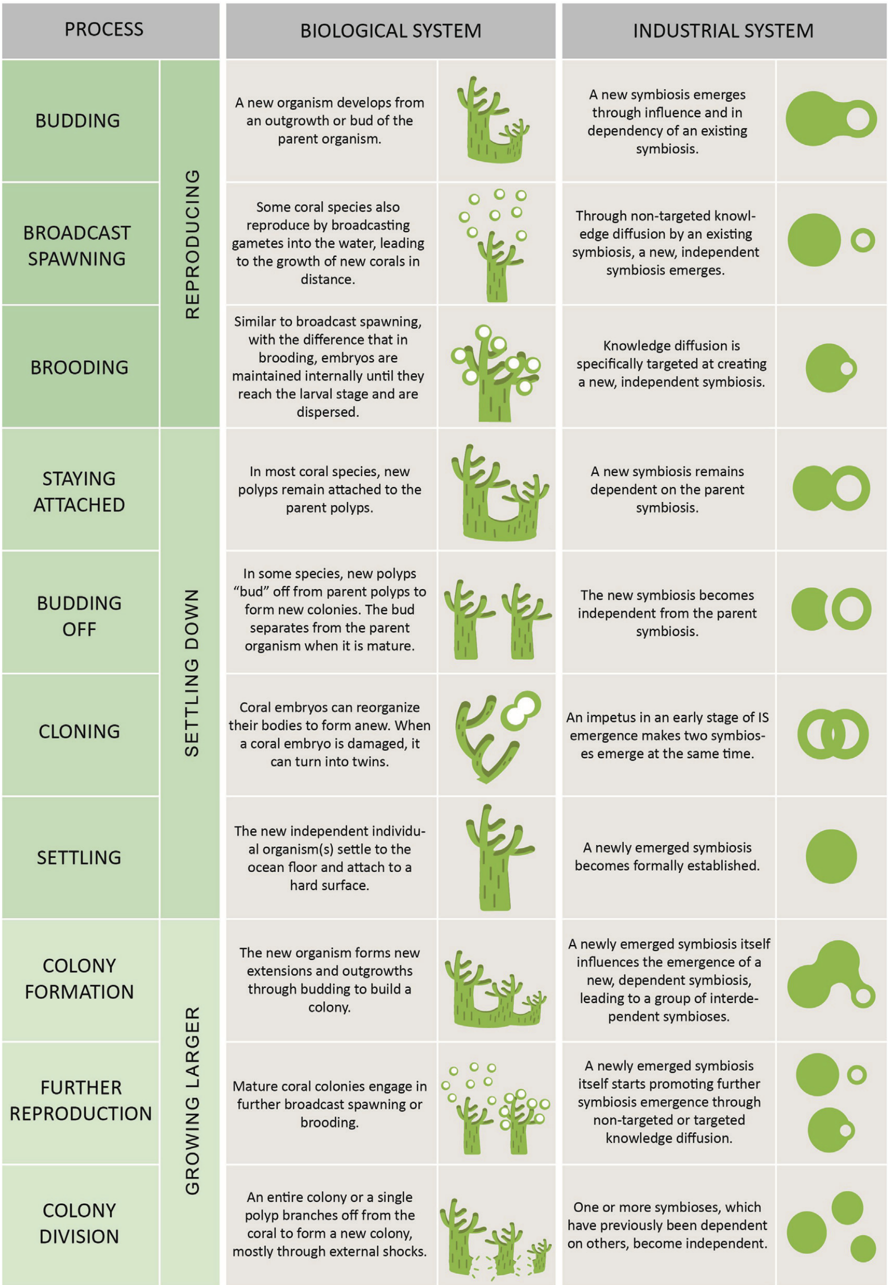

Fig. 2. Overview of analogies from coral to IS reproduction.

symbiotic linkages are created, an ‘establishment’ phase will follow. Here (connectivity and dependence) relationships among existing and new symbioses develop (high dependency in budding, no dependency through brooding and broadcast spawning). The newly emerged industrial symbiosis becomes established, often as one of the linkages in a larger symbiotic network contributing to the network development. Once the new symbiotic linkages are established, the post-emergence phase of the present process is reached. The network can continue developing with new reproductive processes following. Depending on the connectivity and dependence relationships among the symbiotic linkages that developed, the symbiotic network can present different characteristics: a well-integrated network with rich linkages among symbioses is perceived as a colony formation, while a dispersed symbiotic network with little dependence and reliance on shared assets between the symbioses will present characteristics of a colony division.

4.2. Presentation of the IS reproduction model

A closer look at the processual phases and their characteristics in Fig. 2 allowed the development of a model solely addressing the industrial context. Fig. 3 visualizes the outcome of this process and presents the model of IS reproduction.

The conceptual model of IS reproduction supposes that a new symbiosis emerges through influence of an existing symbiosis through one or more of the following reproduction modes: “budding” (1a), “broadcast spawning” (1b), and “brooding” (1c). The model also includes further processes, which are related to IS connectivity and/or dependence in the emergence process, namely “staying attached” (2a), “budding off” (2b), “cloning” (2c), and “settling” (2d), or relate to IS interconnectivity in the post-emergence process, namely “colony forming” (3a), “further reproduction” (3b), and “colony division” (3c).

IS budding (1a) occurs when two companies develop a symbiotic relationship to each other because of a direct and purposely-exerted influence of companies engaged in a similar symbiosis, often in close proximity. The new symbiosis is dependent on the parent symbiosis as it emerges, for example through shared infrastructure, production processes, a common symbiont and existing relational resources, or other factors guaranteeing the commercial viability of the new symbiosis. After budding (1a), the two symbioses either remain connected by “staying attached” (2a) or part by “budding off” (2b).

In *IS broadcast spawning* (1b), symbioses emerge if the needed impetus is given by an existing symbiosis, sometimes even in geographic distance. This impetus can be knowledge relevant for industrial symbiosis emergence, such as knowledge on relevant technologies, available resources, or established relationship to potential symbiosis partners, spread among and across industries and regional and national borders. Explicit knowledge is spread by symbionts of an existing symbiosis through project, research, and communication work, which are available for a long time period, but are only rarely picked up and utilized to make a new symbiosis emerge. Developing symbioses from broadcast spawning is highly influenced by the absorptive capacity of the firms in question. Broadcast spawning is also characterized by the fact that in an early stage of emergence, contrary to budding, the symbioses are not dependent on each other. Symbioses that emerged through broadcast spawning can clone themselves (2c) or settle directly (2d).

In *IS brooding* (1c), contrary to broadcast spawning, knowledge is not randomly “broadcast,” but rather made available for new symbiosis emergence by actors of the existing symbiosis acting as ‘change agents’. Actors engaged in existing symbiosis, even if located in geographical distance, mobilize and make noticeable efforts to share knowledge to facilitate implementation of new symbioses. Brooding can either happen through explicit knowledge being readily codified and articulated between the actors in the two symbioses, or if the knowledge necessary to be exchanged is tacit, through more frequent interactions between companies (Doménech and Davies, 2011). Knowledge from brooding is easier and more quickly applicable to generate a new symbiosis than broadcast spawning; however, the new symbiosis is closer connected to the parent symbiosis during the emergence process. Brooded symbioses can clone themselves (2c) or settle directly (2d).

When *staying attached* (2a) an industrial symbiosis remains dependent on the symbiosis that influenced its emergence. While a connection is a relationship in which the new symbiosis is linked or associated with another, for example through shared partners, material markets, or facilitators, a dependence can be observed if the new symbiosis is relying on or being controlled by the older symbiosis, for example through shared infrastructure or production

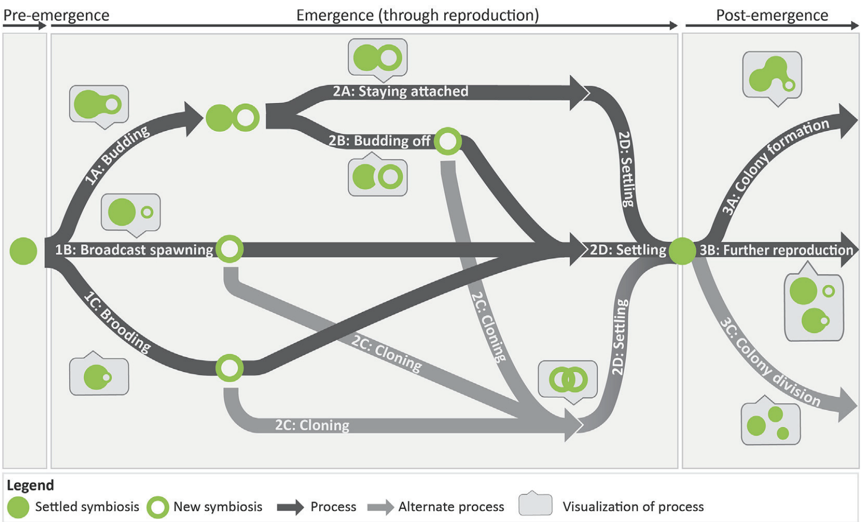

Fig. 3. Model of IS reproduction.

processes. When symbioses stay attached to each other, they "settle" (2d) as dependent symbioses.

When *budding off* (2b), the new symbiosis might still be connected to the parent symbiosis but becomes independent from it. When a symbiosis buds off, it "settles" (2d) as an independent symbiosis.

After a first impetus in an early stage of industrial symbiosis emergence, such as broadcast spawning (1b), brooding (1c) or non-reproductive emergence factors, two symbioses can emerge simultaneously in a *cloning* (2c) process, and can be connected, or even dependent on each other.

Settling (2d) refers to the stage in which commercial viability is assured and the symbiosis is formally established. In this phase, strong contractual mechanisms are beneficial to formally establishing symbiotic relationships (Albino et al., 2016). At the end of the stage of settling, one can observe, depending on the previous steps, either individual existence of the newly emerged symbiosis or a symbiosis dependent on others.

After the emergence phase, the new symbiosis can theoretically form colonies through continued budding (3a) and even engage in further reproduction through broadcast spawning or brooding (3b). In addition, connected symbioses or built colonies can intentionally or unintentionally divide, leading to new individual symbioses that settle again (3c).

In an IS sense, *colony forming* (3a) through further budding can be described as a more advanced process, in which single or connected symbioses promote further emergence of symbioses, which are dependent on it. This leads to the development of a well-integrated and dense symbiotic network.

One can also imagine that actors, after having acquired knowledge and relational capacities through the emergence process, can mobilize these and themselves engage in further IS reproduction through *broadcast spawning* and *brooding* (3b) and promote the emergence of other symbioses.

Colony division (3c) can also take place. Industrially viewed, if a single symbiosis becomes independent from the symbioses with which it is connected, it can be considered bail-out. If more than one symbiosis collectively leaves a larger group of connected industrial symbioses, it can be considered an equivalent to a fragmentation process. Such dynamics can lead to a dispersed and fragmented symbiotic network with few linkages and connections among symbiotic linkages.

Reproduction of IS, just like coral reproduction, does not follow a linear process. It becomes apparent that further activities after the emergence of the symbiosis lead to a circular and highly iterative process. Through colony formation (3a) or further reproduction (3b), the new symbiosis continues the circle of reproduction and engages in budding, broadcast spawning, or brooding, developing the symbiotic network further.

5. Illustration of IS reproduction model

The following section applies the model to case studies to validate and illustrate it. First, the cases from the Aalborg symbiosis network are presented. Subsequently they are analyzed through the lens of the IS reproduction model.

5.1. Introducing the Aalborg symbiosis network and selected cases

The symbiosis network in Aalborg developed starting in the 1950s and was recently uncovered by Schlüter and Milani (2018). The development of the ISN in Aalborg was relatively unplanned and developed mostly through self-organizing processes. The first 'planned' initiative to support this development took place between 2013 and 2015, when the business authority of the Danish government funded a task force to support IS emergence by offering companies a free resource check. Through this initiative, connections were developed in the municipality of Aalborg with a clear agenda (Danish Business Authority, 2015). Since 2016, strategic initiatives, such as the "Environment^{++}" and "Sustainable synergies"[1] projects, and were developed in Aalborg, aiming at the facilitation of IS emergence and the creation of common ground for further development of the network.

The IS definition of the displayed mapping by Schlüter and Milani (2018), which is also used in this study, only takes into account industrial symbioses that focus on exchanges of resources (materials, water, and energy), leaving out the sharing of assets such as personnel, equipment, services, or information. Exchanges that take place *within* a facility, firm or organization, or through third parties, which provide a treatment of the resource that goes beyond trade and logistic services are similarly excluded. Moreover, the figure illustrates symbiotic linkages with actors within or neighboring the same geographical area: Aalborg municipality. According to this definition, 18 symbioses among 17 industrial actors were identified. There were 11 exchanges of materials or liquids and 7 exchanges of heating or cooling. A further examination of these made it possible to detect similar resource transactions and shared symbionts between symbioses. This led to the identification of the 4 cases to which the IS reproduction model is applied. Table 1 presents the four cases, as highlighted in the previous illustration, in detail (including year of emergence, sender, resource exchanged, and receiver).

As it can be seen in Table 1, *Case 1* includes the symbiotic relations among North Jutland Power Station (NPS), Aalborg Portland, and Colas Denmark. It is based on the delivery of fly ash from NPS to cement producer Aalborg Portland and asphalt producer Colas Denmark. Thus, NPS is the connection point between these symbioses.

Case 2 encompasses the symbioses among a number of companies (NPS, Aalborg Portland, Aalborg Utility (Water), Reno Nord, the local crematory, and Alfa Laval) delivering heat to the local district heating provider, Aalborg Utility (Heat). Aalborg Utility (Heat) is the connecting point between theses symbioses.

Case 3 addresses the symbioses between Desmi, Salling Construction company and thre furniture producer Mani Pine. It is based on the delivery of steel bolts from Desmi, a pump solution provider, and used wood from the demolishing company Salling Construction company to Mani Pine, making the last the connection point between the symbioses.

Case 4 includes the symbiotic relation between NPS and Aalborg Portland. It is based on the delivery of chalk slurry from cement producer Aalborg Portland to NPS and the return of gypsum from NPS to Aalborg Portland, which is further used in cement production.

More details on the four cases can be found at the Environment^{++} initiative's webpage (The Danish Centre for Environmental Assessment, 2018) and in the study by Schlüter and Milani (2018).

The cases selected as symbioses were connected through a shared symbiont or exchanged the same type of resource. It was therefore assumed that the symbioses grouped into cases have relevant reproduction factors playing a role in their emergence processes.

5.2. Reproduction of industrial symbiosis in the selected cases

Reproduction was identified as part of the emergence and

[1] see Port of Aalborg and Aalborg University (2017) and Aalborg University (2018) respectively for further information on these projects.

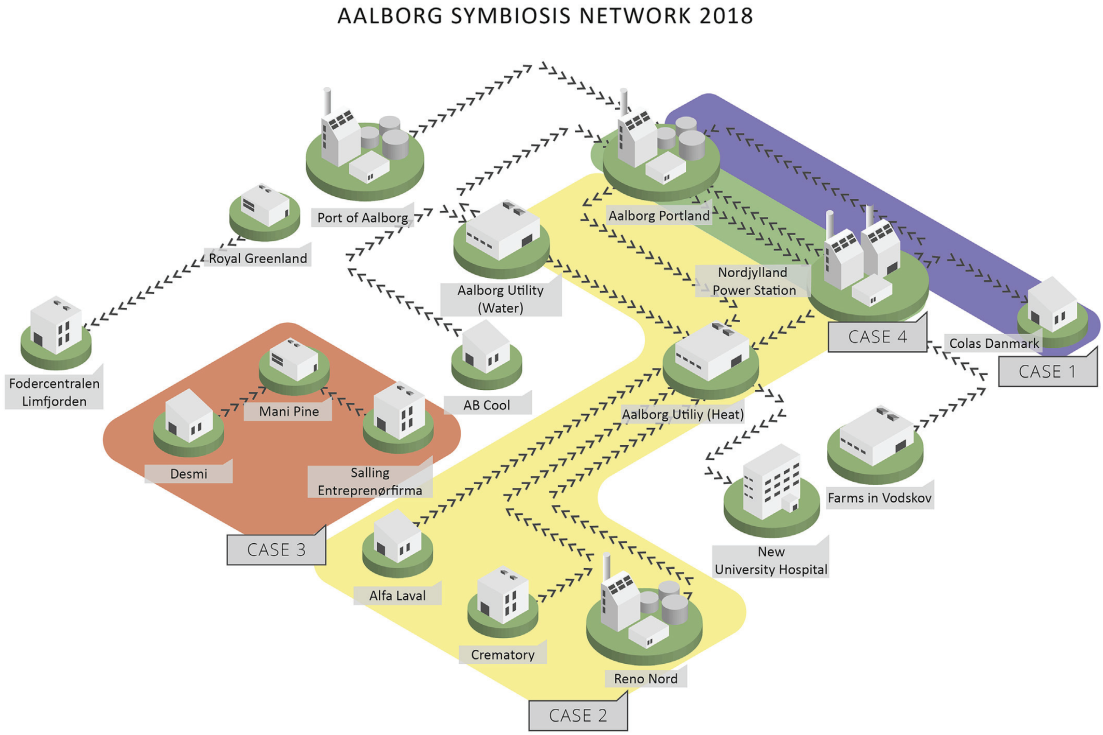

Fig. 4. Cases selected in Aalborg's Industrial Symbiosis network based on Schlüter and Milani (2018).

development process in the four analyzed cases to varying degrees, following distinct pathways in the IS reproduction model. In the following, each case analysis includes a brief introduction of the symbioses that are grouped into the respective case, before an overview of their reproductive pathways is given, with a figure visualizing the pathway. Then, the analysis of the symbioses' emergence processes with the IS reproduction model is presented in detail, starting with the oldest symbiosis.

5.2.1. *Case 1: fly ash symbioses*

This case addresses the symbiosis between NPS and Aalborg Portland and the symbiosis between NPS and Colas Denmark. The material exchanged in both symbioses is fly ash.

As Fig. 5 indicates, the emergence of the first symbiosis is an example of reproduction through broadcast spawning (1b). The emergence process skipped cloning (2c) and the new symbiosis directly settled. The newly established symbiosis itself engaged in further reproduction (3b) and led to the emergence of another symbiosis through brooding (1c). The emergence processes in this case resulted in two established and connected, but not interdependent symbioses.

Broadcast spawning (1b) leads to IS emergence: Even though the symbiosis between NPS and Aalborg Portland can be tracked back to 1977, the potential for using fly ash, a by-product of coal combustion, as a supplementary cementitious material in concrete has been known almost since the start of the last century (Thomas

Table 1
Cases of Industrial Symbioses selected from the Aalborg Symbiosis Network.

	Sender	Resource	Receiver	Year
Case 1	North Jutland Power Station	Fly Ash	Aalborg Portland	1977
	North Jutland Power Station	Fly Ash	Colas Denmark	1980s
Case 2	North Jutland Power Station	Heat	Aalborg Utility (Heat)	1953
	Aalborg Portland	Heat	Aalborg Utility (Heat)	1990
	Aalborg Utility (Water)	Heat	Aalborg Utility (Heat)	1990s
	Reno Nord	Heat	Aalborg Utility (Heat)	1991
	Crematory	Heat	Aalborg Utility (Heat)	2010
	Alfa Laval	Heat	Aalborg Utility (Heat)	2014
Case 3	Desmi	Steel Bolts	Mani Pine	2015
	Salling Construction company	Wood	Mani Pine	2015
Case 4	Aalborg Portland	Chalk Slurry	North Jutland Power Station	1998
	North Jutland Power Station	Gypsum	Portland	1998

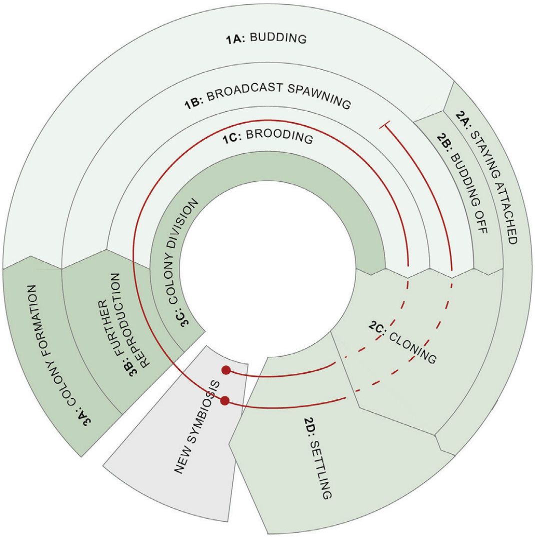

Fig. 5. Reproduction pathway in the IS emergence processes of Case 1.

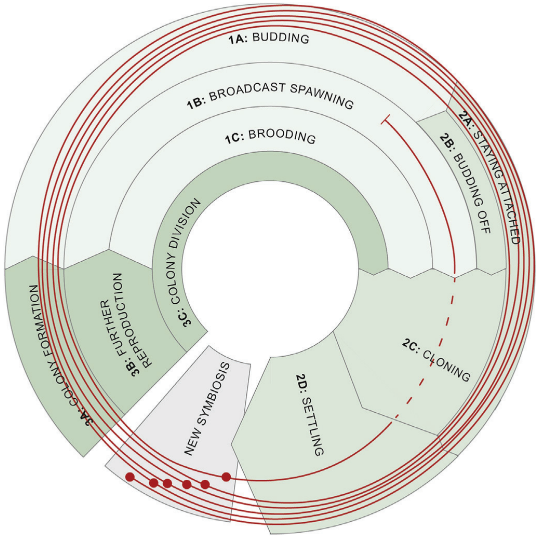

Fig. 6. Reproduction pathway in the IS emergence processes of Case 2.

et al., 2017). The impetus for the symbiosis emergence occurred outside of the regional system and represents an example of broadcast spawning: When the first oil crisis in 1973 was followed by an increased usage of coal in power generation and rising amounts of fly ash, new investigations into fly ash's potential use were conducted. After other countries already had experience with applications of fly ash in the asphalt industry (Emineral, 2018), in 1977, several parties and industries started investigating the use of fly ash in various applications in Denmark (Aalborg Portland, 1977). Technical and economic possibilities of exploiting power plants' fly ash in cement production were evaluated by electricity associations and industrial actors, including the cement concern Aalborg Portland and the local cement factory in Aalborg (Aalborg Portland, 1977). The emergence process of these symbioses is reminiscent broadcast spawning because their emergence was not only based on previous collaborations, technical developments, and the momentum in the industries, but was built on worldwide exchanges of fly ash and several early symbioses of the same nature worldwide (see e.g. Halsted, 1948; Goss, 2008). The knowledge exchanges following these early symbioses were not directly targeted at supporting this specific symbiosis emergence in Aalborg, but, nevertheless, contributed decisively to it. As characteristic for broadcast spawning, the symbiosis of fly ash between Aalborg Portland and NPS was, even though influenced by them, not dependent on the previously existing international fly ash symbioses during or after its emergence stage.

Settling (2d) leads to *IS establishment*: An important part of the settling phase of this symbiosis was the setup of a nation-wide trade organization, which would centralize sales and distribution of fly ash for the cement and concrete industry, called Emineral. After the symbiosis between NPS and Aalborg Portland started in 1977, it was formally established in its current form through the setup of Emineral in 1979 (Emineral, 2018).

Further reproduction (3b) through brooding (1c): Aalborg Portland was, because of their accumulated organizational capacity (knowledge and relational resources accumulated, experience with fly ash), involved in the setup of Emineral. With the start of Emineral's work, a sales campaign for the country's concrete factories was initiated, which led to further symbioses emergence (Emineral, 2018). One of these symbioses was the delivery of fly ash to Colas Denmark in Aalborg. Colas Denmark stepped into this existing market of fly ash exchange, partly initiated by Aalborg Portland's and NPS's pilot project of fly ash exchange. Its emergence was influenced by further reproductive activities, namely brooding (1c) of this previously established symbiosis. Both local fly ash symbioses are dependent on the supply of fly ash from NPS and other power plants in Denmark. Besides having a shared symbiont and being located in geographic proximity, they are however only connected through this shared market of fly ash and not dependent on each other.

5.2.2. Case 2: heat symbioses among various companies

This case encompasses the emergence of six heat symbioses between Aalborg Utility (Heat) and a number of companies (Reno Nord, NPS, Aalborg Utility (Water), Aalborg Portland, Crematory, and Alfa Laval).

The emergence process of the first symbiosis of this case is reminiscent of reproduction through broadcast spawning (1b). This symbiosis became established through settling (2d) before an extensive colony between Aalborg Utility (Heat) and a group of companies in Aalborg formed (3b). As Fig. 6 indicates, through several processes of budding, new symbioses were added to the colony, resulting in six established, interconnected symbioses in one colony that show various dependencies between each other.

Broadcast Spawning (1b) leads to IS emergence. The first symbiosis within the district heating system in Aalborg, emerged between Aalborg Utility (Heat) and the coal-fired power plant, NPS. In Aalborg, the first use of excess heat was established around 1948, when the power plant of the city, called Nordkraft, used excess heat to provide a public bathing institution to the city's citizens. Around this time, the first small pipe was installed from the power plant to the city centre, supplying heat for only a few blocks of houses, but marking the beginning of the district heating network and heat symbiosis in Aalborg (J.M. Larsen, personal communication, April

24, 2018). The utilization of excess heat, however, was by no means the first in Denmark. The first combined heat and power plant in Denmark, a waste incineration plant, was built in 1903 with the core purpose of supplying a large hospital with electricity and heat (Danish Energy Agency, 2012). A collective district heating (DH) system started to develop in some Danish cities like Copenhagen, mostly based on waste heat from local electricity production, in the 1920s and 1930s. In 1953, district heating was introduced on a municipal level (Hørmann, 2005). The first use of excess heat in Aalborg can thus be seen within the bigger picture of DH network development in the whole country. While most likely influenced by these parallel developing symbioses, a clear and purposely directed initiative influencing the symbiosis in Aalborg could not be identified. Thus, it cannot represent a brooding reproductive mechanism, but broadcast spawning. As characteristic for broadcast spawning, the newly emerged symbiosis in Aalborg was not directly dependent on previous symbioses during its emergence phase.

Later this initial symbiosis *settles (2d)* and further develops leading to emergence of new symbioses. Several factors influenced its further development. A new combined heat-and-power (CHP) plant called NPS was opened in Vodskov in 1967 (Aalborg Forsyning, 2018) and in 1997, Nordkraft, the power plant in the city centre, stopped electricity production (Nordkraft Event, 2015). A third unit entered service at the NPS in 1998 and provided a notably larger supply of heat to the DH network than the older units. This stronger symbiosis provided the basis for further symbiotic developments and *colony formation (3d)*.

The first "bud" created with influence from the previously described symbiosis was the delivery of heat from cement producer Aalborg Portland in 1990. Four kilns of the Aalborg Portland cement factory added a substantial amount of heat to the DH network (B.O. Borup, personal communication, May 8, 2018). Another bud, in the form of heat from the Reno Nord waste incineration plant, was added in 1991 (I/S Reno-Nord, 2018). These three first symbioses, of Aalborg's DH provider with the coal-fired CHP plant, waste incineration plant, and Aalborg Portland, today are still the most important contributors in terms of amount to the DH network (Aalborg Energikoncern, 2018). Later in the 1990s, a heat symbiosis with the local wastewater treatment plants emerged, and in 2010 and 2014, excess heat from Alfa Laval and from the local crematory, respectively, were added to the DH network. The interconnectivity of DH symbioses played a role in terms of long-term set-up and emergences of new symbioses. Political decisions led to increases and decreases in heat supply from specific sources. This influenced the strength—and even existence—of symbioses in the network. One example for this case is the increasingly budded industrial heat symbioses. Aalborg Municipality has a clear energy strategy aiming at a reduction of energy from coal. The focus, and thus the strength of resource exchanges, is shifted from the coal-fired power plant to industrial heat sources. Connected to these influences are further "buds", which might be added in the future as the delivery of excess heat from other industrial players is continuously in discussion (Miljø-og Energiforvaltningen, 2015). The symbioses are interconnected through the level of heat consumption activity of the local households determining the demand of heat (Sacchi and Ramsheva, 2017), the shared pipeline system, and through Aalborg Utility (Heat) as a shared symbiont managing this network. This interconnectivity is crucial during and also after the emergence process of the symbioses in two ways: On the one hand, the interconnectivity goes along with a fluctuation of the heat fed into the system from the different sources. Fluctuations can take place through changes in demand for a primary product (like cement) or supply (like municipal solid waste) in one of the symbioses (Sacchi and Ramsheva, 2017). On the other hand, not only the amount, but

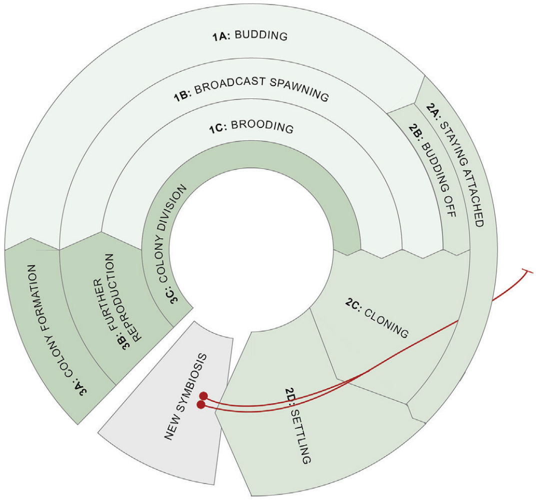

Fig. 7. Reproduction pathway in the IS emergence processes of Case 3.

also the quality of heat delivered influences the characteristics: Heat injected in the pipes from Aalborg Portland that does not reach 80° is for example completed by the CHP plant (R. Sacchi, personal communication, April 13, 2018). The CHP plant also covers for short-term variations in heat demand throughout the year (Sacchi and Ramsheva, 2017). Thus, there is a dynamic interplay between the symbioses during the year.

5.2.3. Case 3: steel bolts and wood symbioses

This case is about the symbioses in which Desmi and Salling Construction company deliver steel bolts and used wood to furniture producer Mani Pine.

It was not possible to identify reproductive factors that led to the emergence of the two symbioses. As depicted in Fig. 7, the symbioses came about through a non-reproductive emergence process. Nevertheless, later parts of the emergence process involve interconnectivity through cloning (2c) followed by settling (2d), resulting in two connected, but independent symbioses.

In 2015, after a rapid growth, furniture producer Mani Pine needed high-quality used wood for the manufacturing of their furniture. The Network for Sustainable Business Development North Denmark (NBEN) built the necessary link to the construction company Salling. This company, which is engaged in the demolition of old buildings and aims at recycling as much material as possible, was interested in finding another customer for the wood recovered. Another company, pump solution provider Desmi, was interested in profiting from an excess of steel bolts from packaging of supplied pump parts. No connection to other, previously emerged symbioses could be identified in this emergence process.

However, the two symbioses shared a common impetus in an early stage of their development, which is reminiscent of *cloning* (2c): Mani Pine's ambition to include used materials in their products, and the symbiosis facilitator NBEN. The resources from both companies were suitable for Mani Pine's furniture production and therefore both symbioses emerged around the same time (Netværk for Bæredygtig Erhvervsudvikling NordDanmark, 2016b). After the emergence process, the two symbioses *settled (2d)* and remained connected through the shared symbiont Mani Pine, but are not dependent on each other's existence.

Fig. 8. Reproduction pathway in the IS emergence processes of Case 4.

5.2.4. *Case 4: gypsum and chalk slurry symbioses*

This case addresses two symbioses: The delivery of chalk slurry from Aalborg Portland to NPS, and the delivery of gypsum from NPS back to Aalborg Portland.

As illustrated in Fig. 8, the emergence of both symbioses that emerged at the same time is connected to a specific form of budding (1a). Later parts of the development process can be explained by looking at the processes of cloning (2c), followed by the symbioses settling together (2d) as two interdependent symbioses.

IS emergence through *Budding (1a):* Both symbioses came about through a budding process to a previously existing symbiosis. This previous symbiosis was between NPS and purchasers of sulphuric acid. Power unit 2 at the plant, which had operated since 1977, produced sulphuric acid as a by-product. However, there were many obstacles with this symbiosis, mainly technical in nature, such as the difficulty to control the sulphuric acid flue. Moreover, the production was a health risk for the employees and the price of sulphuric acid dropped during the 1990s. When unit 2 was close to the end of its lifespan, the managers of NPS decided to analyze the different options available for the construction and by-product generation of a new power unit. The choice was the implementation of a power unit that could produce gypsum out of the chalk used to filter the flue gas (J.B. Jensen, F.V. Nielsen, personal communication, May 9, 2018). When the unit was built, the chalk necessary for the filtering process was delivered to NPS from an open mine in Aggersund for approximately two months in 1998 (J.B. Jensen, F.V. Nielsen, personal communication, May 9, 2018). After that, a business partnership with Aalborg Portland was established, where Aalborg Portland delivered the needed chalk slurry to NPS and in return received the gypsum to use in their production of cement. A special lorry was built with particular technical requirements to transport both materials, commuting from one company to the other (B.O. Borup, personal communication, May 8, 2018).

In this case, it can be observed that the emergence of the two symbioses was connected to the previous symbiosis of sulphuric acid delivery, and emerged in close proximity to it through *budding off* (2b), one of the possible pathways after *budding (1a).* The sulphuric acid symbiosis, however, came to an end as the new symbiosis emerged. Looking back to our biological equivalents, in some species of corals we can observe an unusual habit of forming buds primarily when the parent is moribund or injured, a process known as the “Phoenix effect” (Goldberg, 2013). The reproduction occurring in this industrial symbiosis is reminiscent of this unusual biological form of budding.

The end of one existing symbiosis gave rise to a new emergence process resulting in two new symbioses. The emergence of both symbioses had the shared impetus of the construction of a new unit at the city’s power plant, characterizing the developmental dynamic of *cloning (2c).* These two new symbioses *settled (2d)* dependent on each other and continue to be dependent along their development.

6. Discussion

The application of the IS reproduction model to cases in Aalborg proved to be viable. Analysing the four cases using the developed model showed that IS can emerge and develop as the model predicts. IS emergence and development in the selected cases followed the processes indicated in the model, thus validating the model. This finding makes the model a relevant tool for understanding IS emergence and network development through the connectivity among both new and old symbiotic linkages.

While the model could be applied to all cases, several aspects require attention and need to be addressed. Connections and dependencies between symbioses could be identified in all cases, but the *path* and the *intensity of reproduction modes* varied in the different cases. Moreover, the symbioses’ *interconnectedness over time* varied, and *overall ISN dynamics* were found to influence the reproductive processes.

The *path* of reproductive IS emergence and development processes showed no recognizable pattern in the different cases, which stresses the equal importance of all processes indicated in the model. Even if no development trajectory appeared to be the same, a common reproductive pathway unifying all symbioses studied was identified: the settling process. After the emergence phase (either through broadcast spawning in cases 1 and 2, or budding off in Case 4, or cloning in cases 3 and 4) a settling process (2d) followed, before further development of the symbiosis took place. This finding enriches and validates the reproductive modes represented in the model. While settling appeared to be a case-encompassing process, the optionality of the “cloning” process became very clear. The first symbioses in two out of four cases skipped the cloning process and developed as single symbioses. The critical reproductive factors determined through the previous literature review were recognized in the application of the cases. One example is the district heating network in Case 2, where, once the first IS linkages were established, existing infrastructure such as a shared transportation net between different symbionts enabled local colony building (3b). The second case also involved the local heat supplier as a connection point, which was found to be decisive for colony building in an early phase of IS network development. Other critical factors that affected IS emergence were found to be the varying actors, their individual organizational capacity, and the accumulated institutional capacity in the geographic area.

Another point is the *intensity of reproduction modes* that was found to vary across the analyzed cases. The connection of newly emerging to old symbioses was for example strong in Case 2, where various heat flows led to the same company and an extended colony of symbioses formed. In comparison, in Case 3, the only connecting factor between the two symbioses was the presence of a facilitator. More factors contributing to the interconnectivity between symbioses were however not shown to necessarily mean dependence. Symbioses were found to be connected through factors such as shared symbionts (Aalborg Portland, Aalborg Utility (heat), and Mani Pine) or a shared impetus of emergence (as the facilitator in Case 3) without being necessarily dependent on each other during or after their emergence process. Even though budded symbioses represented a high degree of interconnectedness in Case 2, they were by no means isolated from outside influences and authorities. If anything, especially budded, interdependent symbioses potentially share the same influencers—which can be actors or economic, regulatory, and technical factors. The symbioses were even found to influence each other negatively (based on competition) depending on outside influences.

Interconnection and interdependence were found to be dynamic *over time*. Newly emerged symbioses can be interconnected or dependent on each other, even if they did not come about through the influence of other symbioses, as Case 3 showed. Moreover, Case 4 suggested that previously dependent symbioses can become independent and that “budding off” (2b) is a process that can also be observed in the industrial case. A budded symbiosis (1a) could survive independently when it reached a mature state, even if the parent symbiosis came to an end. The same symbiosis reached a new, different state of dependence afterwards, as it engaged in cloning (2c), sharing symbionts and transportation modes with another symbiosis. Case 3 stresses the importance of viewing the emergence and development as interconnected, long-term processes. After emerging through non-reproductive processes, the symbioses showed that in cloning (2d), twin symbioses emerging at the same time can have a shared symbiont but continue to exist independently. Interconnection and dependence are thus not phenomena exclusive to reproductive emergence processes but can also be found at later stages of IS development. Nevertheless, connections and dependencies related to other existing symbioses were mostly observed as starting in the emergence phase of the symbiosis, indicating that this is an important phase determining the early relations to other symbioses.

A varying role of reproduction modes was noticed in different ISN development stages and *ISN dynamics*. Looking at the development of the ISN in Aalborg (Fig. 4) through the lens of Chertow’s (2007) phase-logic, the symbioses in cases 1, 2, and 4 belong to the initial period of self-organization for reasons of economic efficiency, while symbioses in Case 3 were added to the network through facilitated interfirm exchange. In cases 1 and 2, broadcast spawning was especially important at a young age of the ISN development, when few resource exchanges existed and when there was no strong facilitation structure in place. In contrast, Case 3 showed vividly how in a later stage of Aalborg’s ISN development, facilitated symbioses emerge without connection to or dependence on existing symbioses, due to structural embeddedness and the accumulated mobilization capacity created by Aalborg’s strong coordinators. The current case analysis presents the model as an interesting starting point for a discussion of differences in reproductive modes of self-organized and facilitated IS. Further research and application of the model to other cases (especially on facilitated symbiosis) is needed to be able to understand the exact connection between the different dynamics and reproductive modes of IS emergence. An application of the model to more middle-out and facilitated emergence processes is recommended to engage in a deeper analysis.

Previous studies mainly focussed on the right circumstances for IS to flourish and provided valuable insights, e.g. on the individual, organizational, and institutional capacities and embeddedness required for IS emergence (Boons and Spekkink, 2012). This study used the available knowledge on industrial symbiosis emergence, but went beyond the exiting literature by changing the perspective and zooming in on the effect of existing symbioses on the emergence of new ones. This relation was proven to exist and to follow specific pathways as shown in the model developed.

7. Conclusion

The present study has focused on answering the research question of “*How does an ISN develop through connectivity or dependence between existing and emerging IS linkages?*” By doing so, the research addressed a gap in current IS literature, analysing the role of connectivity and dependencies between symbioses in the IS emergence and ISN development process. The conceptual model developed was shown to be a useful tool to seek answers to the research question and to gain a new perspective on the development of IS networks. The model allows insights into an IS network’s level of interconnectedness and illustrates the level of collaboration, knowledge diffusion, and mobilization capabilities of actors within and beyond the regional IS network.

After using the IS reproduction model, the relation between existing symbioses and new IS emergence was proven to exist and to follow specific pathways as shown in the model developed. It can be stated that the emergence of IS through reproduction leads to the development of the ISN by following different reproductive modes and paths and presenting varying degrees of interconnectivity among existing and new symbioses. Moreover, the symbioses’ interconnectedness over time varied, and overall ISN dynamics were found to influence the reproductive processes. Even though IS reproduction was found to be an important factor to be considered in IS emergence, it cannot be claimed that the reproduction model encompasses the complete web of factors affecting IS emergence. An existing IS linkage could in no case be identified as the single driver for a new IS emergence. IS reproduction is thus one of several dynamics in the IS emergence process.

The conceptual model allows IS researchers to clearly identify reproductive processes involved in the IS emergence and ISN development process. Governmental, academic, and industrial IS practitioners can gain an enhanced understanding of how existing IS linkages facilitate new IS emergence. A discussion and articulation of factors of dependence and connectivity between industrial symbioses facilitated by the presented model is expected to support better choices for enabling further sustainable industrial development.

A counterpart to the macro-level, inter-organizational IS can be Cleaner Production (CP) initiatives CP practices have been shown to foster the implementation of circular economy principles at the industry level (Sousa-Zomer et al., 2018). In turn, the development of an interconnected IS network and the associated increase in awareness of the importance of resource efficiency can also promote the initiation of relevant internal CP practices leading to waste and pollution prevention. Combining inter-organizational waste exchanges through IS with intra-organizational waste reduction activities according to CP principles is necessary to create an industrial system in which resource loops are not only closed, but also narrowed and slowed. The presented IS reproduction model can inspire CP researchers to conduct supporting research addressing the role of the mentioned reproductive processes for the emergence of CP practices. These insights could be merged into an overarching model of sustainable industrial network development.

The presented new perspective on IS emergence also opens up other possibilities and issues that require further research. The developed conceptual model has proven useful to highlight characteristics of connectivity and dependence between symbioses, which refers to the ISN structure. To gain more insights into the dynamics of a specific IS and to measure the interconnectedness and dependency among symbiotic linkages at network level, an analysis of the overall ISN structure and the degree of centrality is recommended. Through social network analysis, also key relationships, roles, and themes can be identified in the ISN, as recently demonstrated by Song et al. (2018). Using both social network analysis and the presented reproduction model as tools can lead to further insights into how actors, their roles, relations, and involvement in existing symbioses lead to new IS emergence. The role of common symbionts and geographical proximity for interdependence and connection among symbioses within an ISN is another point to be investigated in this context. As the application of the model in the present study puts a strong focus on the emergence phase, further research on symbioses in the post-emergence phase is necessary. Developments of IS that influence critical reproductive factors within a network are one of the topics to address within such research. Analyzing how exactly an IS network is formed through the maturing or division of IS colonies is also viewed as promising for the further development of the model. Shedding light on these aspects is thought to enrich the field of IS and contribute to both the understanding of IS network formation and development.

Author contributions

Leonie Schlüter: Conceived and designed the analysis, collected the data, conducted the collection of data in a previous work (2018) through semi-structured interviews, contributed data or analysis tools, performed the analysis, wrote the paper. Lucia Mortensen: Supervised and was involved in the collection of data through semi-structured interviews in 2018 and wrote the paper with attention to the state of art, literature review, discussion, and conclusion. Lone Kørnøv: Conceived and designed the analysis, decisive contribution to highlighting the importance of analogies, contributed data or analysis tools, contributed with insights on model generation and testing, wrote the paper with special attention to model generation, analysis, and conclusions.

Declaration of competing interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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5.3 ON CONCEPTUALIZATION OF INDUSTRIAL SYMBIOSIS EMERGENCE AND FACTORS FACILITATING IT

Although both Mortensen and Kørnøv (cf. 2019 #1) and Schlüter et al. (cf. 2020 #4) engage with analogies to biological systems to explain the IS emergence process, the conceptualizations of IS emergence differ. Mortensen and Kørnøv (cf. 2019 #1) make an analogy to the emergence of plant seedlings that are dependent on the soil (contextual) conditions they are in, while Schlüter et al. (cf. 2020 #4) make an analogy to coral reproduction processes, where emergence of a new organism depends more on another organism than the contextual conditions. Furthermore, Schlüter et al. (cf. 2020 #4) examine the interconnectivity between the symbiotic linkages and refer to the existing symbiotic linkages as antecedents and enabling factors for new emergent symbioses, while Mortensen and Kørnøv (cf. 2019 #1) conceptualize IS emergence as a social collaborative process driven by engagement of various actors in interactions to provide fruitful contexts. The study of connectivity among symbiotic linkages is different from the conceptualization by Mortensen and Kørnøv (cf. 2019 #1) and can present challenges when synthesizing across these on IS emergence.

However, while not directly compatible with each other, these variate perspectives on IS emergence can complement each other and present the complexity of the IS emergence process. With the insights from Schlüter et al. (cf. 2020 #4), IS emergence appears then not only to be a social dynamic process enabled by the contextual conditions, the multiple actors organized in partnerships and engaged in focused processes supported and fostered by platforms as found by Mortensen and Kørnøv (cf. 2019 #1), but also a continuous process were previous symbiotic linkages can serve as enabling factors for the emergence of new symbiotic linkages. The collaborative interactions within the emergence phase can lead to the creation of awareness and interest in IS benefits. Reaching out and exploring connections as described by Mortensen et al. (cf. 2019 #1) can lead to knowledge, information, and experience exchange on previous IS, which can encourage the reproduction of the same symbiosis and leading to it budding, broadcast spawning, or brooding (cf. Schlüter et al., 2020 #4). Analyzing the cases of IS in Aalborg, Schlüter et al. (cf. 2020 #4) find that knowledge and information exchanges did not aim directly at creating new symbiotic linkages but instead contributed to it. The emergence of symbiotic linkages thus should not be studied separately, examining only the emergence of bilateral ties but instead, the interconnectivity between a previous symbiosis and an emerging one should be considered. The emergence of symbiotic linkages thus leads to the emergence of an IS network.

Connecting these findings to the study by Mortensen and Kørnøv (cf. 2019 #1), it can be observed that the findings of Schlüter et al. (cf. 2020 #4) complement the list of factors that enable IS emergence. Just like Mortensen and Kørnøv (cf. 2019 #1), the authors find that various "*actors, their individual organizational capacity, and the accumulated institutional capacity in the geographic area*" (p. 12) contributed to the emergence of symbiotic linkages. Moreover, the authors raise attention to some factors that Mortensen and Kørnøv (cf. 2019 #1) did not investigate: the technical, national, and international factors. Technical factors, such as a shared transportation are found to contribute to IS emergence, while also being an obstacle. Locally, the political support and the Aalborg Municipality's clear strategy seem to have enabled earlier symbioses. The desire of *"a reduction of energy from coal*" (p.11) and for "*political decisions [that] led to increases and decreases in heat supply from specific sources"* (p. 11) encouraged the previous IS emergence. National developments regarding the district heating and "*the investigations into fly ash's potential use"* (p. 10) seem to have pushed the previous symbioses to emerge.

Considering international factors (i.e. other than local and national factors) as exogenous is in line with IS literature where a rich body of research identifies these as important factors for IS emergence and development. For example, Velenturf (2016, p. 166) considers the influence of "*linkages between EU/national and regional/local level governance*" for biowaste-to-resource solutions, Mannino et al. (2015, p. 295) mention "*the global and European restructuring of the chemical sector*," Madsen et al. (2015, p. 860) state that the "*discourse of resource efficiency and circular economy has grown so strong that companies are beginning to feel a need to deliver on this agenda, making it a motivational factor for companies to engage in IS*." Elabras Veiga and Magrini (2009) explain the engagement of Rio de Janeiro with IS as being inspired by the experiences in Europe, North America, and Asia. Schlüter et al. (cf. 2020 #4) confirms such findings and together with the findings by Mortensen and Kørnøv (cf. 2019 #1) confirm the statement of Spekkink (2015, p. 144) who concludes that "*even though we can give a useful description of the development of industrial symbiosis in isolation, to understand why actors involved in its development see opportunities to engage in collective action towards industrial symbiosis we may sometimes need to broaden the scope of analysis to include the other developments that contribute to the conditions under which collective action becomes possible."*

Schlüter et al. (2020, p.13) specifies that "*the current case analysis presents the model as an interesting starting point for a discussion of differences in reproductive modes of self-organized and facilitated IS. Further research and application of the model to other cases (especially on facilitated symbiosis) is needed to be able to understand the exact connection between the different dynamics and reproductive modes of IS emergence. An application of the model to more middle-out and facilitated emergence processes is recommended to engage in a deeper analysis*." The Sustainable Synergies project unfolding in the Aalborg East port industrial area was an obvious opportunity to do this and further analyze how the two conceptualizations of IS emergence can inform and complement each other.

The following chapter presents the results of analyzing the emergence of symbiotic linkages through the Sustainable Synergies project (Appendix I pictures and describes each symbiotic linkage in detail). The emergence of symbiotic linkages through the Sustainable Synergies project is found to lead to the formation of an emergent IS network. Thus, it became possible to apply the IS reproduction model developed by Schlüter et al. (cf. 2020 #4) to this network (Appendix II describes the reproduction of emerging symbioses through the project in detail), and by this informing both the IS reproduction model and the initial conceptualization of IS emergence.

6 EMPIRICAL INSIGHTS FROM INDUSTRIAL SYMBIOSIS EMERGENCE WITHIN 'SUSTAINABLE SYNERGIES' PROJECT IN AALBORG EAST PORT INDUSTRIAL AREA

Within the Aalborg East port industrial area, as presented in section 2.1.2., various actors have been involved in activities aiming at IS initiation for more than a decade, without considerable success. Research was effectuated to uncover the area's potential for accommodating IS and proposing ways to engage with IS emergence. Moreover, the Environment^{++} initiative is being implemented as an intentional and strategic initiative aiming at fostering IS emergence in the area through collaborative approaches to issues and challenges. Its sub-project, Sustainable Synergies, presented in section 4.2., provides a unique possibility to learn from real-time processes that support and facilitate IS emergence, and thus further developing the initial conceptualization of IS emergence.

The empirical study of IS emergence within Sustainable Synergies, collecting data through individual and group interviews, observations, and document analysis, uses the findings of Mortensen and Kørnøv (cf. 2019 #1) as a conceptual framework for the empirical data analysis and understanding of IS emergence through facilitation. Moreover, the findings are also analyzed through the IS reproduction model developed by Schlüter et al. (cf. 2020 #4) in order to connect the two IS emergence conceptualizations and provide further insights on IS emergence and factors that facilitate it. This chapter complements, enriches, and further develops the IS emergence conceptual model presented by Mortensen and Kørnøv (cf. 2019 #1)[6] and further validates the IS reproduction model developed by Schlüter et al. (cf. 2020 #4). Thus, it feeds directly into answering the first and second research questions as also shown in Figure 14.

[6] Mortensen and Kørnøv (cf. 2019 #1) refer to "critical factors" for IS emergence while the presentation of insights from the port industrial area in Aalborg East refers to "factors facilitating" IS emergence. This is rooted in the approach taken to IS emergence. Mortensen and Kørnøv (cf. 2019 #1) analyze generic factors as identified from various (facilitated, planned, self-emerging, etc.) cases aiming at producing general knowledge on IS emergence. Facilitating factors, are not different from critical factors, but just set focus on a facilitated process. In both cases the focus is on enablers for IS emergence.

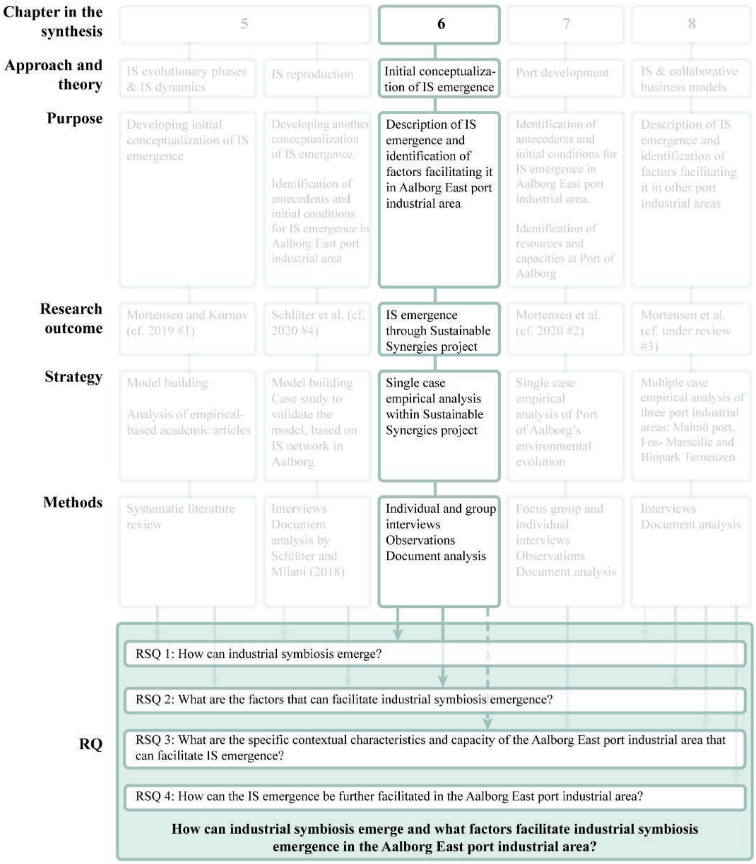

Figure 14: Chapter 6th's contribution to research question (s).

As the empirical study describes IS emergence in the Aalborg East port industrial area, the study presents initial insights into area's existing characteristics and the capacity for enabling further IS emergence. Thus, the study also contributes to answering the third research question. As the aim of the study was not exactly to explore the area's characteristics and capacity, the study feeds indirectly into the third research sub-question. Therefore, the interrupted arrow.

The study is not presented anywhere else, therefore an account of the methods for data collection and analysis follows.

6.1 METHODS FOR DATA COLLECTION AND ANALYSIS

Part of the Sustainable Synergies project, as mentioned in section 4.2., was used as a case elucidating the emergence of symbiotic linkages and the factors that enable it. The focus was on the unfolding of the process, the actions that facilitators took, and the enabling factors that contributed to the emergence of new symbiotic linkages. The study did not focus on the environmental effects and assess their sustainability. Omitted in the case study were the project's assessment of the sustainability effects of each IS and the final evaluation of the project. The former was out of the scope of this research, while the latter will not be complete until spring 2020.

The project is based on a facilitative approach to IS emergence where the actual facilitation of the emergence of symbiotic linkages has been done mainly by a team of six DCEA researchers—a professor, two associate professors, and three research assistants working with sustainability assessment, sustainability design, and sustainable business models generation. The team functioned as a core facilitation team while additional colleagues and partners contributed subject-specific skills and capabilities along the way. The project's geographical context is the port industrial area in Aalborg East, but it also engaged companies from beyond this geographical context into the initiation of symbiotic linkages.

To document the emergence process through facilitation of symbiotic linkages in real-time, the data were collected in two rounds (as schematically represented in Figure 15). First, individual interviews with corporate representatives involved in emerging symbiotic linkages and group interviews with the facilitation team were held in April–May 2019. Second, a follow-up and re-examination of the emerging symbiosis status through oral conversations and written check-ups with the facilitation team was effectuated in December 2019–January 2020. Furthermore, observations were made during the project's completion.

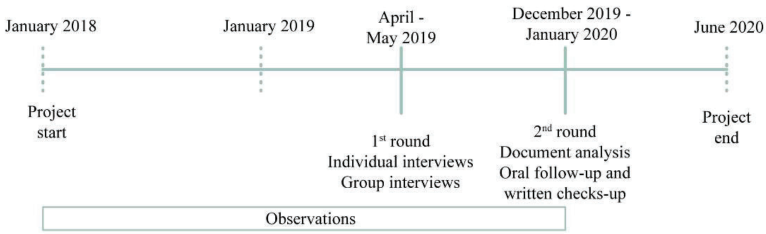

Figure 15: Data collection process.

The insights collected through the second round of data collection complemented the data collected in the first round. By collecting data in two rounds, a deep insight into the emergence process is obtained and the understanding of the evolution of such processes is strengthened.

The project is ongoing and the symbiotic linkages are still emerging. Thus, the data within this thesis envisages only a partial view on IS emergence.

A triangulation of methods (Yin, 2003) was used to collect data on the IS emergence process and factors enabling it: 1) observations, 2) individual semi-structured interviews with companies' representatives and semi-structured group interviews with the facilitation team, and 3) document analysis.

6.1.1 Observation

From January 2018 to January 2020, I participated in and conducted observations at more than ten project status meetings, two reference group meetings, two meetings related to a symbiotic initiative related to recycling of plastic, five interviews conducted by the representatives of the facilitation team, one design workshop, and one resource matchmaking event. These allowed me to follow the process closely and to gain first-hand experience with the facilitative process. This created the background for understanding the emergence of symbiotic linkages and factors enabling it through facilitation.

One of the most important observation was made by participating in the mid-term evaluation meetings of the Sustainable Synergies project conducted by a consulting firm on the 8th of March, 2019[7]. First, a group interview with the project group was held by the consultant. Then, two other meetings were organized with project partners (Port of Aalborg, House of Energy, and DCEA) and with three company representatives (of the emergent symbioses at that time), respectively. These meetings

[7] The mid-term evaluation is one of the two evaluations that the Sustainable Synergies project is subject to. The second is the final evaluation. The Danish Business Authority's evaluation guidelines (DBA, 2015, p. 5) mention that "*the overall purpose of the evaluation in practice is to help maximize the effects of the programs. The evaluations must therefore not only document whether the efforts have worked or not, but also be used as a basis for future optimization of the efforts during the 2014–2020 program period (and possibly in the next program period), so that the Structural Funds are focused on the instruments that create the greatest effect per support crown*." Thus, the evaluation is an important part of collecting results focusing on "*documenting if and how Structural Fund projects actually work and on a systematic collection, dissemination and anchoring of knowledge and learning, which can be used to develop even better projects and tools in the future*" (DBA, 2015, p. 3). The consultancy company COWI was the official evaluator, while they subcontracted another company to effectuate the mid-term evaluation.

allowed participants to express their opinions about the project in separate forums. At these meetings, it was expressed that facilitation and the presence of a facilitation team was the most crucial factor for the IS emergence in port industrial area in Aalborg East. Several questions then arose: What functions did facilitators undertake that enabled the emergence of symbiotic linkages? What capacities and skills did they apply and use to facilitate the emergence of symbiotic relations? What role did the facilitation process play for IS emergence and how did the facilitation process unfold? Answers to these questions were explored at the subsequent two group interviews with the facilitation team and where subject for the subsequent observations.

Notes from observations were taken and served as enriching and validating data for the inputs from interviews.

Additionally, continuous dialogue and follow-up discussions with the facilitation team throughout the project provided fruitful up-to-date insights into the emergence of symbiotic linkages.

6.1.2 Individual and group interviews

Individual semi-structured interviews were conducted with four companies that were involved in specific emergent symbioses. Corporate representatives participating at the interviews were company managers, environmental managers, and/or production and development employees. Each interview had focus on elucidating the process through which the specific symbiosis emerged and the factors that contributed to its emergence. Minutes from interviews were taken.

Two semi-structured group interviews were conducted with the facilitation team. Group interview is a valuable method for data collection that complements the other methods and can be used for exploratory and mapping purposes. As a data collection method, the group interviews benefit from dynamics that exist between the group members, as participants and the interviewer to get rapid access to shared knowledge that otherwise would have taken long time to access. (Frey & Fontana, 1991) The facilitation team was selected as interview respondents as several researchers fulfilled various facilitation functions and thus individual interviews would not have provided a wholistic view on the facilitation and the process of emergence.

The facilitation team’s input was crucial, as they had the overall view of the process and enabling factors. Therefore, both group interviews applied a self-reflective approach, where the facilitation team reflected on its own roles and functions needed to facilitate IS emergence and provided its own perspectives on the IS emergence and the factors enabling it in the port industrial area in Aalborg East.

The first self-reflective group interview (Group interview 1, 2019) was held the 6th of May, 2019. The facilitation team reflected on the tasks, roles, and functions they had during the IS emergence process. Moreover, the facilitation team reflected on the capacities they activated to enable symbiotic linkages. The interview lasted for two hours, during which symbiotic linkages emerging at that time were discussed one-by-one according to following aspects:

1) Facilitation tasks, roles, and functions
2) Tasks, roles, and functions of other actors
3) Technical and professional skills and capacities
4) Personal skills and capacities

Some general functions, capacities, and skills that the facilitation team made use of, were identified for all symbiotic linkages' emergence, while also specificities were mentioned for certain IS. The interview was recorded and later fully transcribed.

The second group interview with the facilitation team was conducted the 23rd of May, 2019 (Group interview 2, 2019). Prior to the interview, a comprehensive desk-research and *document analysis* was made to identify the companies involved in the project up to that point. These were written on a large flipchart, which served as a background for mapping the symbiosis linkages emerging. The group interview lasted for three hours and was structured to include questions and tasks that permitted the following:

- **Mapping the potential symbioses emerging from Sustainable Synergies**. The group was first asked to map the symbioses they could see as an outcome of the project. Material, energy, and liquid flows where inserted on each link among companies.
- **Presentation of the applied facilitation process**. The facilitation team, going backwards from the map created, described the process and the facilitative approach as perceived by themselves. The discussions developed to include the facilitation team's tasks and the roles of other actors involved in the process.
- **Discussion of enabling factors characteristic for each symbiotic tie**. At last, as the discussions evolved, the facilitation team provided insights into factors enabling emerging symbiotic linkages in regard to contextual conditions, individual and organizational capacities, institutional enablers, etc.

Applying group interview as a data collection method, I got rapid access to valid knowledge on the IS emergence process and the facilitation as well as the facilitator's tasks, skills, and capacities. The second group interview functioned to validate the events that took place in Sustainable Synergies project up to that point and to make sense of the facilitation tasks. As advocated by Frey & Fontana (1991), the group interviews also provided an arena for discussions among the facilitation team members where they aligned their views on both facilitation and IS emergence. These also stimulated generation of new ideas, new views, and understandings of the process. Frey and Fontana (1991) refer to opinions of some interviewees as being able to shadow for others and to how the relations among the interview respondents outside the group interview could shape the group dynamics and thus each respondent's engagement in the group interview, as disadvantages of the method. However, as the relations among the researchers who made up the facilitation team were well functioning, and the interviewer (i.e. me) was integrated into the group due to the integration of the PhD project in Environment^{++}, no challenges related to these disadvantages were observed. On the contrary, the fruitful discussions within which all researchers had a voice and place to express own thoughts, brought new ideas and revelations about the process, facilitation methodology, and results obtained up to that point in time.

6.1.3 Document analysis

A thorough investigation and document analysis (Bowen, 2009) was made to identify the companies contacted by the facilitation team and involved in the Sustainable Synergies project. Screening reports and working documents with notes on the companies' profiles were analyzed to collect names on all companies involved in the project. These data served as inputs to the second group interview with the facilitation team the 23rd of May, 2019. Then, document analysis of the mid-term evaluation report (COWI, 2019), minutes from status meetings, and symbiosis business model reports provided data for the study. These offered access to data that provided knowledge on the process through which symbiotic linkages were emerging, the role of the actors involved in the process, the role of their actions and capacities, and the influence of other factors on the emergence of IS linkages.

6.2 DATA ANALYSIS

The inputs from the group interviews provided insights into the symbiotic linkages that were emerging in May 2019 and the factors that were influencing them. These inputs made possible the initial mapping of emerging linkages and the identification of (specific and general) facilitative factors. The other data collected through the transcription of semi-structured group interviews, notes from individual interview minutes, and observations from various meetings before May 2019 served to provide overall information on other aspects of interest regarding the emergence of symbiotic linkages through the Sustainable Symbiosis project. These data underwent a process of thematic analysis as it provided "*a systematic yet flexible and accessible approach to analyze [large and disparate amounts of] qualitative data*" (Saunders et al., 2016, p. 579).

First, I became familiar with the data by reviewing transcripts of interviews and revisiting the notes from observations and meetings. This permitted the integration of related data into one large data set, with data sources annotated in order to keep source accurateness. In this process, common meanings were emerging and the need for coding the data in common thematic groups appeared. Text pieces, sentences, a line of a transcript, etc. served as units of coded data (Saunders, et al., 2016). The coding procedure was guided at first by the categories derived from the conceptual framework related to the actors involved in the IS emergence process, their roles and capacities, the process of emergence and its characteristics, and the activities within such a process. Simultaneously, the coding focused on aspects that are not elucidated by Mortensen and Kørnøv (cf. 2019 #1), leaving space for the codes to emerge from the data collected. Several other groups of themes emerged setting focus on facilitation; the role, capacities, and skills of a facilitation body; and the role of initial conditions such as IS-aiming initiatives, business networks, and the presence of a port for IS emergence. Information specific to each symbiotic relationship was kept for the accuracy of the process description.

The findings from this data analysis process and the initial mapping where complemented with the findings from analyzing the symbiotic business models reports, the mid-term evaluation report, and the inputs from further conversations and written check-ups with the facilitation team up to January 2020. The focus was primarily on identifying changes within each emergent symbiotic linkage identified in May 2019 and the emergence of new ones, while also gathering further insights into the factors that influenced the identified symbioses and the interdependence between the previous and newly emerging ones. This allowed deeper insights into the evolution of IS emergence and creation of an up-to-date overview of the symbiotic linkages emerging through the facilitation process (presented in the Appendix I).

Moreover, the analysis results obtained were further analyzed through the lens of the IS reproduction model to uncover the dependency between emerging symbiotic linkages as factors facilitating IS emergence. By applying the IS reproduction model to the facilitated and emerging IS, the model is validated to facilitative processes and the insights obtained enrich the understanding of IS emergence and the interdependence between symbiotic linkages as an enabling factor for further IS emergence.

The following section present the results from applying both the conceptualization by Mortensen and Kørnøv (cf. 2019 #1) and the IS reproduction model by Schlüter et al. (cf. 2020 #4). A discussion of how these findings enrich the initial conceptualization of IS emergence wraps up this chapter.

6.3 EMERGENT INDUSTRIAL SYMBIOSES

The examination of IS emergence in two rounds (in May 2019 and in December 2019-January 2020) permitted identification of how the industrial symbioses are emerging through the Sustainable Synergies project. The process of the Sustainable Synergies project is found to facilitate the emergence of eleven industrial symbioses based on flows of materials, liquids, and knowledge as presented in Table 7. An in-depth presentation of symbiotic linkages' emergence is given in Appendix I. The symbiotic linkages presented in the Table 7 are only potentials identified at various companies throughout the project, and are described in the business model reports. Not all symbiotic linkages yet emerged. The knowledge symbioses did, while some symbioses are expected to emerge, others will not emerge, and some others' emergence remains unknown. That means the potentials are identified, companies agree on the potentials, but no physical symbiotic flow have yet been established.

Table 7 on the next page presents the sender business organizations, the receivers, and the symbiotic flow that connects the two. As can be seen, seven possible symbioses are identified based on exchange of by-products, one symbiosis around the flow of liquids as by-products, and three as knowledge symbioses. The companies to be involved in the symbiotic relationships are of varying sizes (small, medium, and large according to European Commission's definition on small and medium sized companies [EC 2003]) with local and international profiles. They vary regarding to their business models. Some are production companies and service companies, and others are waste management companies. Furthermore, companies have varying amounts of (human, economic, financial, etc.) resources, corporate values, environmental ambition, and sustainability motivation levels. Moreover, these present varying degrees of proactiveness and willingness to invest time and other resources in the Sustainable Synergies project generally and IS emergence specifically. Most of the companies engaged in the project were motivated and interested in IS emergence for different reasons. Some engaged "*not because of [direct] economic benefits but motivated by [their] own organizational sustainability ambitions*" (COWI, 2019, p. 7). Others "*have a business process that permeates to enter symbiotic relations with a new supplier and through which both economic and environmental benefits can be achieved*" (COWI, 2019, p. 7). And others have highly engaged leadership and personnel that are motivated by personal interest, organizational values, and expected IS benefits.

Several other by-products such as large plastic bags, textiles, and glass fiber, were identified by the project as potential synergistic flows. Some of these constituted resource flows within emerging symbioses identified through data collection in May 2019[8], and which terminated by December 2019. For example, following potential symbioses were identified:

- Recycling of textiles collected from a laundry in Aalborg East
- A potential knowledge symbiosis between a utility company and a production company in Aalborg East potential
- A symbiotic relationship between a waste management company and glass fiber producer company based on recycling of glass fiber
- A potential symbiotic relation between Fibertex Personal Care and a festival-arranging company based on recycling of spin belt material and cardboard tubes.

[8] A total of 31 symbiotic linkages were identified as emerging in May 2019, and by that time 9 industrial symbiotic linkages had already ceased to emerge.

All of these were identified before May 2019, but terminated shortly thereafter.

	Symbiosis	Sender	Resource	Receiver
Material flows	**1 Reuse of Aluzink sheets**	NB Ventilation A/S	Aluzinc	Aalborg Profil og Smedeværksted ApS
	2 Repair of professional electric tools	NB Ventilation A/S	Defective professional electric tools	Råt &Godt
	3 Recycling of agricultural foil	Agricultural and animal farms	Used agricultural foil	Aalborg Recycling ApS
	4 Recycling of defect washing machines and tumble driers	Companies in Aalborg East	Defective washing machines & tumble driers	De Grønne Hvidevarer (DGH)
	5 Reuse of wooden pallets	Danish Laser Technology A/S	Defective wooden Pallets	LC Emballage
		LC Emballage	Repaired wooden pallets	Danish Laser Technology A/S
	6 Reuse of cardboard boxes	LC Emballage	Re-used cardboard boxes	Danish Laser Technology A/S
	7 Recycling of plastic sheets	Danish Laser Technology A/S Brunø Stål ApS NB Ventilation A/S Bobach Stålentreprise A/S Fuglsangs Eftf. A/S	Plastic sheets	Aalborg Recycling AVL
	8 Design for new products of recycled materials (furniture and lamps)	NB Ventilation A/S	Aluzinc	Råt &Godt
		Bobach Stålentreprise A/S	Hardwood by-products	
		Fibertex Personal Care A/S	Cardboard tubes Spin belt material	
		Danish Laser Technology A/S.	Metal offcuts/scrap metal	
Liquid flows	**9 Separation of oil from water within discarded oil-water emulsions**	Companies in Aalborg East	Oil-water emulsion	Kingo recycling A/S
		Kingo recycling A/S	Oil	Aalborg Portland
			Water	Aalborg Rensningsanlæg
			By-product	Fortum
Knowledge flows and shared service	**10 Knowledge and shared mapping service symbiosis on energy and heat loss**	Drone Systems Brix & Kamp	Knowledge	KS-gruppen
				Fibertex Personal Care
				Danish Laser Technology A/S
				2Trendy
	11 Knowledge and shared mapping service symbiosis on feasibility for installing solar panels	FKSol Kenergy	Knowledge	Danbrit Akkumulator Aalborg A/S
				Ultraaqua
				Delika
				Industribejdsning Nord
				Brunø Stål ApS
				Danish Laser Technology A/S
				Aalborg Recycling ApS
				Leif M Jensen
				Skandinavisk Industrimontage
				Moosdorf Hegn
				Bobach Stålentreprise A/S

Table 7: Overview of symbiotic linkages emerging from Sustainable Synergies project.

The identification of the potential for emergence of symbiotic linkages, presented in Table 7, was a highly iterative process through which some new symbiotic relations were formed, and some others ceased. The iterative process of emergence and termination of IS emergence illustrates its dynamic character. The group interviews with the facilitation team and the follow-up discussions confirmed that the emergence process of symbiotic relationships was a highly dynamic and time-consuming one. Symbiotic relationships emerge from a middle-out process evolving organically from completion of the Sustainable Synergies project, from the bottom-up involvement of various other actors, and from the involvement of a facilitation team and identification of various potentials and societal issues with specific by-products' fractions. Furthermore, various specific factors facilitated IS emergence. The group interviews in May 2019 and the follow-up discussions permitted identification of the facilitation processes of the Sustainable Synergies project, the presence of specific actors who played important roles among which was a facilitation team with specific capacities and skills, and the contextual characteristics as enablers for the emergence of the above-presented symbioses. The following sections discuss these.

6.4 PROCESS AND FACTORS FACILITATING THE EMERGENCE OF INDUSTRIAL SYMBIOSES: ENRICHING THE INITIAL CONCEPTUALIZATION

As specified in the beginning of this chapter, the aim of bringing empirical insights from the facilitation process of the Sustainable Synergies project was to develop a better understanding of the IS emergence process and the factors that facilitate it, enriching the initial conceptualization of IS emergence developed by Mortensen and Kørnøv (cf. 2019 #1). The objective of this section is then to discuss how the empirical findings enrich and complement the model. Therefore, the following sections discuss the empirical findings in connection to the conceptualization of IS emergence developed by Mortensen and Kørnøv (cf. 2019 #1).

The authors define the IS emergence process as "*the dynamic (social) process between pre-emergence and post-emergence phases, i.e. building on existing specific factors, agents, and unexploited potentials for synergistic ties, and aiming to establish synergistic relations between at least two organizations"* (p. 58). Within such processes, actors are engaged in interactions that can build awareness and interest in IS by reaching out to new possible partners, encouraging the exploration of new possible connections, and organizing new symbiotic ties. Connecting the empirical findings to this conceptualization, several empirical aspects are identified to enrich the initial conceptualization: First, although multiple actors are involved and can play an important role in an emerging process, the facilitator remains crucial. Being a facilitator implies engagement in various kind of tasks that require professional and personal skills and capacities. Second, the facilitation process, which is shaped by the various mobilization techniques, enables emergence of IS. Such a process is highly dynamic and iterative. Third, contextual characteristics present initial conditions and antecedents for IS emergence. And at last, the emergence of bilateral symbiotic linkages shapes the simultaneous emergence of an IS network.

6.4.1 Actors involved in the facilitative process

The group interviews, the mid-term evaluation, and the observations of the project pointed at and permitted identification of Port of Aalborg, the Business Network 9220, companies as partners in specific symbioses, and individual actors to have involved in the project, supporting and complementing the list of actors and their characteristics identified by Mortensen and Kørnøv (cf. 2019 #1).

The ***Port of Aalborg*** was found by the mid-term evaluator '*to have high engagement in [the Sustainable Synergies] project as it has a long-term focus on sustainability'* (COWI, 2019, p. 8). Three port representatives (the port's environmental manager, the technical and environmental director, and the director of human resources and development department) were involved in the Sustainable Synergies project, besides the financial employee. These individuals presented high commitment to the project and engaged in various symbioses at various times.

Being a pro-active and environmentally concerned company and engaging with IS for more than a decade, as described in the section 2.1.2., the port was in a bridging position facilitating the contact among companies and between companies and the facilitation team. As a co-founder of Environment^{++}, the port was supporting the IS emergence process financially. The Port of Alborg was also lobbying IS as a strategy at the political level. The facilitation team mentioned at the group interviews that, during the IS emergence process, the Port of Aalborg had a supportive function for the facilitation team providing financial and infrastructural resources. The port, in its position within the Business Network 9220, provided dissemination of knowledge and project offers to companies in Aalborg East and functioned as a platform to communicate project offers to its members. For instance, the offer for the two knowledge symbioses and the word about the possibility of transferring defective washing machines to the specific waste management company was sent out and communicated to companies in the network, attracting network members into the projects and involving them in the emergence of symbiotic linkages.

The ***Business Network 9220*** functioned in some cases thus as a bridging actor between companies in the port industrial area and the facilitation team. By bridging the contacts, the network facilitated the companies' trust in the facilitation team and inspired credibility to companies towards the researcher team. The Business Network

9220 was perceived by the business companies' respondents, not only as an arena where knowledge and relations are formed but also as an important mobilization platform that had the potential to activate the knowledge and relational capacities of its members, as well as to build and develop it further through its many activities.

Companies involved in the IS emergence process are mostly seen by the facilitation team and project partners, and perceived by themselves as those directly involved in the emergence processes by entering symbiotic linkages (and later implementing them). In their position as symbiotic partners, these can function as champions and drive IS anchoring it in their own organization and across their network. These companies prove themselves open to sharing knowledge and experience and willing to collaborate and enter new relationships.

The emergence of symbiosis relied on the large interest and openness of the company shaped by the companies' values and ambitions. Those who had sustainability ambitions and whose managers had strong personal sustainability values, presented strong interest and involvement in the project and interest in IS (as is the case of e.g. DLT, NB Ventilation, Brunø, etc.). The management interest and proactivity within the process was crucial as it provided decision power and power to act on possible symbiotic decisions. Organizational characteristics were largely shaped by the company managers and the personnel involved in the project through their continuous contact with the facilitation team. One example is the facilitation team meeting two representatives from the same company at two different times. One represented the company as "*green enough*," while the other one represented it as "*green, but with more place for development*" (Group interview 2, 2019)

The companies' interest in IS was found to be driven by expectations of different IS benefits rather than the type of company. First, some interested companies expected economic benefits as a result of new collaborations, in form of new products, savings from waste disposal, savings from transportation to other regions, and acquisition price for demand companies. Furthermore, if the initiative/project did not impose extra costs on the companies, they would have been interested and willing to collaborate. Then, the symbiosis had to be logistically and technically easy to be implemented. If the companies perceived the new symbiosis as not economically viable and as logistically difficult, the IS was not perceived successful and the efforts for its emergence could be abandoned. Furthermore, the companies expected that new symbiotic relationships will help market the company as environmental responsible. The project was perceived as a good opportunity for many companies to increase their environmental (and in some cases their Corporate Social Responsibility) profile by marketing the good story and inspiring other companies. The interest in IS and project participation had to be accompanied by the willingness of action, action on behalf of companies, and the time given to the project, otherwise IS emergence would not have succeeded.

The data analysis from the group interviews with the facilitation team provided evidence for several ***individuals*** to play a crucial role for specific symbioses. For example, the emergence of the symbiosis concerned with repair and sale of washing machines and tumble driers depended on an individual person, employed at the Reno Nord waste incineration plant. This person established the contact between the waste management company DGH and the facilitation team. Furthermore, this person participated in meetings between the waste management company and the facilitation team, contributed to the communication of results in the press, and functioned as a spurring and coordination partner in relation to the facilitation team. Another person from the local heat utility company showed high engagement and acted as a champion within the symbiosis concerned with the flow of knowledge and shared mapping services on energy and heat loss.

Such individuals were open-minded thinking about symbiosis, being pragmatic and having a pro-active environmental spirit. By engaging in the emergence of symbiotic linkages at different times of the process, these individuals provided enthusiasm to the companies involved directly in the emergent symbiotic relationships and inspired motivation through the process.

Among these the presence of a ***facilitation team*** was mentioned as the most important factor by the corporate representatives and the project partners. They express that "*we would not have been able to do it by ourselves. It is not natural for companies to think this way. It is difficult to know what others can use our waste for. We have enough in our daily routine. So, small- and medium-sized companies are too small to drive symbioses, but we can and would like to come into some if there is somebody to facilitate the process*" (NB Ventilation, 2019). The importance of the facilitation team is described by their implication for the project's completion and the IS emergence process.

6.4.2 Facilitator's tasks and roles

Mortensen and Kørnøv (cf. 2019 #1) mention that facilitators are those who engage the other actors in the various interactions aiming at awareness creation, reaching out and exploring connections among possible partners, and organizing for symbiotic relationships. Furthermore, facilitators "*activate the knowledge and relational resources among business companies, public bodies, and other actors*" (cf. Mortensen & Kørnøv, 2019, p. 63 #1) being responsible for building actors' (knowledge, relational, mobilization, personal, etc.) capacity for IS emergence in the phase of awareness and interest in IS benefits creation. In the subsequent phases—reaching out and exploring connections among possible partners, and organizing for symbiotic relationships—facilitators function more as incubation chambers fostering symbiotic ideas, providing opportunities for interaction, attracting funding, and taking "*responsibility for the collaborative process and IS network formation*" (cf. Mortensen & Kørnøv, 2019, p. 65 #1).

The empirical findings from the Sustainable Synergies project point at various facilitation activities as mobilization techniques for IS emergence. The project application previewed completion of specific project activities that could lead to IS emergence in the port industrial area in Aalborg East. The following five core project activities were included in the project application and drove the emergence of symbiotic linkages:

1) Quantitative meta-mapping of potential resources with the use of the Exiobase database (http://www.exiobase.eu)
2) Identification, screening, and recruitment of specific companies
3) Development of green business models for companies and symbiosis groups
4) Communication and dissemination of results
5) Project management activities

Table 8 on the next page presents an overview of the facilitation process, specific activities implemented during the project, and the facilitative techniques applied by the facilitation team for encouraging IS emergence in the area.

Meta-screening and resource mapping and ***screening individual companies for potential resources.*** Mortensen and Kørnøv (cf. 2019 #1) describe the IS emergence process as based on some initial conditions and antecedents present within each context, and the assumption that each context presents an unexploited pool of resources that present potential for resource flows. The authors present the IS emergence model by stating that "*acquiring knowledge and acknowledging potentials instead of challenges and risks can lead to raising awareness and generating interest in the initiation of new businesses or improvement of a business's own processes*" (p. 59). While the authors do not further examine this aspect and do not specify the actions needed to acquire the needed knowledge on the potential resources, nor which party is to do this, this seems to be the initial approach taken by the facilitation team in the port industrial area. The empirical findings from the Sustainable Synergies project point at the importance of the facilitation team to pro-actively take action and uncover the unexploited resource potential. A quantitative meta-mapping of potential resources among more than 150 companies in the area through the Exiobase database included a quantification of underutilized potential resources present in the port industrial area in Aalborg East. Based on this initial meta-screening, more than 40 companies were further screened via website company profiles and articles to gain an understanding of the type of business, business area, resource consumption, potential by-products discarded, and material needs. Twenty-four companies were identified as having potential resources that could serve as symbiotic flows. These were contacted and visited for individual resource screenings. Thus, the meta-screening served as a point of departure for the next activity in the project: Identification, screening, and recruitment of specific companies.

Table 8: Process phases followed within the Sustainable Synergies project for IS emergence in Aalborg. Mapping by the facilitation team at the group interview (Group interview 2, 2019) and complemented with insights from further follow-up during December 2019–January 2020.

Generic project activities	Specific actions within the facilitation process	Examples of facilitation techniques
Meta-screening and resource mapping	• Screening of underutilized potential of resources in Aalborg East using inputs from an LCA Exio database • Identification of 50 companies to be included in the further process	• Desk research and analyses • Informal discussions • Network meetings
Screening individual company for potential resources	• Developing screening method • Contacting companies • Screening companies for potential underutilized resources • Continuous dialogue with companies assuring their participation in the process • Signing partnerships with interested companies	• Multiple site visits • Continuous dialogue with companies • Face-to face meetings with corporate representatives
Matchmaking	• Continuous looking for potential partners • Analyzing the interested companies' (environmental and business) model and assessment of integration possibility of new IS relationship into the current business model • Spurring on possible symbiotic linkages with potential partners • Establishing contact/meetings with potential partners within a potential symbiosis • Keep continuous contact with potential partners to keep their interest and motivation	• Telephone calls • Desk research • Face-to-face meetings • Company visits • Contact/meetings within potential symbiosis partners
Development of symbiotic business models	• Developing (research, calculation, etc.) tools for business model development • Developing the new potential business model for both companies involved in a symbiotic linkage • Reporting for companies involved • Developing feasibility studies for each symbiotic relationship • Calculating environmental effects and benefits for involved companies	• Desk research • Application of calculation and sustainability assessment tools • Continuous dialogue with companies • Dialogue with (heat and water) Utility Companies in Aalborg • Dialogue with consultants for those symbioses needing external consultancy
Coordination	• Coordination across potential symbioses • Coordination across other similar projects in the region • Coordination of actors involved in the process, their role and functions	• Face-to-face meetings • Continuous dialogue with actors involved and responsible for the other initiatives • Meetings across EU funded projects and initiatives • Meetings with the Port of Aalborg
Communication of results	• Development of informational materials for relevant actors within the project • Dissemination of project results in press /mass media • Dissemination of knowledge within academia	• Face-to-face meetings • Administrative meetings • Conferences • Self-initiated meetings with press/mass media representatives • Self-written news

Building on the meta-screening results and the scientific experience, the facilitation team developed screening method for uncovering the resource potential in the area. This is in addition to the model, which does not refer to building methods and tools based on scientific approach. Qualitative company screenings were performed through multiple company visits, informal discussions, face-to-face meetings, and formal interviews with corporate representatives to identify potential resources. Business organizations were screened for their input-output resources and needs, to identify and map the (resource, energy, water, etc.) potential for synergistic relationships, and to identify (new) market potentials (as in the case of the symbioses concerned with reuse of wooden pallets and cardboard boxes). In such cases, the facilitation team made risk assessments of potential symbiotic partners and as they expressed themselves "*we took us the freedom to terminate the collaboration with companies that were not ready or did not comply with the project aims*" (Group interview 1, 2019). As a result, potential screening reports for 21 companies were developed, describing the resource potential for each company.

Simultaneously, the facilitation team explored some societal challenges with waste management in the area that could create symbiotic possibilities (for example, IS to reduce landfill disposal of insulation and IS to recycle agricultural plastic instead of incineration). Companies that originally were not considered by the meta-screening but identified by the facilitation team as potentially interesting (as was the case of the waste management company repairing the defective washing machines and tumble driers), were purposefully contacted and engaged in the project on the go. The facilitation team was constantly in a searching position. The team made a thorough investigation of the international experiences and symbioses concerning among others the flows of textile, plastic, large plastic bags, and plastic pallets as part of screening the business opportunities. Furthermore, the facilitation team looked for potential resources, potential symbiotic partners that can output and/or receive underutilized resources in the area, analyzed potential symbiotic flows as identified based on the underutilized resources and societal challenges, and contacted the potential partners. Enormous desk research was done, a multitude of telephone calls were made, and various face-to-face meetings and multiple company visits were performed in order to establish the contact with companies, get them interested in IS, keep their motivation in the project, and make the connection between potential symbiotic partners.

Screening the companies for potential resources and resource mapping not only built the facilitation team's awareness of the resources available but also contributed to raising awareness of the symbiotic possibilities that laid within underutilized resources at a company level. This raised the company's awareness on own underutilized resources and interest in expected IS benefits.

Matchmaking and development of symbiotic business models. Symbiotic ideas were developed based on the resource potential identified during the facilitation process.

The facilitation team's identification of societal issues presented potential for symbiotic flows in cases where companies showed themselves interested in the project and open to enter symbiotic linkages. This was in line with Mortensen and Kørnøv (cf. 2019 #1), who affirm that after uncovering the resource potentials "*then comes the meaning creation… [when] the idea of a new business potential is born*" (p. 59).

Furthermore, acknowledging the new symbiotic idea, the facilitation team communicated this to the potential partners, externalizing it and exploring potential connections. Communicating and discussing the symbiotic ideas with potential partners refer to the reaching out and exploring connections. Here, the empirical findings are in line with Mortensen and Kørnøv (cf. 2019 #1) who mention the role of the facilitator, as an important actor to bridge this communication. The empirical findings from the Sustainable Synergies project confirm this, as the facilitation team contacted a total of 48 (new and already engaged) companies for further in-depth screenings and discussions regarding the development of a specific symbiotic idea. Developing symbiotic business ideas, matchmaking potential symbiotic partners, and later developing symbiotic business models reports for companies were important and highly iterative functions undertaken by the facilitation team.

An iterative matchmaking process, with numerous meetings conducted and facilitated by the project team, was necessary. "*First, in the beginning of the project the facilitation process followed closely the project description and took outset in the specific company, looking for what resources it had, what the company could do and could not do. Later, when a critical mass of companies was examined, while still following the project activities, a matchmaking process could be initiated simultaneously while still screening other companies*" (Group interview 2, 2019). The degree of intensity of this process was dependent on the organizational resources identified, the characteristics and capacities of the companies involved, and the capacities and skills of the facilitation team. The facilitation team assumed responsibility spanning from planning the meetings with possible partners, monitoring their engagement in the symbiotic relationship, and contributing to their business idea development.

During the matchmaking process, the facilitation team provided continuous support to companies, making them aware of IS and its benefits and of the ways through which IS could be implemented. Depending on the profile organizations had, their own engagement with symbiotic ideas, and organizational motivation and interest, various kinds of organizational support were offered. The facilitation team provided supportive help that ranged from providing "*the supportive help [that] racing bicyclists get on their biking route in a competition*" (Group interview 1, 2019) in some symbioses, referring to the environmental effects' calculations, dialogue with municipal authorities, and later assigning relevant consultants, to providing 'startup'-like support where the company received "*considerable amount of spurring*" and "*the facilitation team had to shift among various roles*" (Group interview 1, 2019) assuring continuous interactions and support through face-to-face meetings and coordination activities for other companies. The facilitator team was at times also functioning as an external environmental department assisting companies with tasks ranging from providing informational support to providing specific (environmental) regulatory and technical support. In this position, the facilitation team sees itself as *"dependent on other companies"* (Group interview 1, 2019) that had to provide data on resource amounts and content. Through continuous dialogues, face-to-face interactions and personal contact between the facilitation team and companies, trustful relations and friendship bonds were developed. These could bridge the contact among companies that trusted the same facilitator team and lead to the formation of symbiotic relationships bridged by the same facilitator.

Similarly to Mortensen and Kørnøv (cf. 2019, p.60 #1) who mention that "*when initial contact to new potential partners is established through exploration of connections, business ideas and the new business models can be developed. At this point, feasibility studies for such business models can be calculated*," the facilitation team used the system perspective to explore consequential impacts in the value chain, and for changes outside the value chain, and continuously assessed the sustainability of each emerging symbiosis. The facilitation team, due to its own strong competences and research within lifecycle analysis, developed its own assessment methods and tools by developing more comprehensive calculations and securing a scientific approach to these. Moreover, specific environmental assessment tools, such as GAIA model (Kørnøv et al., 2019), were developed to assess the environmental feasibility and benefits of each emergent symbiosis. Such tools are evaluated to "*bridge the screenings and the future symbiotic business models developed [in the same time as] assuring that the symbiotic models developed are linked to the company's operations*" (COWI, 2019, p. 6). As a result, symbiotic business model reports were developed for each company within the emerging symbiosis.

Mortensen and Kørnøv (cf. 2019 #1) refer to these activities as "organizing." While the authors do not specify who develops tools and symbiotic business models, the empirical evidence from the Sustainable Synergies project points at the facilitation team to implement activities that could mobilize resources for IS emergence. The facilitation team went further than the activities presented by Mortensen and Kørnøv (2019) and performed continuous technical measurements and calculations keeping a continuous eye on the environmental regulation and expected effects.

Moreover, while Mortensen and Kørnøv (cf. 2019 #1) mention that "*no formal arrangements, such as contracts, are made at this point and no physical infrastructural constructions are made*" (p. 60), the empirical findings point at facilitation team signing formal partnerships with interested companies. While this was a formal activity required by the project application, it was also a consent the companies showed regarding their formal joining the project. Signing the partnership agreement functioned also as an indication of the ongoing 'organizing' for the specific symbiotic flow and functioned as a proof for its emergence. The signed partnership presented evidence also of the existence of an emerging symbiotic agreement between symbiotic partners. As mentioned in section 6.3., several symbiotic possibilities were identified where contact with partners could not be established and these terminated. In such cases, no partnership agreements were signed.

Furthermore, the presence and implementation of "*a common incubation platform with events supporting the exploration of connection processes, such as networking events and workshops*" (cf. Mortensen and Kørnøv, 2019 p. 66 #1) can offer interaction spaces and possibilities for conducting feasibility studies, developing business models, calculating their technical and environmental feasibility, etc. Such activities are important for the entire process, while they are most important for the last phase of organizing the symbiotic linkages. The empirical findings from the Sustainable Synergies project point at the facilitation team functioning as an incubation platform when conducting activities such as business idea development activities, environmental assessments, etc.

Communication activities. Empirical evidence from the Sustainable Synergies project finds that, besides the capacity building and context transformative actions, strategic network formation, and incubation actions (cf. Mortensen & Kørnøv,2019 #1), communication activities were also of significant importance. These implied the continuous communication with the companies and the communication of project results through various media sources.

Regarding the communication with the companies, the facilitation team worked intensively to get companies interested in potential IS benefits and to motivate them and continuously nourish their motivations to enter and remain in the process and within symbiotic relationships. Through a continuous "*simple and down to earth*" (COWI, 2019, p. 7) communication, the facilitation team assured trust formation among companies. This is also noticed by the evaluator at the mid-term evaluation: "*The companies experience as a positive thing that the project [team] comes to visit repeatedly and that they meet different persons, [and thus] capacities and competences from the project*." (COWI, 2019, p. 7). However, the trust among companies was found to go through the facilitation team and be dependent on it, rather than being between symbiotic partners directly. The facilitation team was therefore in a bridging-trust position between possible symbiotic partners. Through the facilitation team's efforts of facilitation and coordination of communication between companies, companies got to know each other, got acquainted with their interests and agendas, and created the trust needed to open for collaborations and to share stories, ideas, and new business possibilities. Corporate respondents specified that "*it required much exercise and interaction to be able to open up and do business with a potential competitor*" (Kingo Recycling, 2019) and the facilitation techniques of the facilitation team managed to secure this.

Concerning the communication of project results, this included development of a common communication strategy for Environment^{++} regarding the communication with the press, development of informational materials for relevant actors within the project, dissemination of project results in the press/mass media, and dissemination of knowledge within academia. For the implementation of these activities, face-to-face meetings with symbiotic partners were held in order to develop the news in cooperation, and conferences and meetings with various press and mass media representatives were held to disseminate the results of the project and inspire other companies to engage with IS. A series of (local and national) newspaper articles presenting the new symbiotic linkages emerging and the work done for it and video-material on Environment^{++} were the result of dissemination coordination function.

Communication activities can be perceived as part of building the involved actors' capacity as mentioned by Mortensen and Kørnøv (cf. 2019 #1). Communication and dissemination of results can spread the knowledge on the possibilities existing in the region, can share the information on the potential resource flows, and can inspire other actors in the region and beyond to join symbiotic relationships. Furthermore, these can also attract other companies into the symbiosis and to the region. Such activities can increase the environmental awareness and contribute to the formation of a symbiotic mindset in actors that read the communications. The crucial role of a facilitator within such activities that can build capacity is acknowledged both by empirical study and Mortensen and Kørnøv (cf. 2019 #1).

Coordination. At last, the emergence process through Sustainable Synergies involved project management and coordinative activities. As the project was supported financially by the European Commission, it had a given timeline and established goals and objectives that had to be achieved within a specific timeframe. To assure support for IS emergence, the facilitation team undertook specific coordinative activities. Such a coordination function, according to the facilitation team "*was not included in the formal project description but was an important part of the project facilitation"* (Group interview 1, 2019). It was not only about steering the matchmaking between relevant companies, but also about coordination of the inter-organizational exchange of contacts, coordination with other projects in the region9, and coordination of partners in each symbiosis and across symbioses. Moreover, the facilitation team was supporting the exchange of knowledge across other (indirect) IS initiatives in the region. Those responsible for these initiatives, at the initiative of the facilitation team, met periodically and kept each other informed on achievements and challenges. This assured that companies in the region, participating in both initiatives, were not overloaded and that facilitators did not provide the same services to the same companies. In this way the success of both initiatives could be achieved and the

[9] Sustainable Synergies was one of three projects obtaining financial support from the European Regional Development Fund being implemented in North of Jutland (COWI, 2019)

companies in the region could feel support instead of disturbance from several sides (i.e. initiatives and projects). Another important contribution of the facilitation team was the coordination and steering of the strategic partners in the Environment^{++} initiative. The facilitation team organized meetings, developed agendas, kept partners informed with developments in the Sustainable Synergies project, and made sure the network formed among relevant actors in the city who are perceived as important potential organizational champions and bridging actors for IS emergence.

The university researchers in the presence of DCEA representatives at Aalborg University in their position as project "*operators*" (COWI, 2019) functioned, as described above, as the facilitation team for the emergence process of symbiotic relations. As a facilitation team, DCEA researchers engaged various other actors (from its own organization and beyond) in the IS emergence processes, facilitated knowledge, information, and experience sharing, built relationships across actors and sectors. Moreover, they encouraged the promotion of symbiotic thinking among engaged actors and provided institutional support to companies, while making use of a series of professional and personal skills and capacities. These are presented in the following.

6.4.3 Facilitators' skills and capacities

Various actors can take the role of facilitators. These can be individuals, organizations, or even networks. Researchers, public bodies, and businesses are equally able to play important roles as facilitators (cf. Mortensen & Kørnøv, 2019 #1). Public bodies are mentioned by the IS literature as taking the role of facilitators as these have impartial interests for the society and the region in which they activate. However, in the case of the Sustainable Synergies project, the municipality representatives were not engaged in the emergence of symbiotic linkages. Moreover, the facilitation team had to go through various interactions to get them interested in the project and willing to coordinate across other initiatives in the region.

While the role of a facilitator is acknowledged in the literature (e.g. cf. Mortensen & Kørnøv, 2019; Park et al., 2018), what skills and capacities are needed for facilitating IS emergence remained beyond the study's focus and thus unclear. The empirical evidence from the Sustainable Synergies project permitted identification of a variety of professional and personal skills. From the corporate respondents' perspective, such a facilitative entity must present specific characteristics such as neutrality regarding the actors involved in facilitative processes. This must remain and work independently from the other actors involved in the process of emergence. One of the business organizations respondents specified that entering symbiotic relations and initiating IS "*are not our natural competences and the reason a company is set in the world. That is why somebody from outside our companies should come and manage/facilitate it*" (NB Ventilation, 2019).

Furthermore, "*neutrality and orderliness was a crucial characteristic for a facilitative entity*" (Group interview 1, 2019). These relate to remaining objective and maintaining honesty for all partners involved in symbiotic relationships and the criticality related to the sustainability of symbiotic relations. Such neutrality and objectivity are rooted in the researchers' way of being and working.

Various other professional skills and capacities identified through the group interview 1 (2019) are presented in Table 9, and personal skills and capacities presented in Table 10.

As pictured in Tables 9 & 10 in the following pages, facilitative entities are found to be able to think systemically and apply systems thinking in their work with facilitating IS emergence. Solutions to local issues, generation of innovative ideas, and initiating new symbiotic linkages among partners that are not in previous relationships with each other requires a holistic view and understanding of the issues, possibilities, and the context within which such linkages appear. Being open and taking a systemic approach to developing new symbiotic linkages can provide valuable solutions within the local context. On the other hand, while having a systemic and holistic view maintaining an overview of the process, facilitators need to be simultaneously able to dive deep in the details of each symbiotic linkage and their challenges. The balance between the systemic and the individual bilateral symbiotic linkage has to be assured by facilitators. These mentioned that "*we had to assure a high level of strategic thinking [adding the ability to think and act strategically in the benefit of other symbiotic linkages and the entire project], while also benefiting each symbiotic linkage in part*" (Group interview 1, 2019). Thus, a combination of the strategic thinking and operational action had to be assured.

Furthermore, this strategic and systemic way of thinking and acting needs to be mirrored in the rigorous data collection and analysis (from companies). Applying scientific research–based methods seemed to be the right approach. Generally, being involving in the process as a researcher, with the characteristic approach for knowledge creation and sharing, was perceived as most productive and fair. IS emergence, as specified before in this thesis, requires engagement from different actors with different interests and capacities. A facilitative entity that takes no part of one specific actor, but rather stays neutral and engages equally with all actors, is the most likely to succeed. Therefore, the ability to remain neutral and keep objectivity along the process was a key ability of the facilitation team.

Table 9: Facilitator professional skills and capacities as identified by the facilitation team through self-reflection at the group interview, May 2019 (Group interview 1, 2019). While this is a large list it is still not an exhaustive one. Other skills and capacities might be necessary when facilitating IS emergence in the same context, but at different times or in other contexts.

Professional skills and capacities	
To think systemically and apply systems thinking	• Work holistically and systemically • Apply a systemic view on solution generation, identification of symbiotic linkages and sustainability assessment of these
To think and act strategically, while keeping the focus on developing problem-based and case-specific solutions	• To be able to dive deep in the details of each symbiotic linkage • Understand strategic process in the specific context
To have specific analytical and technical skills	• Understand industrial systems • Keep being neutral throughout the entire facilitation process • Have and apply scientific analytical skills to the facilitation process • Apply scientific methods to relevant data collection, actors' engagement, analysis and assessment of data collected, etc. • Have technical understanding of materials, processes, etc. (e.g. plastics, energy flows) • Look constantly for mastering technical competences • Have a knowledge and understanding of relevant (environmental, industrial, etc.) laws and regulations
To have strong communication skills	• Be good at sharing results • Adjust communication to each specific case of IS • Adjust communication to the organizational levels, functions, role, etc • Be a good listener
To have a coaching role and specific coaching skills	• Provide support to companies and other actors involved in the process • Inspire companies by providing knowledge on new ways of dealing with environmental issues • Be receptive to the needs of the organizations involved in the process • Coaching companies to find out what they want and support them in their decision • Engage relevant actors • Develop and maintain network relations • Be aware of the type of relationships developing (trust based relationships, relationships between companies and the facilitator) • Show respect for each company's values, aims, needs, and possibilities for cooperation
To have specific project manage-ment skills	• Have project management skills • Have a systematic overview of project tasks • Work in teams • Engage other actors and assign tasks to involve these • Share and follow-up tasks • Keep the timeline • Have focus on the aim and be results oriented • Collect and manage data collected throughout the project

Table 10: Facilitator personal skills and capacities as identified by the facilitation team through self-reflection at the group interview, May 2019 (Group interview 1, 2019). While this is a large list it is still not an exhaustive one. Other skills and capacities might be necessary when facilitating IS emergence in the same context, but at different times or in other contexts.

Personal skills and capacities	
To stay open and willing to share knowledge, experience	• Willing to share and disseminate results • Search for objectivity and transparency • Be curious, willing, and open to new learning • Be open and willing to collaborate • Be open to personal relationships created along the process • Be open and willing to get on each company's level • Be willing to collaborate with a variety of organizational profiles
To stay neutral in relation to actors	• Keep independence from other actors, but contribute to the benefit of a symbiotic idea development
To maintain positivity and trust in the success of initiatives	• Believe in the success of the initiative • Maintain high ambitions
To be insistent and persistent	• Have a high level of agency • Be proactive and take initiative • Immediately act and react to issues, possibilities, company contact and request, etc. • Be curious and look for alternative solutions that give sustainable meaning for the actors and process
To remain critical to both one's own and other actors' actions	• Be good at reading/decoding companies' characteristics such as e.g. readiness and correctness • Inspire honesty • Be empathic with and inspire empathy to companies
To have a friendship attitude	• Be receptive to the needs of the organizations involved in the process • Be flexible and able to adjust • Have and inspire trust • Create and keep trustworthiness among actors involved • Have, inspire and maintain motivation and interest in IS • Have, inspire and maintain enthusiasm throughout the entire process

Some specific analytical and technical skills were mentioned during the group interview with the facilitation team (Group interview 1, 2019). As facilitators are in the role of providing various kinds of organizational support, they must possess deep analytical skills with the ability to understand the complexity of regulatory and technical frameworks and the ability to communicate and explain these to companies and other relevant actors; thus, bridging the knowledge between institutional conditions and the actors involved in IS emergence processes. For doing that, strong communication skills are a necessity. These are also necessary when maintaining contact with mass-media and communicating the project results to different (academic, popular, newspaper, etc.) forums. Specific communication skills are a necessity when approaching companies. A specific communication mode and vocabulary is identified by the facilitation team for nearly each organization: "*people are different; thus, organizations are different*" (Group interview 1, 2019). Some companies respond to a virtual contact, for example by email, while other companies had to be contacted by personal and face-to-face contact. With some companies, the communication was straight forward, while with others the facilitation team had to take "*a rather psychological approach*" (Group interview 1, 2019). The communication mode to each organization had to be adjusted depending on organizational values, previous experiences with IS, managers' values, etc.

Working with different organizations and providing support for these, the facilitation team was also in a coaching role and needed specific coaching skills to be able to help organizations to identify their needs and to maintain their motivation and interest in IS. High level of pro-activity, commitment to symbiotic thinking, patience, and trust in success were needed from the side of a facilitation team.

Moreover, specific project management skills were highly necessary. As it was presented above, the facilitation team was not only providing support to organizations involved in the IS emergence process, but this process unfolded through initiatives that facilitation team had to secure the implementation and success of.

Beside the technical, communication, and other professional skills mentioned above, the facilitation team made use of specific personal skills. The team had to be, first and foremost, open and willing to share knowledge and experience, and be willing to collaborate with a variety of organizational profiles. Facilitators had to maintain positivity and trust in the success of initiatives even at the darkest times. Furthermore, these had to be insistent and persistent while at the same time remaining critical to both their own and other actors' actions along the entire process.

The facilitation team had specific profiles characterized by the positivity and friendship attitude towards each other and the actors involved in the project. They showed enthusiasm, interest, honesty, and empathy towards the corporate actors involved in the process. This led to the creation of trustworthiness among business organizations involved in the project and the facilitation team through the process. The facilitation team could inspire other (e.g. municipal and corporate) actors along the process and create long-lasting relationships among these. Insistence, flexibility, ability to adjust along the way, and seeing beyond the present relationships, but across the possibility of future relationships were also perceived as important by the facilitation team for the emergence of symbiotic linkages. Within a highly iterative process, where companies were coming in and out, where these had to be constantly motivated along the entire process, such characteristics of the facilitation team could assure the success of companies' involvement in new symbiotic relationships.

Besides the facilitation team's skills, capacities, and their undertaken tasks and roles within the process leading to the emergence of symbiotic linkages within Sustainable Synergies project, specific contextual characteristics are identified to present initial conditions and antecedents for IS emergence in the area. The following section presents these and their contribution to the initial conceptualization of IS emergence.

6.4.4 Contextual characteristics present initial conditions and antecedents for industrial symbiosis emergence

When presenting the conceptual model for IS emergence, Mortensen and Kørnøv (cf. 2019 #1) mention the initial conditions and antecedents existing within a context. These are the basis from which new symbiotic linkages can emerge. While the authors left these aspects '*out of the scope'* (p. 58) of their study, they encourage researchers to "*fully acknowledge the role of specific (institutional and geographical) context for IS emergence and call for a thorough consideration of the pre-emergence phase and specific contextual conditions*" (p.67). The empirical findings from IS emergence through the Sustainable Synergies project permitted identification of several specific contextual conditions that can function as initial conditions without which the Sustainable Synergies project would not have existed.

First, the existence of the ***Environment***$^{++}$ initiative as the platform accommodating facilitative processes similar to the Sustainable Synergies project was mentioned by the facilitation team as being an important antecedent enabling IS emergence in the Aalborg East port industrial area. The facilitation team expressed that "*without this initiative initially, the Sustainable Synergies project would not have existed*" (Group interview 1, 2019). Environment^{++} also functioned as a platform accommodating the emergence of other symbioses that the Sustainable Synergies project could not accommodate, due to the program limitations and requirements[10]. Involvement of large companies in the process of IS emergence was possible due to presence of the Environment^{++} initiative, as it was an open initiative towards possible emergent symbiotic linkages.

Furthermore, Environment++ offered economic incentives and functioned as a prerequisite to the Sustainable Synergies project. The existence of advantageous funding possibilities, such as Environment^{++} and the Sustainable Synergies project, seemed to have encouraged companies to get interested in the project and in IS, respectively. These provided funding platforms through project activities encouraging companies and other actors to engage in the emergence process, leaving them with minimal economic costs.

The importance and the high engagement of the Port of Aalborg and DCEA and their role in initiating Environment^{++} point at a ***high strategical leadership*** for facilitating IS emergence at the port industrial area of Aalborg East. The presence of actors, such as DCEA representatives, with specific personal and professional competences that played the role of a facilitation team is a necessity. These could activate the knowledge and relationships created, monitor the emergence of IS, develop business models

[10] According to the funding requirements only small and medium enterprises, as defined by the European Union (EU, 2003) were allowed to be involved in the project.

assessing their sustainability, and secure IS operationalization and coordination of the process across the actors and initiatives. By doing this, contexts can be transformed and can get more fruitful for IS emergence, as the capacity existing in such contexts is activated and new knowledge, relational, and collaboration capacity is built.

The presence and engagement of the Port of Aalborg was found to create specific geographical and institutional conditions for the IS to emerge in the port industrial area in Aalborg East. The port has been involved, as presented in section 2.1.2., with IS emergence for a decade, and in the Sustainable Synergies project it took the role of catalyzer for symbiotic business models that are believed to be able to enable sustainable development at the port area. That Port of Aalborg, a smaller port, takes the initiative in facilitating IS emergence and engages actively in emergence processes resembles the involvement of larger ports with IS as presented in section 2.1.1.

Following the recommendations of Mortensen and Kørnøv (cf. 2019 #1) for an exploration of antecedents for IS emergence processes, studying why and how the Port of Aalborg managed to become a catalyst for IS emergence process could help better understand the antecedents for the port's implication with IS. This can then shed light on contextual conditions that can support and lead to IS emergence in port industrial areas. A study was made by Mortensen et al. (cf. 2020 #2) to examine the environmental actions of Port of Aalborg for the last decade in order to understand the antecedents for the current IS emergence process and the origins of the Port of Aalborg's engagement. This study is presented in the next chapter, section 7.1.

The empirical evidence also points at the Business Network 9220 as a platform where knowledge between companies' members is exchanged and new partner relationships are formed. Thus, this kind of network can also function as a platform supporting IS emergence. Thus, an incubation platform can be rooted in many ways of organization.

6.5 CAPACITY BUILDING THROUGH EMERGING INDUSTRIAL SYMBIOSES

Knowledge capacity. The insights in the IS emergence process within the Sustainable Synergies project provide evidence for identification and creation of shared frames of reference regarding IS understanding among the actors involved in the process. The interviews with corporate representatives and the facilitation team, as well as informal discussions with project partners, point at the fact that the actors engaged in the IS emergence process perceived IS as a common-sense business, the correct thing to do that gives meaning for the value creation from waste products and to close the resource cycle among companies: the waste and by-products from one company become resources for another company. For the corporate organizations, participation in Sustainable Synergies is about "*removing (material, energy, water, etc.) waste*" (NB Ventilation, 2019), which can be done in collaboration with other actors.

Synthesizing across the shared conceptualizations of IS within the project, the facilitation team defined IS as "*the sharing of surplus resources, such as materials, energy, by-products, and water between two or more companies. It can include sharing logistical solutions, facilities, and expertise. Businesses can be located close to each other or far apart and they can be in the same business category or widely different*" (Kørnøv et al., 2019). Sharing these conceptualizations of IS encouraged the engagement of companies within facilitative processes enabling IS emergence. Furthermore, through participation within such processes, these companies further developed the initial conceptualization and shared new frames of reference. To exemplify, it can be stated that, even though IS remains an unconceivable concept for companies interviewed, it is now understood and translated to the everyday terminology as "*a special way of collaboration. It is about sustainable business development*" (Brunø Stål, 2019). Building on conceiving IS initially as a common-sense business, after interactions within the IS emergence process, IS is perceived as offering new possibilities to companies, which is something that they could not do before. IS is believed to have the potential to open new markets and business possibilities, providing a platform for innovation that has large potential. IS is perceived as a survival strategy. Sustainable Synergies was thus not only activating the existing actors' knowledge capacity but built it further through developing shared frames of references related to the IS definition. Further processes aiming at IS emergence in the same area can take advantage of these. By these findings, the empirical study enriches the understanding of the IS emergence process, pointing at knowledge capacity building as not only relational as mentioned by Mortensen and Kørnøv (cf. 2019 #1).

Mobilization capacity. For IS to emerge, the presence and implementation of "*a common incubation platform with events supporting the exploration of connection processes, such as networking events and workshops*" (cf. Mortensen & Kørnøv, 2019, #1 p. 66) that can offer interaction spaces, and possibilities for conducting feasibility studies, developing business models, calculating their technical end environmental feasibility, etc. are necessary. Such activities are important for the entire process, while it is most important for the last phase of organizing the symbiotic linkages. The empirical findings point at the facilitation team's function as an incubation platform when conducting the various activities aiming at IS emergence. The facilitation team is found to engage mostly with operational activities, such as providing support to business organizations, developing research activities, developing symbiotic business ideas, calculating sustainability effects, matchmaking, and managing the new emerging relations. The facilitation team was however not engaging with strategic activities within the Sustainable Synergies project as these were out of the scope of the project. Such activities as lobbying politically, and strategic visioning and creating a shared vision among other actors were mostly held within the Environment^{++} initiative, within which two representatives of the facilitation team where active part. The facilitation team, as described in section 6.4.2., made use of various continuous interactions with the companies by using multiple mobilization techniques such as face-to-face meetings, telephone calls, company visits, etc.

Regarding the mobilization capacity built during the Sustainable Synergies project, the knowledge and the experience accumulated by the facilitation team was significant. The researcher group, when entering the project, did not have previous experience with facilitating IS emergence. However, through continuous interactions with companies, the trust created between companies and the facilitation team, the knowledge acquired on IS emergence by doing, and the continuous self-reflection strengthened the facilitation team's skills and capacity. The team took on the role of a champion for coordinating the IS emergence in the Aalborg East port industrial area.

Relational capacity activated and built during the Sustainable Synergies project refers to the actors involved in the facilitation process and the symbiotic relationships emerging as a result of it. The range of actors involved in the IS emergence process were mostly the companies themselves, specific individuals, consultants, researchers, and designers, in addition to the project partners. Public authorities were not involved directly in the project, although they were part of the Environment^{++} initiative. The project did not aim at forming a strategic network (which Environment^{++} might be seen as aiming for) but rather to support the emergence of symbiotic linkages. These in their turn can form an inter-firm network (Wang et al., 2017).

Studying the emergence of symbiotic linkages through Sustainable Synergies points at several symbioses containing two or more synergies as is the case of knowledge symbioses. These can therefore be perceived as small symbiotic sub-networks constituted of several synergies. Moreover, by mapping the symbiotic linkages in relation to their shared actors, a larger symbiotic network is obtained, as pictured in Figure 16.

The Figure 16 envisages an emerging symbiotic network that is shaped by the emergent symbiotic linkages and smaller sub-networks. Considering IS as a complex phenomenon that transcends bilateral flows, the emergence of symbioses through the Sustainable Synergies project takes place often in groups of more than two bilateral linkages. Considering Boons et al.'s (2017) definition of IS can be more adequate. The authors state that "*IS involves a network of at least three actors [i.e. two linkages]… [which] implies a certain level of complexity that transcends a flow that is only between two actors, with the latter considered a precursor to IS at the time that a network is still emerging, or as a component of IS once the network has materialized*" (p.4). In other words, the emergence of bilateral linkages is the precursor of an emerging IS network which also reflects the initial evolution phases proposed by Paquin and Howard-Grenville (2012).

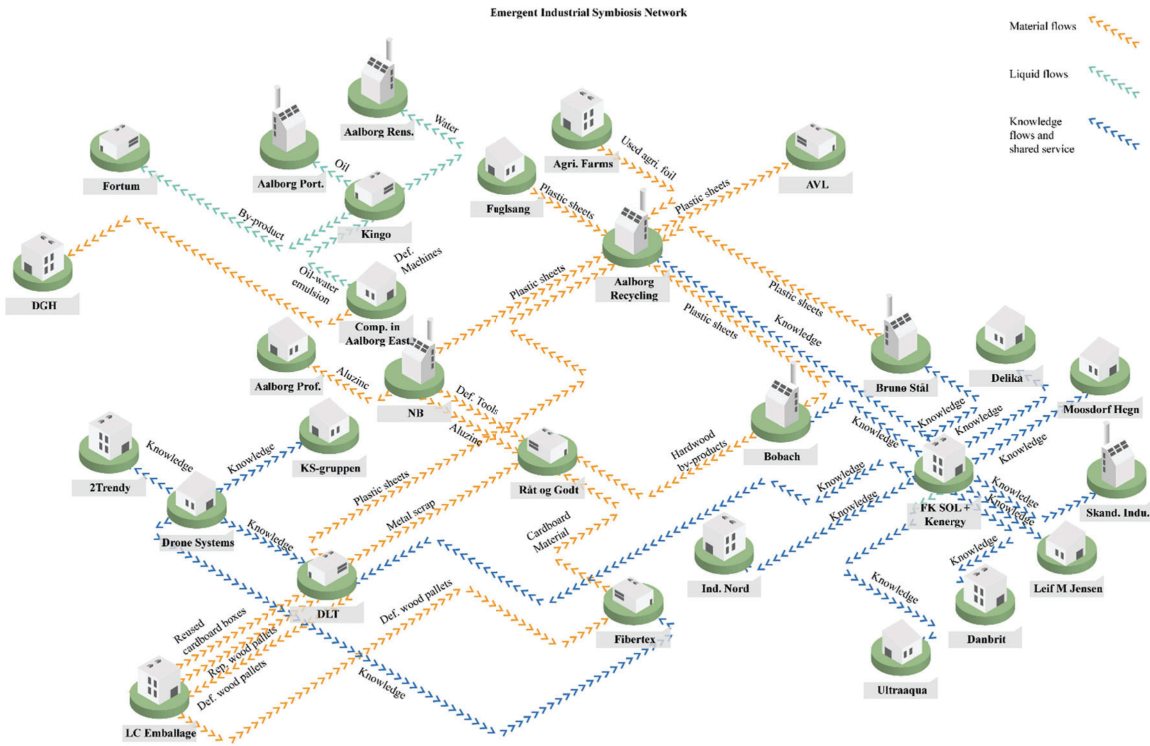

Figure 16: The emerging IS network from Sustainable Synergies project. Developed by author with graphical support of Anton Malmkjær Møller

Acknowledging the IS network emerging from emergent bilateral symbiotic linkages, the empirical study of IS emergence through Sustainable Synergies complement Mortensen and Kørnøv (cf. 2019 #1), who did not consider the initial network formation. Thus, the empirical findings encourage, when studying IS emergence, consideration of both the emergence of bilateral linkages and the initial network formation, as proposed by Boons et al. (2017) and Paquin and Howard-Grenville (2012).

Applying the IS reproduction model developed by Schlüter et al. (cf. 2020 #4) to emergent IS network, important insights on the role of previously emergent symbiotic linkages for the emergence of newer ones are obtained (as presented in Appendix II). At least four symbiotic cases (the symbioses based on the design of recycled materials, the recycling of plastic sheets, the sharing knowledge and mapping services, and the re-use of wooden pallets and cardboard boxes) were found to be dependent (in various degrees) on earlier emerging symbioses. Moreover, the application of the IS reproduction model on the emergent symbioses reflect the relationships between the different dynamics of facilitation and reproduction. While the symbiotic linkages arise through facilitation and as a result of facilitation process, the emergence of the symbiotic network seams to arise from reproduction dynamics. Within this, previous symbiotic linkages bud and brood to clone into other synergies and can, after their settling, lead to colony formations, and thus to an emergent network development. In the cases studied by Schlüter et al. (cf. 2020 #4), most of the synergies arose through self-organization and these budded through using the information and knowledge made available mostly by the symbionts. The reproduction mode of broadcast spawning was found to also lead to cloning and then further development. In the case of the facilitated symbioses emerging through the Sustainable Synergies project, broadcast spawning was not observed. This can be because the knowledge diffusion in the case of symbioses emerging through the Sustainable Synergies project was effectuated by the facilitator (and not the symbionts themselves as characteristic for broadcast spawning). Moreover, knowledge diffusion was targeted towards specific opportunities identified by the facilitator. Thus, the facilitator was the most important impetus that made the information and knowledge available targeting specific companies and mobilized these to enter new symbiotic relations.

Furthermore, it is necessary to specify that the symbiotic linkages emerging through the Sustainable Synergies project are not established ones, as in the case studied by Schlüter et al. (cf. 2020 #4), but still emerging ones. While this is an important difference, it is not perceived as affecting the understanding and application of the model. This is because a consecutive order of emergence between the initial and the follow-on symbioses still exists. Application of the IS reproduction model to the emerging IS network through the Sustainable Synergies project was found to offer insights into how the different dynamics (of facilitation and reproduction) are connected.

First, the facilitation team conducts screenings and identifies possibilities for symbiotic flows. Information on resources available and companies' possibilities, desires, and needs are collected. Then, while the knowledge and capacity of facilitators raises, relational and mobilization capacity is built through continuous interactions, face-to-face meetings, dialogues, etc. A sense of trust and commitment then develops among the facilitation team and the companies involved in the process. The knowledge, relationships, and trust formed between companies and the facilitation team can, when mobilized, lead to the same companies entering new symbioses through reproducing already emerging synergies, budding on, brooding and cloning their symbiotic business idea. One of the facilitation team's members expressed at a group interview described in section 6.1.2. that "*in the start we followed the process step-by-step, while at a later stage, we knew already the companies, we knew their needs and possibilities"* (Group interview 2, 2019) and thus new symbiotic linkages could emerge from the same symbionts.

To conclude, it can be stated that although self-organized and facilitated processes can lead to an (emergent) IS network formation through reproducing existing or emerging synergies, the facilitative dynamic seems to be productive in identifying emergent and reproductive possibilities, as these depend mostly on the facilitator and its built capacity during a facilitation process.

7 INITIAL CONDITIONS FOR INDUSTRIAL SYMBIOSIS EMERGENCE

The IS emergence model presented in section 5.1. points at a “pre-emergence phase,” understood as referring to the (geographical, technological, institutional, etc.) conditions shaping the locality within which IS emerges. These can be, for example, the pool of industries and resources present within a geographical context, the history of collaborations between actors, or the diversity of (organizational and institutional) actors present within the context. Following the call of Mortensen and Kørnøv (cf. 2019 #1) for a better understanding of initial conditions functioning as antecedents for IS emergence when considering the emergence of symbiotic relationships, insights into antecedents could shed light on the factors fostering IS emergence in specific contexts.

The examination of IS emergence through the Sustainable Synergies project finds the emergence process to be ingrained in specific contextual conditions, which build on the facilitative processes and the mobilization of the accumulated (institutional) capacity in the region developed by, among others, the Port of Aalborg’s engagement with IS emergence. Section 2.1.1 presents that ports can engage with IS due to developments organizational, local, and regional levels. Following recommendations of Mortensen and Kørnøv (cf. 2019 #1), it became appropriate to dive into the antecedents that brought the port to take this pro-active role through exploring the developments at the organizational level (i.e. the environmental evolution towards becoming the catalyst for IS emergence in the port industrial area). This evolution is perceived as an antecedent for the port’s actual involvement with IS emergence. Examining this could help better understand the Port of Aalborg’s role during IS emergence through the Sustainable Synergies project. This in turn, can shed light on the capacity that the port has built to further its approach to IS emergence, and can point at future pathways the port can take to support and encourage IS emergence in the region.

Adopting a single case design and collecting data through focus group interviews, individual interviews, observations, and document analysis, Mortensen et al. (cf. 2020 #2) explore the environmental evolution and actions taken by the Port of Aalborg during the last decade (2007–2017) for becoming a catalyst for IS emergence in the port industrial area. The following section presents the study.

While the authors acknowledge the use of a sustainability approach in ports’ relationships with their hinterlands to create “*economically viable, environmentally healthy and socially responsible industrial systems*” (cf. Mortensen et al., 2020, #2 p.

2) in a responsible manner, they began with the environmental actions taken by the Port of Aalborg and seem to leave aside the economic and social aspect within their study. The delimitation and focus on environmental actions were made based on the observation that (larger) ports integrated sustainability into their hinterlands primarily through industrial ecology applications. Such an approach sets focus on the environmental actions with economic and social externalities. Thus, the environmental actions in connection to the Port of Aalborg's evolution, assume that actions also benefit the local/regional economy and society besides benefiting the environment.

Analysis of the antecedents leading the Port of Aalborg towards becoming the catalyst for IS emergence in the Aalborg East port industrial area provides insights into specific factors that can facilitate IS emergence in this area and specific characteristics that this presents for fostering IS emergence. By identifying specific characteristics of the port industrial area, the insights raise awareness of the capacity this area has for facilitating further IS emergence. Elucidating these aspects, the chapter feeds directly into the third research sub-question, as also shown in Figure 17.

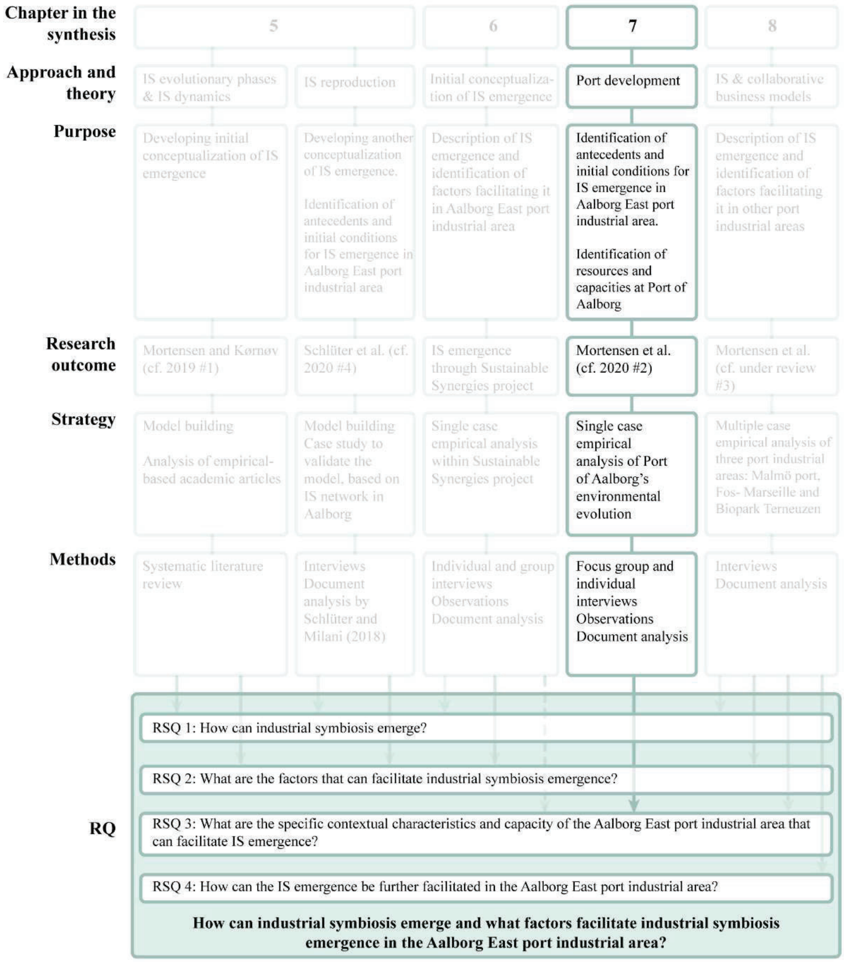

Figure 17: Chapter 7th's contribution to research question (s).

7.1 Port of Aalborg's environmental evolution as antecedents for the industrial symbiosis emergence

This section contains article #2:

Smaller ports' evolution towards catalysing sustainable hinterland development

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ABSTRACT

From simple organizations as gateways for goods and passengers, ports have evolved and transformed into complex organizational systems with multiple functions. Besides providing cargo, logistics, and other kinds of services to its customers, modern ports engage in the development of their hinterlands. Sustainability, evolving from environmental actions over the years, has become the core of many modern ports' approach towards hinterland development and port competitiveness. While the literature is concerned with and presents examples of large ports implementing sustainability initiatives, the literature is scarce on smaller ports. This article addresses this gap by exploring qualitatively the case of the Port of Aalborg, a medium-sized port in Denmark, and its evolution towards using sustainability for port and hinterland development. The research focuses on the actions behind environmental development at the port. Its evolution is mapped and explored using the analytical framework developed based on the (larger) ports' development and their roles. The findings from the Port of Aalborg case exemplify how smaller ports can evolve to drive the sustainable development of their hinterlands and contribute to a better understanding of this kind of port.

KEYWORDS

Ports; sustainable hinterland development; environmental sustainability; port development

1. Introduction

From simple organisations as gateways for goods and passengers (Sakalayen, Chen, and Cahoon 2017), ports have evolved and transformed into complex organisational systems with multiple functions and roles such as (a) providing logistical services (Pettit and Beresford 2009; Robinson 2010); (b) providing customers service functions by being integrated into globalized supply chains (Pettit and Beresford 2009); (c) integrating and catalysing hinterland development (Merk 2013; Hollen, van den Bosch, and Volberda 2015).

A considerable body of literature on port and hinterland development addresses large leading Asian, European, and North American ports such as the ports of Singapore, Shanghai, Rotterdam, Antwerp, Barcelona, New York/New Jersey and Long Beach (Van den Berg and de Langen 2011; Notteboom and Rodrigue 2007; Hollen, van den Bosch, and Volberda 2015; Lee Lam and Notteboom 2014; Schipper, Vreugdenhil, and de Jong 2017; Brooks, Cullinane, and Pallis 2017; Cerceau et al. 2014). These focus on the interplay among ports' development, their role, and the port—hinterland relationship. The evolution of ports' roles and their development is pictured as increasingly integrating hinterland development.

Mainly addressing larger ports' hinterland, the literature defines hinterland generally as the inland-region in (immediate) proximity to the port (Van den Berg and de Langen 2011) and

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connected to the port through the infrastructure permitting the flow of goods (Rodrigue and Notteboom 2010). The hinterland is conceptualised as fluid and dynamic as it depends on the flow of goods coming from either business activities in the immediate port proximity, characterising a captive hinterland, or from farther away through different intermodal infrastructure, characterising a competitive hinterland (Ferrari, Parola, and Gattorna 2011). Furthermore, hinterlands can be integrated within the port region, being thus continuous and direct, or can be scattered around a larger region, being thus disconnected from the port region (Notteboom and Rodrigue 2007). The literature is scarce on smaller ports' development and few are the studies (if any) addressing the smaller ports—hinterland relation. The scarce literature addressing smaller ports' hinterland does not make a different definition of the hinterland concept but merely points to the prevalence of captive hinterlands rather than competitive. This is because smaller ports often lack, e.g. the cargo volumes necessary for development of a well-integrated intermodal infrastructure and depend on their direct hinterlands to a higher degree than larger ports. Smaller ports see it as necessary for them to enter into strong collaborations and integration with their hinterland in order to mutually develop. (OECD and ITF 2009) Studying this mutual interdependence between smaller ports and their hinterland development can create rich insight into possible avenues for smaller ports' development. The present study aims to shed light onto this kind of relationship. For this purpose, a focus on the continuous and direct hinterland in immediate port proximity is set forth, without further distinguishing between the types of hinterlands.

Physical, logistical, and macro-economic perspectives regarding the development of port hinterlands predominate the larger portion of port-hinterland literature (e.g. Shi and Li 2016; Hou and Geerlings 2016). Furthermore, the role of catalysing hinterland development is also increasingly related to sustainability (Hollen, van den Bosch, and Volberda 2015); sustainable hinterland development has become the core of many modern ports' development and competitiveness (Shi and Li 2016; Van den Berg and de Langen 2011). As hubs of resource flows with geographically related clusters of industries and ports' different functions, ports present distinctive characteristics that allow the creation of economically viable, environmentally healthy, and socially responsible industrial ecosystems within their hinterland (Gjerding and Kringelum 2018). Hollen, van den Bosch, and Volberda (2015), for example, describe the case of the Port of Rotterdam, where sustainability is integrated through the application of industrial ecology, development of an industrial ecosystem, and synergistic ties among several industries. Cerceau et al. (2014) present multiple examples of large ports applying industrial symbiosis to achieve sustainability in both port and hinterland development. They conclude that the development of the industrial ecosystem at port perimeters drives the sustainable development of the entire hinterland, and this contributes to port competitiveness.

The current port development models (UNCTAD 1992; Beresford et al. 2006) refer to general evolutionary trends based on the development of these large ports and point to environmental actions evolving over time. How smaller ports come to address sustainability respectively, what role they take, and how they contribute to sustainable hinterland development remains under-researched. Kuznetsov et al. (2015) find that small ports play a major role in local community development through contribution to local employment, assuring regional economic growth, and safeguarding the local environment. Smaller ports are therefore likely to have important roles in terms of sustainable hinterland development. Just as larger ports do, smaller ports focus on infrastructure and logistical development. Due to their higher dependence on their direct hinterlands, their focus, however, tends to be on socio-economic development rather than the logistical inter-modal infrastructures. Their evolution in this respect is relevant to be explored and understood, contributing in this way to the scarce body of literature addressing smaller port development.

This article addresses this gap by exploring the evolution of the Port of Aalborg, a medium-sized port (according to the European Commission's definition on small- and medium-sized companies [EC 2003]) in Denmark, and its transformation into a catalyst for sustainable hinterland development. The Port of Aalborg is used as an illustrative case since, during the last decade (2007–2017), it has implemented multiple environmental actions. Recently, it invested significantly in facilitating the development of industrial ecosystems driving sustainable hinterland development. The research question guiding the present investigation is: What key actions (i.e. activities and decisions) have led the Port of Aalborg to become a catalyst for sustainable hinterland development?

The study is based on the port's perspectives of own actions as a first step towards creating an overview and acknowledgement of its own evolutionary path. Therefore, hinterland perspectives on specific actions are not included. The study focuses on the port's actions and not on their effects, as many actions are started as longer processes than the time frame of this research allows to be tracked. Even though they have been monitored and evaluated, and first evaluation reports and first indices of potential effects have taken shape, a quantitative measurement of these is yet not possible. Only some actions' contributions were possible to be identified and these are included in the paper.

The paper is a contribution to the literature on development of smaller ports and, particularly, how they are a catalyst for sustainable hinterland development, through the presentation of empirical evidence for the actions forming the evolution of smaller ports. Hereby, the paper can inspire modern (smaller) ports on how they can adopt more proactive roles to secure sustainable development in their respective port and its hinterland.

2. Ports' evolution towards sustainability: a literature review

As the literature is scarce on the evolution of smaller ports, the following literature review draws primarily on evolutions among large ports. The aim is to identify environmental actions that shaped the evolution of ports towards catalysing sustainable hinterland development.

2.1. Modern ports' environmental evolution: common historical trends

Recognising that a port's development does not follow a specific model and is not specific to a fixed period of time (Beresford et al. 2006), some common trends closely connected to the changes within the international context (market, logistics, regulatory, environmental, etc.) along the years can, however, be identified.

2.1.1. Ports react to environmental challenges

Until the early 1980s, ports acted as logistical hubs connecting land and sea transport. Traditional activities were cargo loading and discharging, providing storage places and warehouses, and land allocation to (heavy and noisy) industries (Paixão and Marlow 2003; UNCTAD 1992). The low environmental awareness of ports in this period involved 'a reactive response to incidents' (Beresford et al. 2006, 98): reactive attitudes towards environmental concerns around dredging operations and disposal, dust and waste management, noise and air quality relating to the port's users' industrial activities, and port operation (ESPO 2012; Puig et al. 2017; UNCTAD 1992). These activities encouraged the introduction of environmental management systems at the port territories to cope with the companies' internal environmental issues (UNCTAD 1992; Beresford et al. 2006; Mat et al. 2016). Increased global awareness of environmental challenges (such as climate change and resource scarcity) during the 1980s brought the environment onto ports' development agendas.

2.1.2. Ports increasingly integrate with their hinterland and raise their environmental awareness

During the 1990s and beginning of the 2000s, ports became increasingly embedded in the global trends of logistics, information flows, and environmental standards (Pettit and Beresford 2009; Lee and Lee Lam 2016). Ports became commercial, technical, and environmental service centres taking several actions: mediating contact details, providing through-transport and commercial activities for port users, providing technical access to the trade and transport community, and providing the appropriate environmental protection actions (UNCTAD 1992).

With the implementation of numerous port reforms around the world in the late 1990s and early 2000s, ports were encouraged 'to reconnect with their local context and especially rebuild the port-city interface' (Mat et al. 2017, 165). The European Sea Ports Organisation (ESPO) published a Green Guide emphasising 'the significance of good port–city relations and societal integration for the operation of a sustainable port' (2012, 12). Collaborations with local authorities were thus increasingly established (Brooks, Cullinane, and Pallis 2017). Ports offered jobs and economic development possibilities to the city, and the city, in turn, offered basic conditions such as water, telecommunication, housing, etc. necessary for port development (UNCTAD 1992). Initiatives like these collaborations supported and sustained the ports' shift from inward to outward orientation, from a focus on internal matters to a focus on collaboration with their hinterland. In this period, ports were generally adopting a compliance attitude towards an increasing 'regulation of environmental impacts and planning statutes' (Flynn, Lee, and Notteboom 2011, 503). Some ports transformed from service centres offering facilities and passive services into organisations demonstrating active environmental behaviour (Beresford et al. 2006). Common actions among ports concerning environmental development in this period were environmental capacity-building activities, such as internal training programmes on environmental issues; participation in international port organisations, such as The European Sea Ports Organisation (ESPO) and the European Federation of Inland Ports (EFIP); and implementation of environmental management systems and compliance with existing (national) environmental regulations and standards (Beresford et al. 2006; Puig et al. 2017).

2.1.3. Ports have become pro-actively engaged in environmental actions in collaboration with their hinterland

Increased environmental awareness in society has caused an 'increasingly proactive' environmental attitude in the 2010s (Beresford et al. 2006, 98). Modern ports are described as 'agile ports' characterised by a deliberate proactive attitude concerning environmental management strategies, knowledge-informed decisions, and the development of strategic partnerships and alliances with their customers (e.g. Paixão and Marlow 2003). A shift has been made from a focus on compliance and meeting regulations on planning and environment (Lee and Lee Lam 2016, 189) to an increasingly proactive attitude with an 'active outreach to [the] community in [the] planning and decision-making process' (Flynn, Lee, and Notteboom 2011, 503). Actions related to, for example, the establishment of a 'port–city interface,' 'waterfront development,' and an 'active green port policy' (Lee and Lee Lam 2016) have been taken in more and more ports, and these are evidence of the ports' environmental efforts directed towards the local communities. Environmental actions and management systems have become an active instrument in addressing environmental challenges of both port operations and their users' industrial activities. The environmental attitude has been either a 'short-term reaction to a declared urgent situation' or a precaution strategy in response to environmental regulatory changes (Cerceau et al. 2014).

2.1.4. Sustainability becomes the ports' and their hinterland's development strategy

In the last decade, sustainability has entered ports' business strategies (Acciaro et al. 2014; Lu, Shang, and Lin 2016). Socio-economically, ports have been concerned with their (direct and indirect) contribution to the local employment rate, the development of education and knowledge, the 'liveability' of the surrounding area, and the overall relation between the port and the city (Pettit and Beresford 2009; ESPO 2012). Environmentally, these ports have been increasingly concerned with coordination and implementation of industrial ecosystem initiatives and symbiotic relations between the port, industries, and the city through industrial symbiosis, in addition to the initiatives at the port perimeter and activities supporting environmental management systems (Lee and Lee Lam 2016; Cerceau et al. 2014).

2.1.5. Ports enter increasingly pro-active partnerships to achieve port and hinterland sustainability

Industrial ecology initiatives have been widely carried out in collaboration with public bodies, research institutions, and ports through partnership creation (Merk 2013; Cerceau et al. 2014; Spekkink 2015). Generally, modern ports have been given an interesting role within these (Merk 2013; Cerceau et al. 2014; Mat et al. 2016), being described as potent platforms for fostering new synergistic possibilities (Notteboom and Rodrigue 2007; Verhoeven 2010), for collaborative efforts across organizational boundaries, and for being able to contribute to economic and social development within both the private and public sectors. Moreover, they are described as 'laboratories for the implementation of industrial ecology' (Cerceau et al. 2014, 2), and found to play the role of proactive coordinators between private and public actors and sustainable hinterland developers (ESPO 2012; Cerceau et al. 2014; Shi and Li 2016; Van den Berg and de Langen 2011).

Actions like the above reflect a deliberately proactive attitude oriented towards increasingly integrating port and hinterland development (Lee and Lee Lam 2016; Flynn, Lee, and Notteboom 2011; Lee Lam and Notteboom 2014). The relationship with the local community has been positioned high on the ports' environmental priority lists, along with the inputs on environmental issues and challenges (Puig et al. 2017). Ports increasingly have taken a community focus and a managerial approach to stakeholders when addressing related issues (e.g. environmental pollution and port development) and have implemented these in a cooperative way through close cooperation with stakeholders and by creating partnerships (Flynn, Lee, and Notteboom 2011). Developing partnerships is found to be 'critical for ports' sustainable performance in environmental, economic and social contexts' (Sakalayen, Chen, and Cahoon 2017, 943) and to contribute to fulfilling the role of catalysing sustainable hinterland development.

3. Analytical framework for investigating port evolution

The literature review of the historical development of ports, described above, outlined how ports' evolution has been driven by environmental actions towards sustainable hinterland development. Based on the evolutionary trends described in the literature review, we propose the following analytical framework, showed in Figure 1, for investigation of key actions leading ports to become catalysts for sustainable hinterland development:

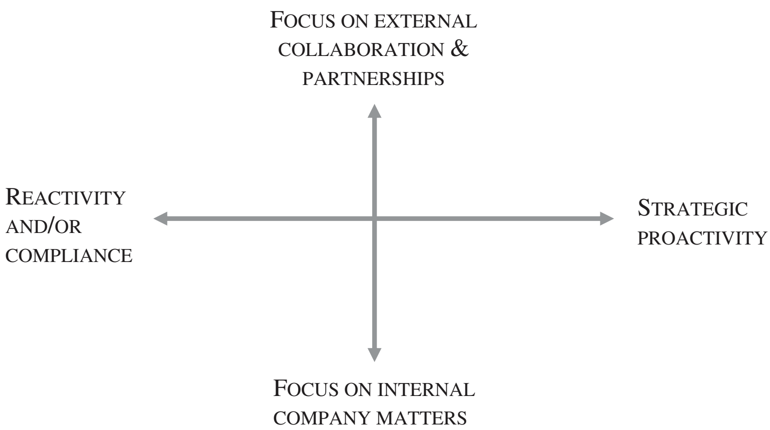

Figure 1. Analytical framework for understanding port development based on two dimensions related to degree of proactiveness and focus on collaboration.

The analytical framework allows the representation of actions in accordance with proactiveness/reactivity and internal/external collaboration/partnerships. By mapping actions this way, a two-dimensional overview of key actions' characteristics for port and hinterland development can be provided. Understanding actions through these two dimensions allows for a more holistic understanding, embracing the complexity and specificity of each action. Furthermore, it allows setting these actions and their possible effects in both micro and macro environmental perspective. Furthermore, mapping actions through the two dimensions provides a possibility for identifying similarities/differences in port development trajectories between (larger) ports and the case study of the Port of Aalborg. Additionally, it can serve as a starting point for discussing development trends in both larger and smaller ports.

To operationalise the framework, the extremes of the dimensions are defined in the following. 'Reactivity and/or compliance' are actions occurring as reactions to external issues, regulations, or desires for better control (Cerceau et al. 2014). They present a short-term vision with a low level of environmental ambition and the aim of reducing and preventing the impacts of an external requirement. 'Strategic proactivity' can be characterised as key actions with a high level of ambition (Beresford et al. 2006) and the aim of creating desired sustainable futures by changing institutional conditions or provoking changes among stakeholders (Cerceau et al. 2014). These actions typically have a long-term perspective. What falls in between these two extremes are the precautionary actions. These can be a response to forecasted changes, technological innovations, and/or the use of port infrastructure. These are considered by Cerceau et al. (2014) as actions with a medium level of environmental ambition and time perspective.

Actions with a 'focus on internal company matters' are oriented towards developing the corporate aspects of the port without collaboration with society. These actions aim at improving business by having an inward-orientation of activities and processes, and they typically have a short-time perspective. Actions with a 'focus on external collaboration & partnerships' reflect a view that port development inherently relates to the society's development. Therefore, these actions are about collaboration, alliances, and partnerships with external actors, and aim at long-lasting relations. Actions that are in the middle of this axis reflect that port development is achieved through dialogue with the port's stakeholders. These actions are related to the port's operation and development activities, as well as, for example, the industries at the port's perimeter (Puig et al. 2017).

The framework is applied on the single case that constitutes the analysis unit of this paper. It is however considered a generic framework that can be also used in multiple case studies of port transformation processes.

4. Methodology

The investigation of ports' actions in their evolution to become catalysts for sustainable hinterland development is done through qualitative research using a case study approach. The use of a single illustrative case study is a well-recognised qualitative research method for both descriptive ('what' types of questions) and/or explanatory research ('how' or 'why' types of questions) (Yin 2006). It is a particularly strong tool when performing an in-depth analysis in a real-life context. This is precisely the aim of this study.

The study was carried out as part of a larger collaboration between Aalborg University and the Port of Aalborg. This comprises a strategic partnership, called Environment^{++}, aiming to catalyse sustainable business development through industrial symbiosis. Special attention has therefore been given to the relation and interaction between researchers and the port management, and what it may mean for the validity and reliability of the study. The approach is in line with the change agency approach described by Kørnøv et al. (2011), in which the relationship is acknowledged and considered in the research approach.

4.1. Data collection methods and analysis

A focus group interview is the core method used for data collection. An in-depth, semi-structured interview is supported by observations and document analysis and is validated through follow-up conversations. The qualitative methods elicit descriptive data and opinions from respondents who have first-hand insights and experience into the process of the port's development.

4.1.1. Observation and document analysis

Participant observation took place during a period of 1.5 years (between 2016 and 2018). The observations were unstructured in order to observe as many details and aspects as possible. The extent of observation varied throughout the period. The authors took part in internal port meetings and meetings between the port and external stakeholders. For some periods, they also observed daily activities. The data were collected both as passive observation and more actively through unstructured and informal conversations with participants. The observations gave significant input for the understanding of participants' actions and their sense-making. Moreover, they contributed to the understanding of the context and contextual conditions for port development. This understanding provided a basis for undertaking the focus group interview.

A preliminary document analysis of written documents related to the Port of Aalborg's development (e.g. the port's strategy and development plan, CSR policy, and sustainability strategy) informed the focus group interview. A post-interview document analysis provided in-depth information on key actions identified by interview respondents and served to validate them.

4.1.2. Focus group interview

The focus group interview aimed at mapping the (environmental) actions within the Port of Aalborg's evolution towards catalysing sustainable hinterland development. For guiding and directing the discussions in the group, the following main question was addressed: What significant actions have been taken by the Port of Aalborg from 2007 to 2017 that have had a focus on environmental and/or sustainability concerns? Moreover, the respondents were asked about the motivation/driver/rationale behind these actions, to get a more in-depth description of each of them.

The participants for the focus group interviews were selected according to the following criteria: (a) respondents must have knowledge and/or competences related to environmental/sustainability concerns, (b) respondents are internal to the organisation and represent different levels of management, (c) respondents know each other, and (d) respondents must have at least five years of employment in the organisation.

The production of knowledge in a focus group depends upon the participants' social interaction (Morgan 1997); therefore, criteria (b) and (c) were chosen with the aim of balancing heterogeneity and homogeneity—allowing for exchange and less risk of unconstructive conflicts between participants. Having participants who know each other also allows them to deepen each other's perspectives because of shared experiences (Bloor et al. 2001).

The respondents from the Port of Aalborg included all relevant stakeholders in the port: the CEO, the resource and development director, the technical and environmental director, the sales and marketing director, and the environmental coordinator.

The focus group was conducted by two researchers: a facilitator and an observer. The role of the facilitator was first and foremost to maintain the focus with help from the interview guide and to encourage the interaction in a non-evaluative environment. The observer's role was to record the focus group, observe, and take notes. The observer also supported facilitation with complementary questions.

The focus group was undertaken as a 'funnel-based interview' (Morgan 1997), balancing a structured approach. The compromise between a more and less structured approach 'makes it possible to hear the participants' own perspectives in the early part of each discussion as well as their responses to the researcher's specific interests in the later part of the discussion' (Morgan 1997, 14). For the mapping of key actions during the focus group interview, a visualisation technique based on the developed framework and inspiration from Larondelle, Frantzeskaki, and Haase (2016), was used. Mapping is a relevant method for identifying the 'hot spots' in an evolutionary process, visualising and communicating them to relevant actors, and for reflecting on their consequences. Inspired by the method used by Larondelle, Frantzeskaki, and Haase (2016), the mapping was carried out as follows:

(1) Identifying the historical key actions: The focus group interview started with an individual brainstorming session on actions the port undertook in the period of 2007–2017 relating to environmental development in order to identify the key actions. Each action was written down on separate cards. Open discussions of each other's cards followed. Then, together, the respondents identified the most important actions and co-created the 'common past' through reconstructing the overall picture of port's environmental evolution.
(2) Mapping the key actions on the diagram visualising the analytical framework. The respondents were introduced to the analytical framework (see Figure 1) and to characteristics of each end of the two axes. The respondents had a few minutes to discuss the ends of the graph and agree on common criteria for placing actions on a specific spot on the graph. Then, together, they analysed each key action, discussed its place on the graph, and agreed on a specific position. Mapping the key actions was subject to complex discussions, negotiations, and agreements among participants.
(3) The final placement of each action was thus the result of all respondents' trade-offs, with no influence from researchers. The respondents were asked to communicate any remarks they might have on positioning the key actions on the graph. For the objectivity of the study, the position of each action was kept as mapped by the respondents and not as perceived by the researchers. However, the researchers, through further observations and discussions with the port staff, realized that actions can move from being perceived as reactive towards being perceived as pro-active as they are further implemented. This fluidity of actions is acknowledged, without being considered for this study. Presenting the (rather static) picture of actions as they were perceived at the time of the key-informant interview has been considered the more appropriate method for an overview of the port's evolutionary path. Further studies of the same case (or comparing multiple cases) could focus on both the fluidity of actions and their effects.

The analysis of the focus group interview was based on the full transcript and observation notes. The transcript was analysed manually through a content analysis exploring key actions and their characteristics.

5. Findings from the Port of Aalborg

5.1. Introduction to Port of Aalborg

Port of Aalborg is a public limited company with Aalborg Municipality as the only shareholder. Located predominantly in the eastern part of the city of Aalborg, Denmark, the port spans an area of 5.5 km of quay and 5,200 ha of industrial areas encompassing its present infrastructure (quays, roads, buildings, halls, etc.). The Port of Aalborg is the fifth largest port in Denmark measured on revenue. However, it is a smaller port, having a turnover of approximately €26 million, 90 employees, and up to 3.1 million tons cargo throughput (Port of Aalborg 2015, 2018), when compared to large ports such as, e.g. Port of Rotterdam, which has a turnover of €710 million, 180,000 employees, and 467.4 million tons cargo throughput (Port of Rotterdam 2018). The Port of Aalborg functions as both a traditional port (with traditional port activities such as logistics and cargo management) and as a landlord port (owning and managing the sites in the port's perimeter). Recently, the port has taken an active role in transforming the existing industrial system at its hinterland into a sustainable ecosystem through collaborative strategies. The Port of Aalborg's continuous and direct hinterland spans more than 150 companies within a wide range of businesses organized in several clusters, such as cement, wind energy, oil, waste management, food companies, ventilation, logistics, etc. The port has taken a series of actions related to sustainable hinterland development in recent years and thus is an interesting case.

5.2. Evolution in actions at Port of Aalborg

The document analysis and the discussions at the focus group interview, followed-up by individual conversations and participant observations, revealed multiple actions regarding environmental and sustainability concerns shaping the port's development from 2007 to 2017, as presented in Table 1.

Table 1. Actions regarding environmental and sustainability concerns shaping the Port of Aalborg's development over 2007–2017 period.

No.	Action	Year
1	Fjord clean-up activities. Attention is given to environmentally friendly sediment clean-up in the Limfjord and dredging activities. Limfjord is the sound that separates the Nørrejyske Island from the rest of Jutland peninsula and on which shores Aalborg is situated. The Port of Aalborg is responsible for the maintenance of the fairway.	2007–2008
2	Infrastructure improvement actions.	
2a	Building a cold store for goods transported through the harbour (more efficient than many small stores).	2007
2b	Enlargement of the container terminal, allowing the movement of a larger quantity of goods.	2007
3	Employment of the first environmental coordinator.	2009
4	Implementing the environmental management system ISO 14001 at the port.	2010
5	Employment of a new environmental coordinator with a more strategic orientation.	2011
6	Establishment of Business Network 9220 in the Aalborg East area with a green ambition.	2011
6a	Promoting industrial symbiosis in Aalborg East through the Business Network 9220 activities.	2012
6b	Approaching port development deliberately through different levels of environmental awareness.	2011–2012
7	Customer oriented environmental services	
7c	Improving the processes of obtaining environmental permits.	2011–2012
7d	Using the environment as a lever in developing relations with new customers.	2011
8	Voluntary environmental improvements	
8a	Establishing energy-saving and optimisation solutions at the port's perimeter, such as LED bulbs, solar panels, and passive buildings.	2012
8b	Improving the waste management on the port's territory.	2013
9	Increasing focus on waste management companies and developing environmental clusters at the port's perimeter.	2012
10	Sustainability strategy development and formulation of decision principles leaning on sustainability.	2014
11	Voluntary environmental improvements	
11a	Introducing efficiency activities such as diesel filters on the port's equipment.	2014
11b	Establishing the railway for goods transportation connecting the port with national/international railway lines.	2015
12	Decision to become a CO2-neutral port.	2014
12a	Increasing the focus on companies working with green energy solutions.	2014
13	Developing a compliance analysis in relation to planning and environmental law.	2015
14	Exploring possibilities within circular economy principles application.	2016
15	Initiating the strategic initiative Environment^{++} with a focus on developing sustainable business models in the port's region through industrial symbiosis.	2016
15a	Initiating an industrial PhD with a focus on strategic stakeholder engagement in Environment^{++}	2016
16	Enlarging the port's environmental management system to incorporate quality and risk assessment systems.	2017
17	Developing the Port Reception Facilities (PRF), such as onshore sewage facilities for ships.	2017
18	Adoption of the quadruple helix approach within the port's activities.	2017
19	Considering environment as a strategic parameter in relation to the port's customers.	2017
20	Developing a voluntary environmental codex for the port's customers.	2017
21	Working with sustainable development goals.	2017
22	Mapping the existing industrial symbiosis in the Aalborg region.	2018
23	Deciding to make Aalborg East the most sustainable part of the city.	2018

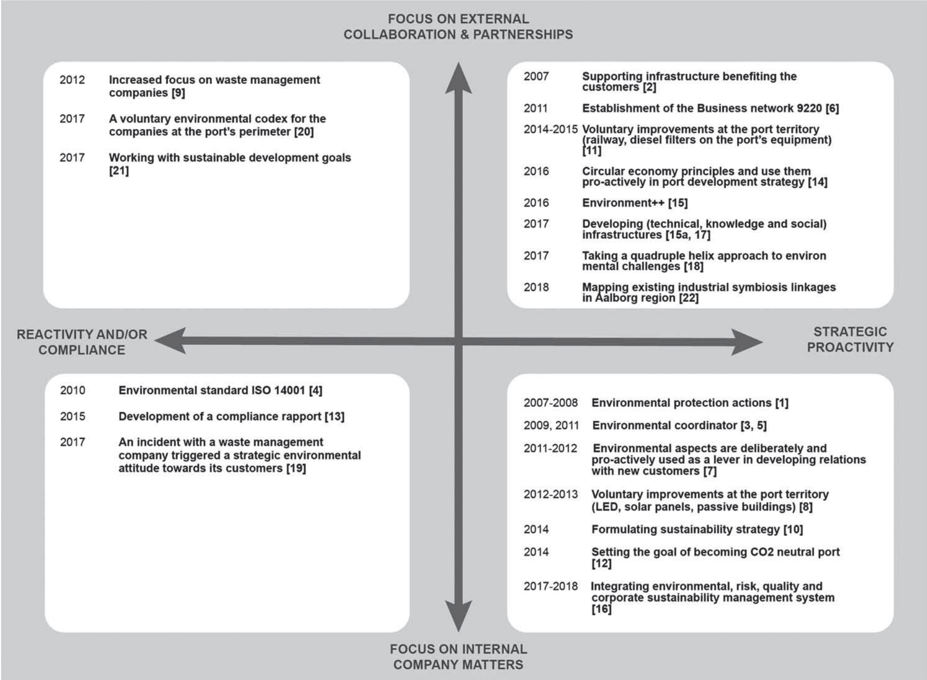

Figure 2. Respondents' mapping of significant actions in relation to the level of reactiveness–proactiveness and the level of collaboration–proactiveness.

The key actions identified were mapped by the respondents and the result is pictured in Figure 2. The figure shows that the Port of Aalborg is concerned with environmental issues and has acted in all quadrants of the analytical framework over time. The actions are presented chronologically in Figure 2.

A closer analysis of the key actions identified by the respondents in the specific quadrants indicates a change in the environmental focus, developing from a narrower (sector-oriented) concept of environment to a broader (holistic) sustainability one. Whereas the more sector-oriented activities (e.g. cleansing of sediment, energy saving) continue as part of the ordinary port operation, wider and more holistic initiatives are being launched for future port and hinterland sustainable development. This observation makes it possible to group the actions in four categories, presented in Figure 3. Actions characterised as being internally oriented and reactive are about standardising internal environmental compliance to contextual developments. Actions characterised as externally oriented and reactive are about improving environmental compliance in the port's hinterland. Actions characterised as internally oriented and proactive are about fostering a sustainable port. Actions characterised as externally oriented and proactive are about co-generating sustainable hinterland development. The relatively longer list of actions on co-generating sustainable hinterland development in the last couple of years seems to indicate the present direction and future tendency of port development. However, the recurring actions in the other quadrants seem to suggest that attention and actions in these categories need to be a continuous focus.

5.2.1. Standardising internal environmental compliance

In the period before 2009, the Port of Aalborg was confronted with initial environmental challenges arising from dredging and sediment clean-up activities in Limfjord (i.e. the sound that separates the Nørrejyske Island from the rest of the Jutland peninsula and on the shores of which Aalborg is

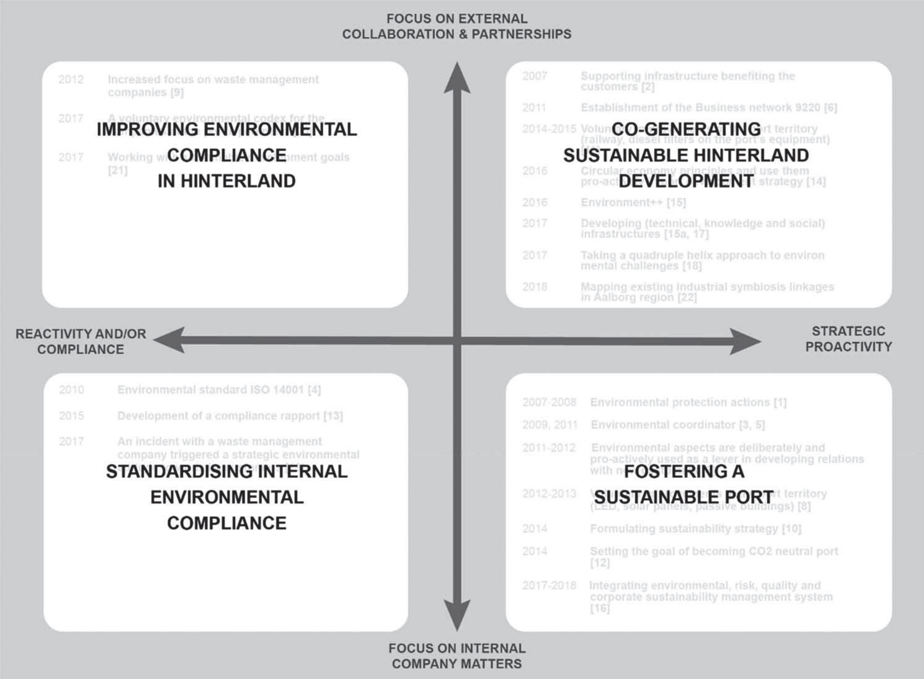

Figure 3. Categorisation of the activities of the Port of Aalborg in the four quadrants.

situated) and energy efficiency challenges related to the storage of goods. The port took a reactive attitude towards establishing supporting infrastructure benefiting the customers [2],[1] using the best available technology at that time, and began to consider environmental protection actions focusing on internal environmental issues [1]. Based on these considerations, interview respondents classified these actions as proactive. These were the first steps towards putting environmental issues on the port's agenda and articulated the port's decision to make the environmental aspect a competitive parameter for port development. The focus on transforming environmental issues from a threat into economic possibilities, and the managerial and leadership support for this, sets the foundation of port transformation through further environmental and sustainability actions.

5.2.2. Fostering a sustainable port

The actions towards sustainability achievement at the port's perimeter were consolidated with the employment of the port's first environmental coordinator [3], who was later replaced with the present one [5]. The employment of an environmental coordinator was perceived as a proactive action at the firm level, as it has generated and contributed to the implementation of a series of further environmental actions that drove organisation and sustainability at the company level. One of the first actions towards organising and standardising the port's environmental compliance was implementation of the environmental standard ISO 14001 [4]. It was first thought of as an instrument to react to environmental challenges at the firm level (hence its position on the graph). Later, this view on ISO 14001 changed, and, based on observations, it is currently used for proactive port development, being integrated with risk- and quality-management systems [16]. Implementation of ISO 14001 has generated continuous focus on environmental improvements, a strategic approach to environmental development, and savings from the environmental improvements that have been implemented. Integrating it further with the risk- and quality-management systems is expected to result in an increase in environmental benefits and a decrease of risk regarding environmental and quality issues.

This work at the company level, and an increasing customer engagement in 2010 and 2011, led to actions towards fostering and co-generating sustainable hinterland development. Establishment of the Business network 9220 [6] is perceived as the first collaborative action proactively catalysing sustainable hinterland development. The experiences from being one of the co-founders of the network fuelled port development towards adopting a more proactive attitude towards environment and sustainability as a whole. The activities of the network were based, among other things, on promoting industrial ecology through developing symbiotic linkages among and in collaboration with different industries in the port hinterland. As a result of this work, the port's commitment to environmental development is structured and port development is approached through the various environmental awareness levels. Furthermore, the establishment of the Business network 9220 has contributed to the establishment of a collaboration platform, improved knowledge capabilities of port and other companies in the hinterland, improved relations between the port and the companies in the network, and the establishment of collaborations among companies regarding waste management. Internally, at the port's level, customer-oriented services such as improvements in the process of obtaining environmental permits were offered and environmental aspects started to be used deliberately and proactively as a lever in developing relations with new customers [7] aiming for sustainability achievement.

The increased environmental awareness and concern with implementing environmental activities led to a series of voluntary technical improvements at the port territory [8]. Energy-saving and optimisation solutions such as LED bulbs, solar panels, and passive buildings were established; the waste management on the port's territory was likewise improved. The focus on waste management increased the focus on waste management companies [9]. These technical improvements increased the port's energy efficiency and savings on energy. The technical improvements at the port allowed for the shaping of the port's experience with energy technology and waste management possibilities that later could be transferred to customers and other companies in the business network and in the port's hinterland.

Furthermore, technical improvements contributed to formulating the port's first sustainability strategy [10] and to encouraging the port in establishing the ambition of becoming a CO_2 neutral port in 2014 [12]. As a result of the port's technical improvements, the negative effect on the climate steadily decreased in the years up to 2017 at which time these improvements contributed to the port reaching a CO_2 neutral state.

Even though it was perceived as a proactive action taken at the company level, the sustainability strategy's implementation was through a series of other technical improvements and environmental actions taken in collaboration with and for the port customers and stakeholders [11]. Efficiency activities such as introducing diesel filters on the port's equipment and the railway for goods transportation, and connecting the port with national/international railway lines, were established. These actions were perceived by respondents as a significant success, as they contributed to the port's image and were a profound example of sustainability in practice in focusing on internal matters (such as creating practical examples of environmental improvements) or in focusing on developing collaborations (such as developing networks and improving the company's relational capacity). They inspired the port to continue with other voluntary technical initiatives. Furthermore, the first sustainability strategy that was formulated encouraged the identification and formulation of decision principles used in the port's overall decision-making process based on the sustainability concept.

Moreover, the formulation and implementation of a sustainability strategy [10] and the development of a compliance report [13] that advised the port to take a more proactive attitude than it had before kick-started an avalanche of ambitions. These are the background for anchoring environmental aspects and sustainability actions deeper into the port's development. One respondent mentioned that they 'dared to think big and set some "crazy" goals' and that this had inspired them to think differently and see different ways of port development.

5.2.3. Co-generating sustainable hinterland development

At the same time, focus has been raised on the port's relation to its hinterland. The concepts of industrial ecology and the circular economy have infiltrated into national and international policies. The Port of Aalborg let itself be inspired by these trends and has started to explore the possibilities of applying circular economy principles and use them proactively in the port development strategy [14]. Environment^{++} [15] is one of the largest initiatives that the port has developed with a focus on actively using environment as a strategic growth parameter. Attention has been given to both contributing to the initiation of new sustainable businesses at the port perimeter and its hinterland, and to actually thinking about and developing a model for encouraging and sustaining these through investments in an industrial PhD project focusing on these aspects. These initiatives were unanimously mapped as proactive, in that respondents agreed that these investments are probably 'the most daring "soft" investments.' Soft investments include and contributed to creating the knowledge infrastructure necessary for developing new models driving sustainable development in the port hinterland. These initiatives are still unfolding and no specific contributions, other than the acquisition of knowledge, relational, and mobilisation capacity are yet identified. It is, however, expected that a multitude of synergies will be established as an outcome of these initiatives and these will lead to a specific amount of CO_2 savings and resource efficiency.

The last couple of years can be characterised by steadily increasing levels of proactiveness and collaboration balanced with reactive actions. In line with this ambition and building up on Environment^{++} actions, the port has taken an increasing role in the sustainable development of its hinterland through the mapping of existing industrial symbiosis linkages in the Aalborg region [22] and contributing to new ones. The port also got involved in developing (technical, knowledge, and social) infrastructures, such as the establishment of new port reception facilities (e.g. onshore sewage facilities for ships) [17], and networking activities. Furthermore, sustainable development goals [21] have been considered in addressing the port's transformation towards fostering environmental actions and catalysing sustainability within its hinterland. The most strategic and collaborative action is perceived to be the adoption of a quadruple helix approach to environmental challenges [18], accentuating the high ambitions of making the Aalborg East area the most sustainable part of the city.

5.2.4. Improving environmental compliance in the hinterland

An incident with a waste management company on the ports' perimeter caused environmental problems with significant economic consequences in 2016. This triggered the port to adopt a strategic environmental attitude towards its customers [19] when organising environmental actions. The company's problem provoked similarly reactive, but more collaborative actions such as developing a voluntary environmental codex [20] addressing the companies at the port's perimeter and within its hinterland. However, it is found that incidents not only provide the background for environmental sustainability improvements but also organisational restructuring and new acquisitions. For example, acquisition of new quay areas in January 2016, where windmills had previously been established, and the focus on implementing the port's sustainability strategy, provided the possibility and background for the long-desired goal of becoming CO_2 neutral [12]. This inspired the port to take further actions in the pursuit of this goal and towards achieving sustainability.

6. Discussion

6.1. Methodological considerations

The paper studied the Port's actions towards catalysing sustainable hinterland development. The research took a reflexive approach on the port's own actions without including the voices of hinterland actors. This was due partly to the need for ports' acknowledgement of their own evolutionary path and partly due to the fact that no effects can yet be quantitatively measured in the hinterland. First indices on actions' effects are taking shape, but it is yet too early in the process to be quantitatively measured. Further monitoring and research on actions, resources used to implement them, and actions' effects on sustainable hinterland development are needed. Including the voices of hinterland actors will bring significant value to further studies.

6.2. Small- and medium-sized ports versus large ports

This study aimed at supplementing the considerable literature on large port development with insight into smaller port development through the case of the Port of Aalborg. It is therefore relevant to discuss similarities and differences between the Port of Aalborg and the literature on large ports.

The evolutionary path of the Port of Aalborg has exemplified a possible development trajectory for smaller ports. This trajectory has proven to follow the developmental path of larger ports, albeit time-delayed.

A shift in (both larger and smaller) ports' roles from marine and cargo handling to being 'a multimodal node in logistical chains' and to a focus on the sustainable development of their inlands-hinterlands poses an increase in the complexity and uncertainty of ports' strategies and actions (Taneja, Ligteringen, and Walker 2012, 84). Just the size of ports may indicate different strengths and weaknesses in this situation: large ports have resources and competences to manage increased complexity and uncertainty, whereas smaller ports may be more agile (Paixão and Marlow 2003) with faster decision-making systems, less bureaucracy, and higher adaptability levels. This study indicates that smaller ports like the Port of Aalborg may have an advantage in being agile and thus have the potential to be frontrunners in sustainability initiatives. In the case of the Port of Aalborg, the agile organisation is combined with a profound bottom-up decision-making model, labelled by one focus group participant as 'professional democracy,' which seems to be a strong approach towards being proactive on contextual developments.

Whereas large ports have considerable resources, e.g. human, land, and financial, and are able to self-support many of their port-development actions, smaller ports depend on resources among actors in their hinterland and contexts to support their ports' development (OECD and ITF 2009). In the case of the Port of Aalborg, these resources are found to be in strong collaboration between the Port and its stakeholders: Aalborg University, Aalborg Municipality, businesses in Aalborg, etc. Smaller port hinterlands set specific requirements and expectations on port development (Merk 2013) to a larger degree than larger ports' hinterland. It is therefore likely that the environmental development actions of smaller ports are dependent upon and influenced by other actors to a higher extent than in larger ports. This might pose considerable challenges to smaller ports' ambitions on sustainability, and smaller ports' actions may thus need to be even more collaborative to create the desired developments. As in the case of the Port of Aalborg, the environmental pro-activeness of the port has increased with the years and so have the collaborative actions. Even though the port is the one taking the environmental initiative and pushes its hinterland development towards sustainability, it cannot do it alone, but rather only in collaboration and in partnerships with hinterland actors. How this is similar or different from larger ports' relationship with their hinterlands needs to be identified through further research. Special focus on the effects of actions is needed in order to identify the exact outcomes of actions.

6.3. Future development as institutionalisation of actions?

The evolution of the Port of Aalborg indicates a stepwise institutionalisation of actions: The reactive and internally oriented actions have been made for several decades and have now been well standardised. The proactive and internally oriented actions also have a long history and have recently been standardised in management systems and strategies. The reactive and externally oriented actions are historically newer and have been systematised in a codex. The proactive and externally oriented actions are still developing in nature and format; however, the Port of Aalborg is eager to institutionalise these actions through partnerships. One interviewee formulated it: '[Otherwise, we cannot] get close enough [to stakeholders and] achieve our vision. The role distribution is missing, in one way or another. You get it through partnerships.' The interviewees are aware that acting in partnerships requires them to 'redefine nearly everything' in terms of self-understanding and port identity, because 'the control is dispersed among actors within the [partnership] network.' The port has a need to reflect on and develop new capacities to navigate within collaborations and partnerships. Questions such as 'what kind of power lies in the different models of [network] governance?' and 'what is our role and what should we do?' are outlined by interviewees as key challenges. The future development of the port depends on how the port will interpret and act on such questions, but also on the port's awareness of its own capacities and openness for building new ones.

In contrast to this institutionalisation of action, the study also indicates a dynamic movement of actions across quadrants. As examples, observations of the Port's activities indicate that the initiative on the UN's Sustainable Development Goals is changing from reactive action to proactive action, as is the initiative on an environmental codex. As another movement, the Port's initiatives on being a CO_2-neutral port and the implementation of the port sustainability strategy seem likely to be increasingly collaborative actions due to the dependency on other actors, especially in the implementation.

7. Conclusion

The in-depth investigation of environmental actions in the evolution of the Port of Aalborg provided detailed insight into the smaller ports' trajectories and possibilities for sustainable development. The study provides empirical insight into (smaller) modern ports' evolution and contributes thus to the literature on port development and ports' roles for sustainable hinterland development.

The analysis of actions leads to identification of four action categories undertaken by the Port of Aalborg in its evolution towards catalysing sustainable hinterland development. Although actions from all categories occur simultaneously throughout the studied decade (2007–2017), the actions on 'co-generating sustainable hinterland development' are dominant, especially in recent years.

In discussing the findings of the case study in relation to developments in large ports, arguments are provided to support the idea that large and smaller ports have different strengths and weaknesses in their capacities to develop and implement sustainable strategies. Smaller ports, it is argued, are more dependent on other societal actors than larger ports. As a consequence, sustainability may be a vital instrument to uphold societal support and to survive as a port. These arguments support the tendencies of increased collaborative and proactive actions in smaller port development, as observed in the Port of Aalborg. In this way, the paper outlines important insight and inspiration for how modern (smaller) ports can adopt more proactive roles in sustainable port and hinterland development.

With the findings on the Port of Aalborg, numerous smaller ports worldwide can now be regarded as potential core actors in local initiatives for promoting a more sustainable society. Further research on other smaller ports is suggested as a means to validate and better understand evolutionary paths and possibilities among smaller ports and to clarify and substantiate the smaller ports' potentials in terms of sustainable hinterland development.

Note

1. The numbers in brackets correspond to the items listed in Figure 2 and Table 1.

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7.2 AALBORG EAST PORT INDUSTRIAL AREA'S CHARACTERISTICS: INITIAL CONDITIONS FOR INDUSTRIAL SYMBIOSIS EMERGENCE

Port of Aalborg's evolution has built its capacity for IS-aiming initiatives. Analyzing the environmental evolution of the Port of Aalborg, as presented by Mortensen et al. (cf. 2020 #2), permits the observation that the port's environmental evolution has brought the port towards deeper engagement with sustainability through the application of IS strategies. Catalyzing industrial symbiosis emergence and development in the port industrial area through Environment^{++} appears rooted in the port's environmental decisions and actions taken through the years, both at the organizational level and in the relation with its hinterland. These appear to be built on the port's various motives and the capacity accumulated over the years through experiences from such activities.

First, experiencing environmental issues that increasingly put pressure on the port's development and that were associated with increased costs, in 2009 the port established an environmental department and made the strategic decision of "*making environment the port's competitive parameter"* (Focus group interview, 2018). Because *"if it only becomes a cost, we will die in competitiveness ... we need to create something more valuable than just a cost"* (Focus group interview, 2018). With this decision, the port moved from being reactive to having a "compliance plus" strategy (Roome, 1992, pp. 18–19). The decision to establish an environmental department marked an increased focus on environment as the port's competitive parameter and started a series of environmental actions, which Cerceau et al. (2014, p. 11) calls "*short-term reactions to a declared urgent situation and the middle-term strategy of precaution in response to environmental challenges*".

The perceived need to increase the port's competitiveness through creating good stories and providing inspiration for other companies in its hinterland through own environmental actions led the Port of Aalborg to engage with implementing energy saving, waste reduction, and management initiatives through the last decade. Such actions seem to have created credibility around other actors in the port hinterland and legitimized the port's role as a catalyst for later IS initiatives. The value of the concrete and visible results was highlighted by the focus group interviewees (Focus group interview, 2018): *"Some of the things, we know are good for something like this, is that we get it out in the open—that there is something to see. We are an engineering company where you can see and fee+l it and show it to other people, so it shows you are in progress."* Having concrete examples to show others demonstrated the port's seriousness and commitment*: "We showed others in the world that we meant this. The solar panels were the symbol of it"* (Focus group interview, 2018). Through these actions, the port got experience with environmental processes, acquired knowledge and information on various (legislative, energy, etc.) aspects, and created new relations with various partners, including researchers at AAU, the municipality, and private companies that provided the technology needed.

Later, in 2017, learning from the experiences with a company going bankrupt at the port's perimeter and leaving its environmental challenges to the port, the port decided to integrate environmental concerns and risks into its business strategy and into the port's relationships with companies at its hinterland: *"It [was] not about that X going bankrupt, but it was about not to be scared [of such incidents] and to want to become more competent [tackling such situations],*" and *"we are getting wiser and stronger. Because we say 'that's what we cannot afford' ... we simply have to arm the system, so that we become immune"* (Focus group interview, 2018). This experience seems to have accentuated the necessity of the port taking more pro-active action towards its own organization and toward sustainable hinterland development.

The acceptance of risk in not showing proactivity with regards to environmental concerns was balanced against the acknowledgement of the business opportunities that could lie in environmental proactivity: "*What would be great is if you can do both: Create [economic] prosperity while benefiting the environment. This is actually the art. Because if it only becomes a cost, we will die in competitiveness ... We shall be able to do this in every aspect—also commercial*" (Focus group interview, 2018).

The port's motivation, rooted in the convergence between economic growth and environmental protection, combined with the acknowledgement of its own role within its hinterland encouraged the port's engagement with circular economy principles. These, as Mortensen et al. (cf. 2020 #2) present, are used actively in port and hinterland development, and the port adopted industrial symbiosis as a strategy for the Aalborg East port industrial area's development and initiated Environment^{++}. The vision is to make the port industrial area in Aalborg East an incubation area for modern and sustainable solutions and business models based on industrial symbiosis (Port of Aalborg, 2019b). With this initiative, the port sought to create sustainable business development, generating new jobs in the area and its surroundings, and to increase the competitiveness of existing companies while increasing the attractiveness of the entire area. Such motivations for adopting industrial symbiosis for both port and hinterland development are in line with the developments in other port areas as presented in section 2.1. and confirms what Cerceau et al. (2014) call a long-term ambition in order to provoke needed change towards regional sustainable development.

The port's geographical, institutional, logistical, and infrastructural resources make the port industrial area a natural habitat for IS-aiming initiatives. Modern ports, as section 2.1. presents, are perceived as fruitful geographical and institutional contexts with capacity for fostering eco-industrial activities and, through this, catalyzing regional sustainable development. The role of ports in transportation networks and value chains, as well as a spatial framework accommodating various types of industries and business organizations, has led industrial ecology research to recognize ports as veritable hot spots for IS emergence (Schiller et al., 2014). Examination of IS emergence process through the Sustainable Synergies project, presented in chapter 6, points to specific geographical and institutional characteristics that function as resources important for IS emergence, making the port industrial area a relevant geographical space and institutional environment. These characteristics are shaped by the specificity of the port area and the interest of the Port of Aalborg in supporting IS.

As *a geographical space,* the Aalborg East port industrial area is the bed for industrial co-location, accommodating a considerable number of diverse organizations from a variety of sectors, as described in the section 2.1.2. The area accommodates more than 200 small-, medium-, and large-sized companies at the Port of Aalborg's perimeter and in its hinterland with close geographical proximity. This co-location of diverse companies forms an agglomeration of diverse industrial activities that can constitute the basis for symbiotic linkage emergence and development. The presence of a concentrated pool of industries at the Aalborg East port industrial area appears to constitute an important pool of (material, knowledge, and liquid) resources that could be uncovered by the facilitation team within the Sustainable Synergies project and could shape the emergence of the symbiotic linkages as described in section 6.3 – 6.5.

The insights from the IS emergence process through the Sustainable Synergies project show that such co-location can be conducive to IS emergence to some extent. Based on the screening for potential results, the facilitative team identified six symbiotic linkages possible among co-located companies, four among geographically dispersed companies and one as a mix of these. Involving companies across geographical borders was necessary as competences and capacities dealing with the potential resources identified at port industrial area were not present or were not sufficient. Thus, despite the various roles of geographical proximity for the symbiotic linkages' initiation, it is not certain that the geographical proximity of organizations clustered at the port industrial area can further facilitate symbiotic connections. This observation is in line with the discussions present in IS literature and disagreements on the extent to which geographical proximity influences IS emergence and development (Jensen et al, 2011).

Interestingly, geographical co-location did not only present benefits for the IS emergence process in port industrial area in Aalborg East. It was observed that the co-location of organizations presupposes past relationships and existence of a collaborative tradition. When collaborative experiences and traditions were positive, the companies involved within Sustainable Synergies were more open to collaborations than when historical experiences consisted of unsuccessful collaborations between potential partners. Thus, geographical proximity can also inhibit the initiation of symbiotic relations.

Nevertheless, the Sustainable Synergies project seems to have benefited to some extent from the existing knowledge sharing traditions and relationships developed among companies. Some companies participating in the Sustainable Synergies project at the port industrial area in Aalborg East seem to have known each other, and some of them already had (business, economic, etc.) relationships with each other. These were members of similar networks and shared interaction platforms where knowledge and experience were shared, and relationships were built. Sharing information, knowledge, and relationships with each other encouraged the creation of a certain degree of trust among organizations (in a few of the emerging symbioses) and among the facilitator and companies (in most of the emerging symbioses), which benefitted the project and IS emergence in the Aalborg East port industrial area. Such benefits confirm the findings in IS literature referring to the externalities of geographical co-location (Chertow et al., 2008).

As *an institutional environment,* the Aalborg East port industrial area rests on the integration of public and private interests, due to the presence and role of the Port of Aalborg in the area (Group interview 2, 2019; Brunø Stål, 2019). As a publicly owned company, the port is a special entity that accommodates both private and public interests. As such, the port has access to various relational resources from both the private and public sectors. The insights from the IS emergence process through the Sustainable Synergies project, as presented in section 6.4., acknowledge the Port of Aalborg's bridging position of opening doors to companies and to authorities, and bridging the communication between these. This 'double' (public-private) identity of the Port of Aalborg makes it act both as a company and as an authority. As such, the port can provide inspiration for other companies and authorities in taking pro-active action regarding IS emergence by entering symbiotic linkages itself, and by initiating IS-aiming initiatives. For example, the Port of Aalborg, through entering symbiotic linkages with other companies in the region, developed experiences with IS (Schlüter & Milani, 2018). Communicating such experiences to other companies could inspire these to enter into symbiotic linkages. Through co-founding the Environment^{++} initiative, the port took the role of an integrator, providing support to other companies for entering IS. This initiative could inspire the municipality to take pro-active action towards more IS emergence in Aalborg. Thus, the port has a specific institutional status that can be beneficial for IS emergence when activated and mobilized.

The second group interview with the facilitation team (Group interview 2, 2019) pointed at the emergence of symbiotic linkages in the port industrial area being dependent on the *logistical possibilities* that the port context presents. Ports are important logistical and infrastructural hubs. The Port of Aalborg's availability of encouraging and supporting infrastructure, such as roads, pipes, quays, cranes, utilities, and facilities, can provide infrastructure opportunities for new activities involving flows of material, which can make the implementation of IS real and motivate actors to get involved. Furthermore, the willingness of the Port of Aalborg to support more infrastructural projects that can lead to IS emergence can be observed in the continuous development projects implemented at the port's territory.

To conclude, it can be stated that the Port of Aalborg has important geographical, institutional, logistical, and infrastructural resources that could facilitate IS emergence. While the institutional resources seem to have mostly supported the implementation of the Environment^{++} initiative, bridging contacts and engaging actors in IS emergence process across sectors, the geographical, logistical, and infrastructural assets have benefited Sustainable Synergies. However, important resources at both the port's perimeter and its hinterland remain underutilized by the Sustainable Synergies project so far and thus are available for further IS emergence.

Related to the further IS emergence in the Aalborg East port industrial area and the Port of Aalborg's engagement with IS emergence, Mortensen et al. (cf. 2020 #2) point at future tendencies and ambitions that the port has. A holistic approach to regional development (with equal focus on the three aspects of sustainability: economic, environmental, and social) is sought within Aalborg East port industrial area and "*more holistic initiatives [are] being launched for future port and hinterland sustainable development*" (p. 10). Among others, taking a quadruple helix approach to managing environmental challenges and port and hinterland development is the one that characterizes the port's future engagement with IS emergence. The following section details the port's future ambitions with IS emergence and development.

The Port of Aalborg has ambitions to increasingly enter partnerships for fostering industrial symbiotic relationships. The port respondents at the focus group interview (2018) made it clear that entering partnerships with various actors for creating regional growth and achieving symbiotic relationships between societal, industrial, and public partners in the future is the port's strategy. The port's new strategy specifies that the port aims to enter partnerships with public and private actors, research and education institutions, and the community for achieving its mission: To make the port and its hinterland an attractive area for business organizations (Port of Aalborg, 2020).

One of the initiatives that lay the foundation for further IS emergence, and within which the Port of Aalborg is an important driver, is *the establishment of a National Green Test Center*. The port, together with a coalition of other actors, including Business Region North Denmark (BRN)[11], Aalborg University, House of Energy, Port

[11] BRN is a collaboration among 11 municipalities in North of Jutland and the Region Nordjylland. The collaboration focuses on creating business development in the region. (BRN, 2019)

of Aalborg, Invest in Aalborg[12], North Denmark Chamber of Commerce [13], and Business Network 9220, lobby for establishment of physical areas as platforms for testing (e.g. energy and water) technologies, where consumers and companies meet within the frameworks of large-scale test projects (Port of Aalborg, 2019c).

The port takes various smaller (symbiotic) initiatives to establish test beds on some of the port's territory. One of the initiatives is the development of a new 110.000m^2 industrial area at the port's territory. The development of this area is perceived by the port as a direct continuation of Environment^{++}. The initiative applies industrial symbiosis as a strategy for sustainable business development. The aim is to "*unfold the idea behind Environment^{++} within a test area, where we can develop optimal frameworks for business organizations to share resources among each other from the start*" (Port of Aalborg, 2019c, p. 16). Industrial symbiosis is thought of as a strategy to attract companies to a new area where they can join other companies in the sharing of resources. In this way, the area will function as a prototype of a symbiotic platform where synergistic flows, digitalization, and collaboration among business organizations and new technologies will provide innovative frameworks for organizations to be established (Port of Aalborg, 2019c, p. 16). Aalborg municipality, Aalborg Utility companies, Aalborg University, and other actors joined the collaboration for making this test area a reality. At the moment, the initiative has encountered institutional challenges and has not developed as desired. However, the experiences, knowledge, and relationships developed during Environment^{++} can be mobilized to address these challenges and support further symbiotic initiatives' development.

Another initiative that deserves to be mentioned is the development of the business concept *Sustainable Industrial Park AALBORG (SipAAL)*. Through launching the SipAAL initiative, the port aims at transforming the port industrial area into an attractive sustainable area for existing and new companies. The ambition is that SipAAL functions as a platform for growth, development, innovation, cluster formation, and green transformation (Port of Aalborg, 2019b). Through this initiative, the port wants to offer companies at its perimeter and hinterland, sustainable frameworks for their development, as well as a unique position, possibility, and active

[12] Invest in Aalborg is a collaboration between NOVI Research Park, Port of Aalborg, Aalborg University and the City of Aalborg to ensure businesses one-point-of-contact and easy access to location and research possibilities, and local authorities. (Invest in Aalborg, 2020)

[13] North Denmark Chamber of Commerce is Aalborg and Northern Denmark region's largest interdisciplinary business network focused on creating collaborations across various areas such as collaboration with the public sector, education and employment, and infrastructure. (Erhverv Nord Danmark, 2019)

support to meet their own organizational aims regarding sustainable development. Through localizing in the industrial park, companies are expected to secure access to knowledge environments at Aalborg University and join an important network of start-up and scale-up companies in the region. The concept develops at the port's initiative and in partnership with Aalborg University, Aalborg municipality, and private actors that support growth and green transformation in Aalborg. (Port of Aalborg, 2019b)

Thus, the Port of Aalborg has significant ambitions and visions regarding future engagement with IS. These, however, can be overshadowed by the challenges that acting in partnerships poses. The actual initiative aiming at fostering IS emergence, Environment^{++}, is characterized by the disagreement and challenges to finding an agreement on a way to continue the partnership and establish a fruitful platform for facilitating IS emergence in the Aalborg East port industrial area. The partners' roles and functions within such collaborative structures as partnerships that can facilitate IS emergence in the port industrial area seem to be unclear. Insights into other IS emergence processes in similar contexts could provide inspiration for both the Port of Aalborg and the other partners in shaping their own roles within Environment^{++}. Mortensen et al. (cf. under review #3) engaged in a study of three processes of IS emergence in distinct port industrial areas and provide insights into various roles that can be fulfilled within IS emergence processes and collaborative structures aiming at IS emergence. Moreover, such insights also present ideas for how such collaborative structures as Environment^{++} could be organized so that they lead to further IS emergence in the Aalborg East port industrial area. The next chapter examines these aspects among others.

8 DEVELOPING A DEEPER UNDERSTANDING OF INDUSTRIAL SYMBIOSIS EMERGENCE

The last chapters conceptualized IS emergence and complemented its understanding with empirical insights from real-time processes in the port industrial area in Aalborg East. The empirical insights confirmed the conceptualization of IS emergence as a dynamic social process where multiple (groups of) actors are engaged in various activities, within which they play different roles at different times in the process. The empirical insights point at the presence of a facilitator as the most important factor enabling IS emergence. Furthermore, it is found that geographical and institutional environments can create specific contextual conditions for fostering IS emergence. The port industrial area in Aalborg East benefits from the existence of co-located companies and the specific character of the Port of Aalborg being a publicly owned company integrating both public and private interests.

Mortensen et al. (cf. 2020 #2) complement the findings regarding IS emergence through the Sustainable Synergies project by examining antecedents of the emergence process. The authors do this by exploring the environmental actions that the Port of Aalborg took before initiating the IS-aiming initiative, Environment^{++}. These actions are perceived as the antecedents and initial conditions supporting the present process. The findings of Mortensen et al. (cf. 2020 #2), and the subsequent discussions in section 7.2, raise awareness and interest in the future role of the Port of Aalborg within IS emergence processes, pointing to partnership creation as a way to facilitate IS emergence.

While the new Port of Aalborg strategy (Port of Aalborg, 2020) provides insights into what the port would like to achieve, empirical insights from the Sustainable Synergies project and the study by Mortensen et al. (cf. 2020 #2) provide important insights on the port's actual roles and actions in IS emergence processes. Based on these, it remains unclear what role can the port (and the other partners) take within collaborative structures that support and encourage IS emergence and how these can be established. Within the Environment^{++} initiative, the port was one of the initiators together with DCEA. The port supported the initiative financially and acted as a bridge between companies, authorities (and other relevant actors), and the facilitation team. The Sustainable Synergies project finishes in June 2020, and the Environment^{++} initiative has an ending date in December 2020 with an intention of prolongation. In addition to these, the port engages in and initiates a few other initiatives that aim at symbiotic relationship formation. This puts the port (and the other actors) in the position of redefining its role with IS emergence. Furthermore, it positions the partners in the Environment^{++} initiative to redefine the initiative's vison and mission, and to reformulate strategies and plans for continuation. How can Environment^{++} continue and how can it absorb the experiences and insights gained from the

Sustainable Synergies project? What form can the collaboration among partners within such collaborative structures take? What roles can the partners play within such collaborative structures facilitating IS emergence? —These are questions addressed in this chapter.

To answer these, inspiration from three cases of IS emergence processes in three European port industrial areas are brought in. Mortensen et al. (cf. under review #3) presents the study, which is included in the following section. The authors consider IS emergence as "*the collective efforts of actors to bridge economic, environmental, and social objectives across private and public sectors*" (p. 1). Perceiving IS emergence as the actors' collective effort across sectors resonates with perceiving IS emergence as a collaborative process (which the authors refer to as "stakeholder processes"), which can result in (new) collaborative business models. Collaborative business models refer to the symbiotic connections resulting from the collaborative process. This conceptualization of the IS emergence process is shown schematically in Figure 18. Mortensen et al. (cf. under review #3) focus on the process that leads to collaborative business models, which are the symbiotic relationships between business companies.

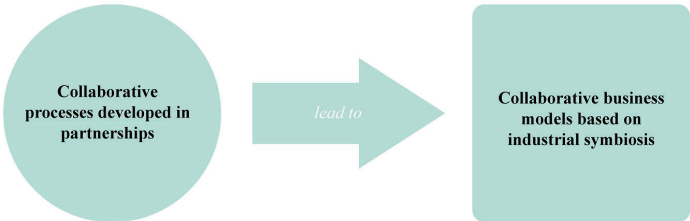

Figure 18: IS emergence as a collaborative process leading to collaborative business models based on symbiotic linkages.

The authors present arguments for how IS can be perceived as a collaborative business model. According to these, industrial symbiosis is a collaborative business model because the value proposition of symbiotic relationships stem from the (material, liquids, and energy) resource flows and benefit more than one actor. The symbiotic flows are assumed to create value for more than just the actors implementing the synergy, as they can benefit the environment and society.

Furthermore, Mortensen et al. (cf. under review #3) acknowledge the fact that the actors[14] through entering collaborative processes (or partnerships), which can lead to

[14] Mortensen et al. (cf. under review #3) refer to public authorities, knowledge institutions, private actors, and consultancies, whereas Mortensen and Kørnøv (cf. 2019 #1) refers to public bodies, research and education institutions, businesses, and consultancy companies. These are

symbiotic relationship emergence, can establish collaborative business models and create another type of IS. This can be based on sharing and/or exchanging information, capacity, and competences, and aim at initiating symbiotic relationships among business companies. This is in line with Spekkink (2016) perceiving IS as a social process based on collaborations that can lead to symbiotic exchanges of resources among companies. Wang et al. (2017) refers to such collaborations as to an IS coordination network. This is the collaboration among actors across sectors who engage in collaborative processes. Such collaborative processes within IS coordinative networks can lead to symbiotic relationships that can develop into an inter-firm IS network Wang et al. (2017). This kind of network is formed by symbiotic relationships based on (material, energy and liquid) resource flows, and which Mortensen et al. (cf. under review #3) refer to as collaborative business models based on IS.

By perceiving IS emergence as a collaborative process and addressing the form of the collaboration structures and partnerships together with the role of Port of Aalborg within these, new insights are added to the understanding of the IS emergence in port industrial areas. The conceptualization of IS emergence, as resulting from the compilation of the findings of Mortensen and Kørnøv (cf. 2019 #1), Schlüter et al. (cf. 2020 #4) and the empirical insights from the Sustainable Synergies project in Aalborg East, is enriched. More exactly, by examining how IS emerges in other port industrial areas (insights obtained through interviews, document analysis, and archival documents), Mortensen et al. (cf. under review #3) shed further light onto the IS emergence process and factors that facilitate it in such areas. Moreover, by applying the knowledge acquired to the case of IS emergence in the Aalborg East port industrial area, insights are obtained into the specific characteristics and capacities that this area has, which can further facilitate IS emergence. Section 8.1. presents the study by Mortensen et al. (cf. under review #3) and section 8.2. connects their findings to the IS emergence in the Aalborg East port industrial area context. Thus, the chapter feeds directly into all research questions as shown in Figure 19.

used interchangeably in this thesis and refer to public authorities, research, education and knowledge institutions, business companies, and consultancy firms.

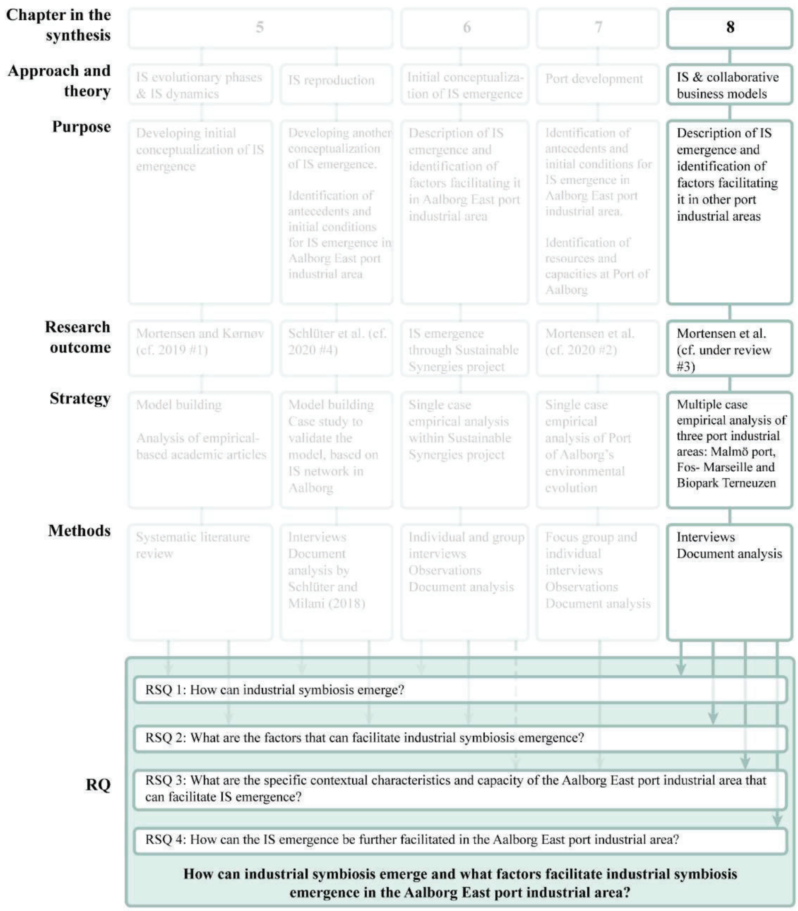

Figure 19: Chapter 8th's contribution to research question (s).

8.1 INDUSTRIAL SYMBIOSIS EMERGENCE IN OTHER PORT INDUSTRIAL AREAS

This section contains article #3:

How Industrial Symbiosis Emerges through Partnerships: Collaborative Business Models in Port Industrial Areas

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HOW INDUSTRIAL SYMBIOSIS EMERGES THROUGH PARTNERSHIPS: COLLABORATIVE BUSINESS MODELS IN PORT INDUSTRIAL AREAS

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Abstract

The present paper explores how industrial symbiosis emergence unfolds within port industrial areas. A multiple case study shows how industrial symbiosis emerges through partnering and stakeholder processes that take the form of collaborative business models. Focusing on actors, platforms for collaboration, and content of stakeholder processes, the study identifies drivers for industrial symbiosis emergence, including the importance of geographical proximity and agglomeration, which identify port industrial areas as natural habitats for industrial symbiosis. A defining characteristic of industrial symbiosis emergence within port industrial areas is the collective effort of actors to bridge economic, environmental, and social objectives across private and public sectors. Finally, the paper suggests that future research on industrial symbiosis and the emergence thereof within port industrial areas may benefit from insights into corporate social responsibility and the emerging field of servitization.

Keywords*: Industrial symbiosis; partnership; platform; sustainability; port industrial areas; collaborative business models.*

Introduction

Industrial symbiosis represents a systemic approach to developing sustainable business models where otherwise unrelated companies and organizations mutually benefit from engaging in non-traditional transactions and make use of underutilized flows of materials, energy, water, capacity, expertize, and assets (Lombardi & Laybourn, 2012a; 2012b; Chertow, 2000). It assumes the form of networked economic activity as co-located companies and organizations, develop collaborative business models based on synergistic relationships, often perceived as industrial symbiosis networks or eco-industrial parks (Zhang et al., 2014). A typical example can be retrieved from the recently uncovered industrial symbiosis network in Aalborg, Denmark (Schlüter & Milani, 2018) where the cement company Aalborg Portland delivers chalk slurry to the Nordjylland power plant, which uses it to the flue gas cleaning and returns it as gypsum to Aalborg Portland.

Industrial symbiosis opens up opportunities for economic, environmental and societal gains. Economically, industrial symbiosis can produce operational savings, increased profitability and economic performance as well as corporate competitive advantage. Environmentally, it can contribute to improved ecological footprint in terms of CO_2 savings, increased resource efficiency and minimizing resource scarcity (Boons, Chertow, Park, Spekkink & Shi, 2017; Verguts et al., 2016; Massard, Jacquat & Zürcher, 2014; Behera, Kim, Lee, Suh & Park, 2012; Bechara & Magrini, 2009). Furthermore, societally, it implies a multitude of benefits such as increased quality of life and social development in terms of job creation and improvement of the quality of jobs, especially regarding physical working conditions (Behera et al., 2012; Gibbs & Deutz, 2007; Mirata, 2004; Cohen-Rosenthal, 2000). In effect, industrial symbiosis creates a mutually beneficial connection between business, sustainability, and society.

The merits of collaborative business models based on industrial symbiosis have made them an important policy target. At the EU level, industrial symbiosis is recognized as a means to implement circular economy (EU Commission, 2011, 2014; Horizon 2020, 2015). In 2012, the European Resource Efficiency Platform (EREP, 2014) named industrial symbiosis as a top priority area with the potential to trigger the transition towards both sustainable business development and sustainable societies. It is increasingly being used as a strategic tool for green (economic) growth, eco-innovation, resource efficiency (Laybourn & Lombardi, 2012), and as a marketing strategy for regional development (Deutz & Gibbs, 2004). Industrial symbiosis as an eco-industrial park concept has been seen as especially important to regional development strategies, as it can "contribute to business diversification and to the emergence of new industries" (Massard et al., 2014, pp. 37).

The networked character of business models in industrial symbiosis implies a broader view on the composition and engagement of stakeholders than is conventionally applied to business modelling. In order to realize the economic potentials of industrial symbiosis, stakeholders must adopt a systemic view on how they can integrate activities and resource flows, thus collaborating on intertwining business models and creating a context in which the potentials of symbiosis are stimulated and can emerge. The context does not appear as an automatic outcome of transactions, but requires deliberate strategic and operational decision-making. As argued by Spekkink (2013, pp. 343), "there should be a network of actors that trust each other and have some level of mutual understanding (relational resources), that have shared definitions of problems and solutions, possibly codified in plans or even strategic visions (knowledge resources), and that among them there are actors with sufficient power and resources to mobilize others for action (mobilization capacity).” This implies that industrial symbiosis emergence takes place within a physical and institutional context where actors form an organizational framework that is conducive to partnering and relies on collaborative stakeholder processes.

Modern ports are important to industrial symbiosis because they can provide exactly the physical and institutional context in question. By “modern” ports, we mean industrial areas at port perimeters that are not only logistic hubs, but also accommodate a large spectrum of industries and organizations. Furthermore, these areas have evolved into both industrial spaces and institutional actors that are important to industrial development at their own local, regional, and national level. Modern ports are increasingly characterized by their ability to bring industrial actors together, stimulate partnering, integrate services, cooperate across organizational boundaries, link urban and regional development, and provide opportunities and incentives for the creation of new business models (Beresford et al., 2004; Verhoeven, 2010; Ghiara, Demoulin & Marini, 2014; Ballot, 2017). The modern port authority spans various organizational roles including being a company in its own right, as well as a regulator of business activities, a landlord for providing physical space for industrial activity, a manager of professional communities, and a systemic coordinator of networked activities (Gjerding & Kringelum, 2018). In the following, we will refer to such modern ports as port industrial areas, which provide the agglomeration effects and mobilization capacities necessary for industrial symbiosis to emerge. Port industrial areas appear increasingly to be incubators for industrial symbiosis, e.g., port authorities providing coordination and financial resources (Mat et al., 2016; Cerceau et al, 2014; Spekkink, 2013).

The study of how industrial symbiosis emergence unfolds within port industrial areas is still in its infancy (Mortensen & Kørnøv, 2019). This is hardly surprising, because industrial symbiosis is still a rare phenomenon. Anticipating that industrial symbiosis will become an important trend for industrial sustainable development, as encouraged by European policy, we argue that the understanding of how industrial symbiosis emerges within port industrial areas can encourage the formation of collaborative business models in such specific contexts. Experiences and lessons from such specific contexts could be transferred to other industrial areas and thus have a direct contribution to business, policy, society and sustainability.

With the present study, we contribute to this understanding by focusing on the role of partnerships in industrial symbiosis emergence. The emergence of industrial symbiosis is understood and described in terms of the “gestation period” (Van de Ven, Polley, Garud & Venkataraman, 1999, pp. 23) and the process that occurs before any bi-lateral synergistic relation is formed (Sun, Spekkink, Cuppen & Korevaar, 2017), i.e., "*the dynamic (social) process, where actors are engaged in processes of building awareness and interest in industrial symbiosis, reaching out to new possible partners through interactions that encourage the exploration of new possible connections, and organising new symbiotic ties*" (Mortensen & Kørnøv, 2019, pp. 58). As industrial symbiosis is a systemic phenomenon, our basic research question is how partnerships for industrial symbiosis emergence unfold in port industrial areas. In order to answer this research question, we pursue the following sub-questions:

- Who are the stakeholders in the partnerships by which industrial symbiosis emerges, and by which roles, interests, and capacities do they contribute to the stakeholder processes involved in the emergence of industrial symbiosis?
- How do modern ports constitute a context for the emergence of industrial symbiosis in terms of inter-organizational arrangements and platforms supporting partnerships?

We pursue these questions by studying three rather different modern ports located in Sweden, France, and the Netherlands. Together, the variety that we find across these ports represent important aspects of how stakeholder processes and institutional arrangements contribute to the emergence of industrial symbiosis. Our findings contribute to the literature on (a) how industrial symbioses are initiated and can be fostered by partnerships and platforming, (b) how partnerships contribute to collaborative business models for sustainability, and (c) how modern ports can provide contexts for partnerships fostering the emergence of industrial symbiosis. In deriving these contributions, we provide a mapping of stakeholder engagement for industrial symbiosis emergence in port industrial areas and contexts in terms of actors, organizing principles, partnership properties, stakeholder processes, and extra-organizational context.

Industrial Symbiosis as Collaborative Business Models

The study of how industrial symbiosis emerges through partnerships that involve various stakeholder processes yields insight into how business models are innovated, especially in the form of collaborative business models. Industrial symbiosis can be classified as business models in several ways. Common to the various classifications is that the value proposition from industrial symbiosis stems from the conversion of waste into useful resources within a synergetic relationship among independent economic actors. The value proposition is of a systemic nature in the sense that more actors benefit than just the focal firm. Araujo, Pintão & Rosa (2011, pp. 564) stress that benefits are achieved by mutual action among companies where "the value created by them becomes greater than the sum of the eventual value created by each one individually," which reflects that value can only be created through collaboration and partnerships (Bocken, Short, Rana, & Evans, 2014). Fraccascia et al. (2016, pp. 85) point to "positive effects for society and environment in addition to the economic value for the firm," thus adding to the idea that sustainable business models are nested within a societal discourse in the sense that the "value proposition reflects a business-society dialogue concerning the balance of economic, ecological, and social needs" (Boons & Lüdeke-Freund, 2013, pp. 13).

The literature on industrial symbiosis does give examples of business models that are not synergetic in an inter-organizational sense. These examples concern internal exchange, i.e., instances where an individual company converts its own waste into new use by using a by-product of one process in another process, or by using a by-product in developing new products (Chertow, 2000; Fraccascia et al., 2016). However, these cases are intra-organizational and we do not perceive them as symbiosis. Consequently, they are excluded from this study. Industrial symbiosis refers, in our view, to collaborative business models based on external exchange, which may occur in various ways. According to Fraccascia et al. (2016), external exchange comprises the cases where a by-product of one company is used (a) as input of another company, (b) to develop new products or services in another company, or (c) to set up a new company for generating new products or services. Araujo et al. (2011) also point to joint provision of services and the sharing of infrastructure, which might include equipment, technology, and office space sharing (Boons et al., 2017), and expertise, knowledge, and information sharing (Lombardi & Laybourn, 2012a). Such collaborative business models based on industrial symbiosis may be characterized by geographical proximity, or it may take place across regional borders (Chertow, 2000; Zhang et al., 2016).

In general, geographical proximity seems to be of crucial importance to the emergence of industrial symbiosis (FORA, 2010). This has to do with the fact that co-location increases the opportunities for new synergistic flows (Park, Park & Park, 2016; Spekkink, 2015; Mannino, Ninka, Turvani & Chertow, 2015; Cutaia et al., 2015; Ashton, 2009). Co-location and clustering of companies and organizations do not only ease the inter-organizational flow of resources due to smaller transportation costs (van Beers, Bossilkov & Lund, 2009), but also increase the probability for new flows, because business opportunities are positively related to the diversity of companies and organizations (Sharib & Halog, 2017; Massard et al., 2014). As argued by Park et al (2016) and van Beers et al (2009), a large diversity within geographical proximity promotes new input-output match opportunities, because "different companies have different needs and different things to offer" (Madsen et al., 2015, pp. 859). Diversity and a large pool of resources also increase the likelihood that new companies and organizations are attracted, and thus contributing to the dynamics of the space in which industrial symbiosis takes place (Ashton, 2009).

The collaborative nature of industrial symbiosis business models represents a challenge to conventional business model theorizing. Even though business models are boundary-spanning activity systems, they are often regarded as firm-centric (Zott, Amit & Massa, 2011). However, the notion of collaborative business models has flourished since 2013, thus providing business model concepts that can assist the understanding of industrial symbiosis. Rohrbeck, Konnertz & Knab (2013, pp. 8) define collaborative business models as a process where "multiple organizations that might differ in type (industry, public research, and non-profit), their position in the value chain (manufacturing, service, etc.), and industry (energy, ITC, etc.) work together to create a value creation system." They add that in "some cases, they will also attempt jointly to create the value capture system." While this definition seems an ample description of industrial symbiosis, it also points to the need for deepening our understanding of how the collaborative business model is coordinated. Discussing this from a business model theoretical point of view presents some difficulty, because the business model concept is ambiguous and multi-faceted, as it is rooted in strategy, entrepreneurship, and innovation research (Foss & Saebi, 2015) and is interpreted differently from various theoretical positions (Gassmann, Frankenberger & Sauer, 2016). However, the business model concept connects a variety of perspectives in a wider scope of strategic management (Ritter & Lettl, 2018), which lends itself to understanding the concept as a formal conceptual representation of how collaboration functions (Massa, Tucci & Afuah, 2017). This approach is the point of departure for the ensuing discussion.

Collaboration on business models must comprise four properties. First, collaboration requires that commitment is established and interests are aligned, and that actions are adjusted across the collaborating parties in order to sustain alignment and promote mutual learning on how operations can be harmonized (Gulati, Wohlgezogen & Zhelyazkov, 2012; Heikkilä & Heikkilä, 2013). Second, collaboration must be driven by intrinsic motivation and caring trust between the collaborators (Miles, Miles & Snow, 2005), to an important extent based on shared values (Breuer & Lüdeke-Freund, 2017) that support alignment and mitigate the detrimental effects of wicked problems (Rittel & Webber, 1973). Third, collaboration must be subjected to governance structures that strike a balance of what is needed in terms of integration and formalization in order to maintain consensus on decision making, while at the same time allowing the potential inclusion of relevant stakeholders that might contribute to the dynamics and development of collaboration (Todeva & Knoke, 2005; Vangen, Hayes & Comforth, 2015). Fourth, collaboration must be open to changes, e.g., in terms of business model innovation and adjustment of the organizational set-up (Malhotra, 2000; Heikkilä & Heikkilä, 2013).

These properties are essential when it comes to addressing how industrial symbiosis emergence unfolds in spaces characterized by geographic proximity. The success of establishing industrial symbiosis is highly dependent on the engagement, participation, and coordination of a multitude of actors (Park et al., 2016; Costa & Ferrão, 2010; van Beers et al, 2009; van Berkel, Fujita, Hashimoto, & Geng, 2009; Heeres, Vermeulen & de Walle, 2004). The set of actors is characterized by very different stakeholders such as private companies, public bodies, knowledge and research institutions, interest organizations, consultancies, and community representatives (Wang, Deutz & Chen, 2017; Sharib & Halog, 2017; Sun et al., 2017), who all hold different aspirations and goals. Consequently, the emergence of industrial symbiosis in a setting of multiple stakeholders necessitates strong management and coordination (van Berkel et al., 2009). Physical and institutional anchors may provide management and coordination (Sun et al., 2017; von Malmborg, 2004). Physical anchors are actors that create opportunities for industrial symbiosis by offering resource flows and providing physical infrastructure. Institutional anchors are actors that influence the context of industrial symbiosis, support capacity building, provide financial support and safety, promote the benefits of industrial symbiosis, and engage other actors in activities. How the anchors drive the organizational set-up of an industrial symbiosis depends on the need for balancing integration and formalization.

It appears that management and coordination of an industrial symbiosis is less troublesome when companies and organizations co-locate. Co-location is conducive to network conditions, where the actors can benefit not only from geographic proximity, but also from social proximity. Social proximity can be understood in terms of embeddedness (Doménech & Davies, 2011; Boons & Howard-Grenville, 2009), i.e., that a multitude of actors enjoy among them short mental distances, trust, and mutual understanding, which leads to the sharing of visions and reflects a common culture of collaboration and cooperation (Heeres et al., 2004; Ashton, 2008; Boons & Howard-Grenville, 2009; Paquin & Howard-Grenville, 2012). In the case of industrial symbiosis, network conditions are seen to facilitate trust-based communication, knowledge sharing, and actors' capacity building (Ashton, 2008; Spekkink, 2013, 2015; Taddeo, Simboli & Morgante, 2012). This reflects that companies and organizations that engage in industrial symbiosis emergence share a concern with resource scarcity, are generally proactive and collaboratively spirited, and willing and committed to support intra- and inter-organizational changes that create synergies (Valentine, 2016; Velenturf, 2016; Wu & Wang, 2016; Paquin, Tilleman & Howard-Grenville, 2014; Panyathanakun, Tantayanon, Tingsabhat, & Charmondusit, 2013; Taddeo et al., 2012; Elabras Veiga & Magrini, 2009; van Beers et al, 2009).

Co-location will, of course, only yield benefits to the extent that the embeddedness of companies and organizations are translated into activities. This is why management and coordination of industrial symbiosis are important. The presence of coordinating and decision-making roles (Sun et al., 2017; von Malmborg, 2004) contribute to breaking down barriers to cooperation by establishing collaborative platforms for fostering individual, intra-, and inter-organizational capacities and the creation of partnerships (Wang et al., 2017; Park et al., 2016; Cutaia et al., 2015).

Ports as Platforms Promoting Partnerships for Industrial Symbiosis Emergence

Ports are found to have significant potential for contributing to sustainable development trough industrial symbiosis (Merk, 2013; Mat et al., 2016; Cerceau et al., 2014). Based on the co-location of industrial activities, the integration of public and private interests at port industrial areas, and the facilitating role of port authorities, modern ports represent a potent context for exploring sustainable collaborative business models (Notteboom & Rodrigue, 2005; Verhoeven, 2010; Gjerding & Kringelum, 2018). The facilitating role reflects that ports are platforms for cross-sectoral cooperation, and that port authorities are required to manage diverse strategic objectives for value creation and sustainability achievement (Kringelum, 2019; Lee & Lam, 2016; Suykens & Van de Voorde, 1998).

Port authorities are often organized as public, government-owned organizations; because of this, their central motivation is based on a self-sustaining rather than a profit-maximizing business logic (de Langen & Haezendonck, 2012). However, as port authorities are facing increasing inter-port competition, they are widening their strategic scope (Parola, Risitano, Ferretti, & Panetti, 2017) to ensure economic viability by assuming a more commercial approach to port development (de Langen & van der Lugt, 2017). At the same time, ports are put under pressure to focus more on environmental and social issues (Schiller, Penn, Druckman, Basson, Royston, 2014; ESPO, 2012; de Langen & van der Lugt, 2006). In effect, ports must balance both public and private objectives (van der Lugt, Dooms & Parola, 2013), which requires them to deviate from the traditional business model of ports that focused on regulatory issues and asset heavy logistics (Carpenter, Lozano, Sammalisto & Astner, 2018; Kringelum, 2017). This creates a new strategic organizational role for ports that is conducive to the emergence of industrial symbiosis and sustainable development. On the one hand, port authorities are increasingly expected to create value by becoming community managers (de Langen, 2004) that aim at solving collective action problems across the port area within both economic and societal dimensions

(Verhoeven, 2010). On the other hand, ports are operating within the spatial constraints of a port perimeter that limits the opportunities to earn rents based on the traditional role of ports as landlords. Furthermore, ports seek land-area enlargement and development of new industrial areas. Therefore, value creation is sensitive to the ability of ports to increase the value obtained from land by attracting and facilitating symbiotic industries (Schiller et al., 2014).

For this reason, ports are increasingly adopting sustainability as a strategic option and turning industrial symbiosis into a viable business case (Merk, 2013; Cerceau et al., 2014); this is done by applying multiple-stakeholder approaches for port industrial area development. Initiatives for creating industrial symbiosis at port industrial areas are widely carried out as collaborative efforts between private companies, public bodies, research institutions, and ports (Merk, 2013; Spekkink, 2013, 2015; ESPO, 2012; Costa & Ferrão, 2010). In these endeavors, ports often assume a management role as proactive facilitators of communication and collaboration between private and public actors across the port-city community, and as economic facilitators that contribute financially to the implementation of environmental initiatives.

Research in sustainability management has recognized that there is a need for applying a systemic business model concept when studying the relationship between economic, societal, and environmental value creation (Lüdeke-Freund, Carroux, Joyce & Massa, 2018), especially due to the interdisciplinary nature of such studies (Schaltegger, Beckmann & Hansen, 2013). This implies that while the development of new technologies is essential for creating sustainable solutions, innovative business models are crucial for the success of these solutions (Yang, Evans, Vladimirova & Rana, 2017). Business modelling for sustainability is multi-dimensional in the sense that it cannot focus only on profit-maximizing value creation for private companies, but must include the regeneration of natural, social, and economic capital across organizational boundaries as well (Schaltegger, Hansen & Lüdeke-Freund, 2016, pp. 6). This requires actors to bridge conflicting interests of short-term profits and long-term sustainability (Patala et al., 2016), which calls for collaboration through which actors are able to create both economic and social value that become mutually reinforcing (Dahan, Doh, Oetzel, & Yaziji, 2010). The ability of ports to bridge conflicting interests, sectorial affiliations, different time horizons, and public and private objectives (van der Lugt, Dooms & Parola, 2013; de Langen & Haezendonck, 2012; de Langen and van der Lugt, 2006) is conducive to multi-dimensional business modelling, thus making port industrial areas a natural habitat for industrial symbiosis emergence.

Analytical Framework of the Present Study

Summing up on the discussion so far, we have arrived at the following insights: In order to understand and explain the phenomenon of industrial symbiosis emergence, we must conceive industrial symbiosis as the outcome of stakeholder processes by which partnerships are established in the form of collaborative business models. Partnerships develop through cooperation that stimulates mutual trust and the alignment of business strategies and cognitions on business opportunities. Partnerships may be planned and orchestrated by actors in the form of brokers, facilitators, and agents of policy deployment, or they may evolve from existing relationships and networks. In most cases, industrial symbiosis rest on the co-location of actors, which is conducive to knowledge-sharing, joint efforts on creating ideas and opportunities, and economization on resource consumption.

The nature of industrial symbiosis depends on how stakeholder processes emerge and evolve. Stakeholder processes may be more or less difficult, depending on the degree of commonality of behavior and interests among stakeholders, and the extent to which interaction among stakeholders is supported by institutional anchoring (Freeman, 1984, Sun et al., 2017). In order for stakeholder processes to evolve and arrive at business relations that are economically viable, the actors involved must have a "meeting point," i.e., some kind of arena or platform where mutual trust and joint activities can develop. In the case of industrial symbiosis, collaborative business models constitute an institutionalization of commonalities that are both the outcome of and the vehicle for stakeholder processes. Institutionalization is supported by agglomeration and mobilization capacities that are frequently found in port industrial areas, where port authorities act proactively in order to bridge or coordinate private and public interests.

Analyzing industrial symbiosis means uncovering phenomena that are highly context-specific. When undertaking comparative study, this may give rise to a "problem of equivalence," i.e., "the difficulty of finding concepts that identify equivalent empirical phenomena in different countries" (Boons et al., 2017, pp. 938). That important qualification is of relevance to the present paper as our study focusses on three different ports, in three different countries, comprising three different contexts of industrial areas. The preceding discussion suggests that the problem of equivalence can be addressed by focusing on the following phenomena:

- *Partnerships*: Which kinds of partnerships are present, what are the rationales of the partnerships, and how do they develop?
- *Actors*: Who are the stakeholders involved, which roles do they assume, and how do they develop joint interests and mutual goals?

- *Context*: How do port industrial areas provide inter-organizational arrangements and coordination that support partnerships and the agency of actors?

The points of interest that we suggest are sufficiently broad to encompass the requirements of comparative analysis suggested by Boons et al. (2017), and furthermore, they do lend themselves to the kind of backward, forward, and counterfactual approaches that have been suggested by Boons, Spekkink & Jiao (2014). The focus is on how contextualized stakeholder processes form industrial symbiosis by institutionalizing partnerships and creating collaborative business models.

Methodology

The study covers a variety of institutional settings by adopting a multiple case study design (Yin, 2009). As industrial symbiosis emergence is a complex social phenomenon, a qualitative approach is applied (Yin, 2009; Flyvbjerg, 2006), based on the assumption that a qualitative approach is particularly well-suited to embrace and uncover the kind of collaborative processes and partnering that pertain to industrial symbiosis emergence. In order to identify relevant information-rich cases, second-order literature on European cases was screened through a process of purposeful sampling (Patton, 2002). The following *criteria for selecting cases* were applied:

- The cases represent a European port industrial area.
- The cases comprise a social process for industrial symbiosis emergence that is currently developing or has been developed, i.e., representing a stage where the process leading to industrial symbiosis emergence can be uncovered.
- There is only one case per country as the aim of the study is to reflect a variety of settings by which a general view on industrial symbiosis emergence can be suggested.

Cases that complied with the selection criteria were listed and the most relevant subsequently contacted, of which three cases were willing to share their experience with industrial symbiosis emergence. These cases were Malmö port industrial area (Sweden), Industrial area of Fos-Marseille under the Plateforme Industrielle et d'Innovation du Caban Tonkin (PIICTO – the industrial platform for innovation of Caban Tonkin) (France), and the industrial area of Biopark Terneuzen within North Sea Port (The Netherlands). Table 1 in the following pages presents an overview of the three cases, which represent diverse approaches to management of industrial symbiosis emergence through establishment of partnerships, even though similarities exist regarding co-location and the diversity of companies and organizations present at the port industrial areas. The industrial symbiosis emergence in Malmö port area is at the beginning stage where initial synergies are explored. In the Fos-Marseille industrial area, the industrial symbiosis emergence process is at its extending phase as several symbioses are created and new synergies are explored. The process at Biopark Terneuzen is at a development stage where several synergies are functioning, and new synergies are being explored. The variety of phases meant that we were able to study experiences of industrial symbiosis emergence at varying temporal distance from their point of inception, where the number of stakeholders across the cases varied from 12 to more than 40.

Table 1: Overview of the three cases studied

Parameters/cases	Malmö Port	Foss-Marseille	Biopark Terneuzen
General overview	The industrial port area is at the heart of the city's energy and waste management. The infrastructure is well developed for logistics, electricity, heat, gas, and wastewater treatment. There are more than 200,000 m2 available land for further development.	The industrial port area accommodates 17 industries. Due to its previous activities, PIICTO is a major hub for energy, chemistry, and material with world-class infrastructure. There are more than 6,000,000 m2 available land for further development.	The industrial port area was initiated in 2007 as part of a larger project—Bio Base Europe—managed by Zeeland Seaport, today the North Sea Port accommodates more than 60 companies in a large variety of industries.
How the industrial area serves as a platform for industrial symbiosis	• Large network of actors across sectors. • Focus on building institutional capacity for symbiosis, operationalized by a Symbiosis Function.	• Large networks of actors across sectors. • Focus on innovation and plug & play opportunities to support industrial and environmental transformation.	• Large networks of actors across sectors and a computer-aided platform. • Focus on identifying opportunities for existing and new collaboration.
How industrial symbiosis emerges	Through a number of EU and government funded projects, aimed at developing collaborative visions that eventually have come to comprise the whole city.	Through a system of working groups, each targeting specific themes, the system fosters projects on synergetic relations and establishment of new firms.	Through industrial park promoters that foster symbiotic linkages, building relational, knowledge, and mobilization capacities among actors.
The rationale of industrial symbiosis	• Focus on increasing long-term collaboration among companies within the port industrial area, including customers and urban actors (e.g. municipality). • Providing test beds for developing a clean-tech city and contributing to sustainable development. • Attracting new companies and organizations.	• Focus on consolidating the existing industrial ecosystem. • Increase the attractiveness of the territory in order to support regional development in terms of new companies and jobs. • Contribute to sustainable development.	
Port Authority involved	The Copenhagen Malmö Port actively assumes responsibility for specific working packages, and engages in coordination of activities, including marketing and environmental affairs.	The Fos-Marseille port is an important stakeholder in the PIICTO association, which comprises the system of working groups. The port manages specific projects when relevant.	The former Zeeland Seaport initiated Biopark Terneuzen and coordinated the process. Today, other actors have been engaged, but the North Sea Port still coordinates main part of the initiative.
Other actors involved	• Malmö municipality • Research and education institutions • Consultancies • Companies within waste management, water treatment, energy etc.	• Eighteen manufacturers • Two local authorities, one consular chamber, and several government services such as ADEME • Union of Chemical Industries • Four competitiveness clusters	• Businesses in the area • Knowledge institutions • Local, provincial, and national authorities • Innovation institutions • Consultancies • A variety of other national entities

Data collection. Data collection took place in three steps. First, secondary data were collected through in-depth desk research in order to create a thorough overview of each case and identify representative interviewees for subsequent semi-structured interviewing. Then, primary data were collected through interviews with a variety of port environmental managers, researchers, and private actors. The purpose of the interviews was to yield primary data, validate secondary data collected and indicate the need for further investigation and data collection. Third, additional secondary data were collected through document analysis, complementing the data collected through interviews and providing deeper insights into the cases. The data collection (both interviews and document analysis) were structured according to the analytical framework. The interviews were conducted by one member of the research team, recorded, and subsequently fully transcribed. Data sources are presented in table 2.

Table 2: Overview on data collection sources.

Case	Data type	Data format	Sources
Malmö Port	Semi-structured interviews with: • Environmental manager, Copenhagen Malmö Port • Climate Strategist at Malmö municipality	Digital sound recordings (length 1 [1:12:38]; length 2: [1:20:36]) Full transcriptions (length 1: 16 pages; length 2: 14 pages)	Environmental manager (2018) Climate Strategist (2018)
	Websites	Archival data	City of Malmö & Malmö Industrial Park (n.d.) City of Malmö (n.d.) Epic 2020 Consortium (2014)
	Online articles		City of Malmö (2018) Fraser (2017) CMP (2012)
Fos-Marseille	Semi-structured interviews with: • General Secretary, Project manager, PIICTO Association • Researcher, Post-doc in industrial ecology in port industrial areas	Digital sound recordings (length [0:41:42]) Full transcriptions (length: 6 pages)	General Secretary & Researcher (2018)
	Websites	Archival data	PIICTO (2018a)
	Informational leaflet		PIICTO (2018b)
	Research paper		Cerceau et al. (2014)
Biopark Terneuzen	Semi-structured interviews with: • Director of Project development and innovation at North Sea Port • Director of one company within industrial symbiosis	Digital sound recordings (length [0:53:06]) Full transcriptions (length: 10 pages)	Director of Project development and innovation & Director of one company (2018)
	Websites	Archival data	Biopark Terneuzen (2018)
	Informational leaflet		Biopark Terneuzen (n.d.a) Biopark Terneuzen (n.d.b)
	Online articles		Flanders Bio-based Valley (2018) Särnblom, L. & Maaskant, A. (Eds.). (2016a) Särnblom, L. & Maaskant, A. (Eds.). (2016b) Särnblom, L. & Maaskant, A. (Eds.). (2017).
	Academic papers		Spekkink (2013; 2015; 2016)

Data analysis. Data analysis was based on a retroductive approach to exploring the mechanisms that affect the empirical phenomenon in question (Bryman, 2012; Reed, 2005). Nvivo11 software was used to manage the transcribed interviews. As the structure of the interviews was guided by our analytical framework, a few initial provisional codes (Miles, Huberman & Saldãna, 2014) were identified deductively á priori to data analysis. Based on the analytical framework, two members of the research team undertook independent first-order coding of all interviews. Data processing was characterized by inductive coding that emerged progressively. The computer-aided qualitative software then enabled the comparison of codes (Saldãna, 2015) through several rounds of discussion among members of the research team with the aim of developing second-order coding. The discussions resulted in a process of cross-case second-order coding in terms of a thematic analysis to identify common themes across the data. The result was a visual mind map that served as organizing principle for the analysis presented in the next section. A subsequent iteration of discussions and revisiting data (Eisenhardt, 1989) resulted in an overall graphic representation of the findings (see figure 1 in the next section). By interchanging independent and joint coding, researcher triangulation was enhanced in order to ensure the validity of the qualitative data analysis.

Findings

The overall findings are summarized in Figure 1. As the figure shows, the partnerships for industrial symbiosis are found to develop with the aim of achieving commercially viable results at strategic and operational levels of industrial symbiosis. Five groups of actors are predominantly participating in collaboration by contributing their specific organizational capacities to the development of partnership. The processes by which partnering develops are characterized by strategic and operational activities that are nested in particular forms of platforms that comprise various networks and associations.

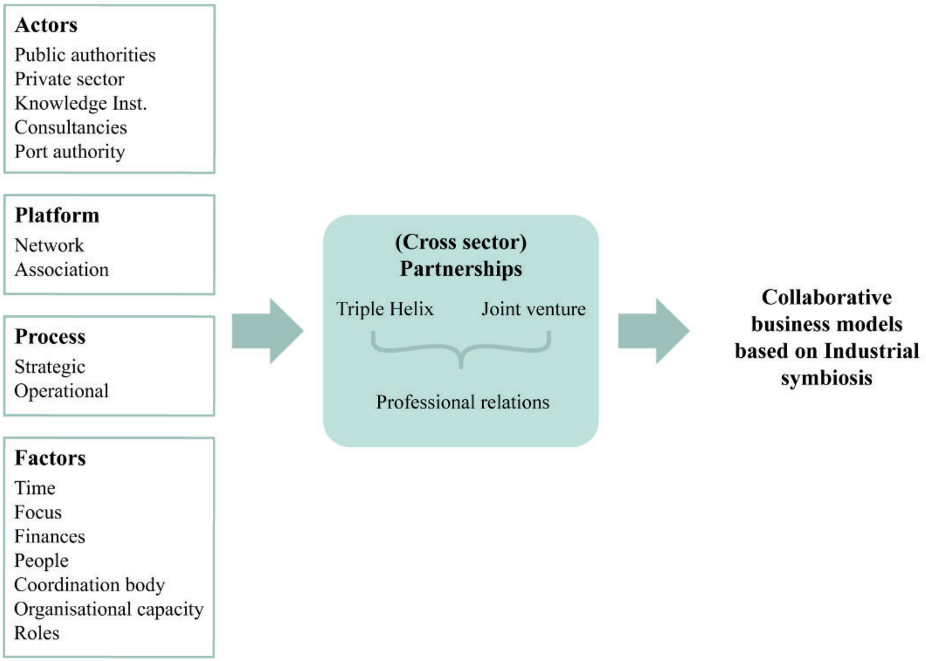

Figure 1: The overall findings

The *partnerships* are dynamic. Often, they evolve from existing relationships, projects, or other types of collaboration, but during the process, new actors, mostly embedded in existing networks, enter, while some of the original actors depart. The partnerships are characterized by a small core of leading actors who, in most cases, remain core figures throughout the process. Storytelling often plays an important role in attracting new actors. The relationships are often informal and based on verbal agreements, common interests, and mutual trust; rather than contractual agreements, the economic and strategic interests of actors are the glue that keep the partnership together. In general, the relationships are of a professional nature, anchored in joint operational and strategic activities, and to an important extent reinforced by project applications, joint mission statements, and mutual letters of intent. The relations that carry partnerships are purely professional and occur mainly in terms of joint venturing (i.e. a joint business enterprise which is distinct from the existing business of the organizations) and Triple Helix formation (i.e. a cross-sector collaboration among private, public and research organizations). Joint ventures mostly occur as business-to-business collaborations aiming at achieving specific operational goals and inter-organizational synergies, while Triple Helix formations are often more characterized by private companies, public bodies, and knowledge institutions pursuing more long-term and strategic goals, albeit sometimes with operational activities as drivers.

The *platforms* supporting partnerships vary from case to case, which was reflected in the fact that the interviewees used the term “platform” ambiguously. While some referred to a technical way of organizing data for industrial symbiosis flows, others referred to the way in which activities supporting partnerships were organized. Two kinds of organizations appeared to function as particularly significant platforms: networks and associations. Networking was extensively used in the case of Malmö, especially in the form of workshops, study visits, breakfast meetings, and conferences with the purpose of aligning visions and interests, and shaping practices of working together. Networking was also formalized in the form of a Symbiosis Function, i.e., an arrangement by which collective decision-making on establishing synergies could be made. The composition of the Symbiosis Function varied from case to case as only the actors engaged in the specific case entered the decision-making body. Networking was also the platform used in creating Biopark Terneuzen, in this case connecting companies within chemical process industry with those in agricultural sector (Spekkink, 2013; 2015), and as in the case of Malmö, a coordination body assures alignment of visions, missions, and strategies. The dominant form in Fos-Marseille was association, where a specific multi-actor association (PIICTO) had been created with the purpose of improving competitiveness and synergies among the participants. The association represents a specific juridical entity focused on a collective approach to industrial symbiosis facilitation carried out by a coordinating body. The association is endowed with a board that makes strategic decisions on area development, while thematic working groups engage in creating synergies at the operational level.

Among the *actors within partnerships*, port authorities play an especially important part in staging industrial symbiosis emergence. This is because port industrial areas are conducive to the emergence of industrial symbiosis. The agglomeration of multiple companies and other organizations, comprising manufacturing, system operators, services, consultancies, and public bodies within a diverse set of industrial activities opens up potential synergies that are supported by port authorities in various ways. In all cases, port authorities dispose of plots of available land for industrial development, and take initiatives for developing, supporting, and coordinating synergies. They provide financial resources and infrastructure for synergistic relations, and facilitate connections between existing or new companies. They link logistic activities and transmissions between the port area and the local, regional, and national/transnational surroundings. They work on attracting new companies or participants in specific projects and participate in knowledge dissemination. Finally, they often bridge public authorities and private companies, because they play dual roles as both part of the public fabric and the private market.

The main role of public authorities, besides functioning as regulators and gatekeepers of legalization of activities, is to provide public and political support to initiatives for industrial symbiosis. The support covers a range of phenomena, including financing projects, coordinating activities, disseminating knowledge, and anchoring industrial symbiosis in different departments of the municipality. The role of knowledge institutions is mainly to support the coordinators of industrial symbiosis in terms of knowledge generation (e.g., feasibility studies), project dissemination, raising awareness of the potentials of industrial symbiosis (e.g., through workshops), and assuming an advisory capacity in relevant activities. In performing these activities, knowledge institutions often facilitate the connection of actors across sectors. Consultancies are especially important as administrators and managers of project timelines, knowledge disseminators, and knowledge generators (e.g., feasibility studies). Finally, the role of private actors depends on whether or not they are core in the activities going on. Depending on the centrality of their position in the partnerships, they may be supporting the coordinator, contributing with knowledge and resources, or taking the lead during the process. In almost any case, they will be applying industrial symbiosis.

In general, the partnerships for industrial symbiosis emergence seem to be driven by the desire to produce economic, environmental, and social impact in the region where industrial symbiosis takes place. Actors share the idea that industrial symbiosis can contribute to competitiveness and cost efficiency, and open up new business opportunities that can be exploited collaboratively. Furthermore, there seems to be a sense of "obligation" to sustainable development that informs the decisions within the partnerships. How these motivations affect partnering depends on the development of relational, knowledge, and mobilization capacities. In all three cases, the ability of actors to combine intra- and inter-organizational structures was important. Furthermore, the actors leading the partnering process were characterized by a proactive approach, strong communication culture, and the ability to align strategic and operational goals within and across organizational boundaries.

Important were, of course, the kind of people that drive the process. In the cases of Fos-Marseille and Biopark Terneuzen, especially people with decision-making power, e.g., CEOs, were important drivers for industrial symbiosis emergence. In Malmö, this was the case to a smaller degree as the composition of people important to an ongoing initiative tended to shift as processes went along. However, keeping a sustained focus on the aims and outcomes of activities were important in all three cases. The need to sustain focus may reflect that industrial symbiosis emergence takes a lot of time. Time appeared to be a key element in the process of partnership formation for identifying potential, achieving strategic alignment, building operational consensus, and establishing actual activities. This also pertains to setting up the overall structure of the platform for the industrial symbiosis emergence (four years in Fos-Marseille, seven years in Malmö, and eleven years for Biopark Terneuzen).

Conclusion

This paper contributes to filling the gap of how industrial symbiosis emergence unfolds within port industrial areas and contributes to sustainable development. It shows that within port industrial areas, industrial symbiosis emerges through collaborative stakeholder processes that take the form of collaborative business models. Port authorities of modern ports exert a range of organizational roles, spanning the traditional port roles of operator and landlord to the modern roles of community manager. facilitator. and coordinator of innovative activities. Our study exemplifies that the diversity of these roles, in combination with the agglomeration effects of developing port industrial areas, make ports a natural habitat for industrial symbiosis. The way that life proceeds in these habitats are characterized by collective efforts that bridge economic, environmental, and social objectives across private and public sectors, in effect blurring the organizational borders between private companies and bodies of public and semi-public activities. The decision-making processes and the activity systems of the actors involved become intertwined by partnerships that lead to sustainable business models.
There are three important lessons to be learned from this paper. First, industrial symbiosis emergence is a cross-sector phenomenon that will take the form of collaborative business models when strategic aspirations and organizational goals are aligned. Alignment requires strong coordinative leadership that is facilitated by one or more platforms for collaboration. It is based on commitment to something more than operational and economic goals, i.e., the desire for contributing to the combination of economic, environmental, and social goals. Second, modern ports are arenas for collaborative efforts across organizational boundaries and sectors that contribute to economic and social development within both the private and public spheres. Industrial symbiosis appears a promising pathway for how port industrial areas can develop in the future, and certainly must invoke the strategic interest of actors involved in creating and developing port industrial areas. Third, the importance of geographical proximity, which is frequently mentioned in the literature, on industrial symbiosis is, in particular, present in port industrial areas in terms of economies of scale and scope, the spanning of sectoral boundaries, and stakeholder processes conducive to industrial symbiosis.

These lessons may give rise to interesting lines of future research. First, while the present study has indicated that actors in industrial symbiosis often are motivated by something more than economic objectives, there has been no reference to the issue of corporate social responsibility. Recent research suggests that corporate social responsibility is increasingly applied to the issue of sustainability with an emphasis on collaborative efforts and the development of shared visions (Hens et al., 2018; Porter & Reischer, 2018). Second, the relationship of partnerships in industrial symbiosis may imply that activities across organizational boundaries will become integrated to an increasingly larger degree. In the case of industrial symbiosis, a larger degree of integration will blur the distinction between manufacturing and servicing activities. In consequence, the emerging scientific field of servitization (Bustinza, Vendrell-Herrero & Baines, 2017; Wang et al., 2015; Droge, Hildebrand & Forcada, 2009) may become a fruitful line of inspiration for future research on industrial symbiosis emergence.

The present study does not pretend to have created a generalized understanding of industrial symbiosis emergence. We have purposefully selected three cases, which can create bias, of course, especially since a process of coding interviews is inevitably based on the researchers' frame of reference. We have tried to mitigate the sources of bias by presenting the case selection process in detail, emphasizing variety in case selection, and applying researcher triangulation to the interpretation of data.

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8.2 Enabling industrial symbiosis emergence in Aalborg East port industrial area

8.2.1 Enriching the understanding of industrial symbiosis emergence

IS emergence in the three studied port industrial areas enrich the understanding of the IS emergence process and the factors that facilitate it. Mortensen and Kørnøv (cf. 2019 #1) find that **five groups of actors**—public authorities; business companies; research, education and knowledge institutions; consultancies; and port authorities—are engaged in multiple interactions that aim at symbiotic relationships. After conducting the systematic literature review of empirical-based studies, the authors find that the actors engaged in such processes take various roles, among which the facilitator role is the most important, through the activities they implement. These can build other actors' capacities, develop a strategic network, and provide an incubation platform, and by these transform the context into a fruitful one for IS emergence.

The empirical insights from the IS emergence process through the Sustainable Synergies project (presented in chapter 6) complement these findings by examining the roles and functions of a facilitator within a facilitative process, as well as their necessary skills and capacities, and set focus on the contextual conditions as antecedents and important factors for IS emergence. Likewise, the existence of an IS-aiming initiative, such as Environment^{++} and the Sustainable Synergies project, was an important condition for the development of a facilitative process in the area.

By studying three cases of the IS emergence process in port industrial areas Mortensen et al. (cf. under review #3) found that IS emergence is a collaborative process engaging a multitude of actors in collective efforts towards creation of collaborative business models based on symbiotic linkages. The paper complements Mortensen and Kørnøv (cf. 2019 #1) and the empirical insights from the Sustainable Synergies project. While all studies find the same actors involved in different ways and degrees in such processes, Mortensen et al. (cf. under review #3) complement these and specifically review the role and capacities of port authorities.

Regarding the actors' roles, Mortensen et al. (cf. under review #3) find that public authorities provided "*public and political support to [various] initiatives for industrial symbiosis…besides functioning as regulators and gatekeepers*" (p. 16). These have functioned as financial supporters for the projects and coordination bodies, communicating and disseminating knowledge, by "*anchoring industrial symbiosis in different departments of the municipality*" (p. 17). While these findings confirm the findings of Mortensen and Kørnøv (cf. 2019 #1) these are different from the context of Aalborg East, where the public bodies did not have a central role in the emergence of symbiotic linkages.

Research, education, and knowledge institutions were found in one case by Mortensen et al. (cf. under review #3) to function as facilitators that could assist in formulating and implementing specific activities within the IS process, attract companies into the network of collaborators for IS emergence, and even raise funds for IS processes at different foundations. The interviewees from Malmö explained that the "*university was involved in preparing the workshops, talking about the content and how it should be… and applying for funding*" (*Interview 2 Malmö, 2018*).

Furthermore, they supported the coordination bodies, through dissemination of knowledge and information of best-case examples and taking the role of a bridging actor, bridging the contacts across actors and sectors. "*[he] had a lot of advising role. From how to work…a networking role also, to connect with different [actors]…and to see what is happening in Sweden, in different places, and how it can connect with our work… Also, he was doing all the disseminations, following each process. He is very good at explaining the IS concept and its benefits. From being to conferences, to being out talking with smaller businesses, he has a very good eye for opportunities, connecting things and …so he is also kind of coordinator in his way without being an official coordinator of the work.*" (*Interview 2 Malmö, 2018*)

In the other cases, Mortensen et al. (cf. under review #3) find that these institutions contributed with knowledge generation in form of feasibility studies, communication, and dissemination of project offers and by acting as "advisory" bodies for the coordination body. While these findings support those of Mortensen and Kørnøv (cf. 2019 #1), they are different from the process of IS emergence in Aalborg East, where the researcher team undertook the facilitation and coordination of the process, supporting companies in various ways, communicating and disseminating the knowledge and results of the project, designing symbiotic business models, developing screening and assessment methods, and keeping continuous contact with companies and other actors involved along the process.

Business companies, depending on their core or peripheric position in the partnership, supported the coordinator and facilitator in the IS emergence processes in other port industrial areas by "*contributing with knowledge and resources, or taking the lead during the process*" (cf. Mortensen et al. under review #3, p. 17). However, in the case of business organizations' involvement in the Sustainable Synergies project, the engagement of these was mostly found to be dependent on their motivation, interest, management's team, and organizational values and norms. Only after these showed themselves interested in the project and were motivated to join a symbiotic relationship, were formal partnership agreements signed. Until then, they had a stand-by place in the partnership, i.e. they were considered as companies with possible potential.

Synthesizing across the insights from the four port industrial areas studied, it is observed that the functions of various actors not only differ in nature, but also in degree of involvement. Public bodies in some cases were coordinators of IS emergence processes while in another case, they were sparsely involved. Researchers, while being a supportive actor for a coordination/facilitation body in some cases, in the other cases were the facilitators who, as in the case of IS emergence in Aalborg East port industrial area, took on functions that in other contexts are undertaken by various actors.

The study by Mortensen et al. (cf. under review #3) raised focus on the role of port authorities, complementing the findings from the study of the IS emergence process through the Sustainable Synergies project and by Mortensen et al. (cf. 2020 #2). While the last studies present the Port of Aalborg as co-founder of the IS-aiming initiative Environment^{++}, providing financial support for it and supporting the facilitation team by bridging the contacts between it and companies, by communicating project offers to companies, and by lobbying the initiative at political level, Mortensen et al. (cf. under review #3) find that port authorities engage actively in collaborative processes for IS emergence, and:

"*dispose of plots of available land for industrial development, and take initiatives for developing, supporting, and coordinating synergies. They provide financial resources and infrastructure for synergistic relations and facilitate connections between existing or new companies. They link logistic activities and transmissions between the port area and the local, regional, and national/transnational surroundings. They work on attracting new companies or participants in specific projects and participate in knowledge dissemination. Finally, they often bridge public authorities and private companies, because they play dual roles as both part of the public fabric and the private market.*" (p.16)

Mortensen et al. (cf. under review #3) did not only complement the findings of Mortensen and Kørnøv (cf. 2019 #1) and from the Sustainable Synergies project regarding the roles of various actors within collaborative processes of IS emergence, but also provide important knowledge on **activities** that such actors can organize and get involved in.

No one single way of organizing activities fostering actors' interaction is found across the cases and the systematic study of case-based literature (cf. Mortensen & Kørnøv, 2019 #1). Such activities are organized to address and respond to both the actors' needs and interests and those of the IS emergence process. Mortensen and Kørnøv (cf. 2019 #1) refer to three groups of interactions that trigger IS emergence and respond to the different actors' needs: a) interactions that build awareness and interest in IS benefits, b) interactions that facilitate reaching out to other possible actors and exploration of possible connections, and c) interactions that explore various ways of organizing new symbiotic connections. Furthermore, the authors identify activities, the most relevant of which are educational trainings and seminars, conferences, company and site visits, policy tours, and synergy forums, and used mobilization techniques for actors' interaction. Mortensen et al. (cf. under review #3) complement these by pointing at continuous meetings on different occasions, e.g. site visits, breakfast meetings, business lunches, resource workshops, matchmaking seminars, and boot camps as relevant interactions. IS literature presents other examples of such activities as both part of a formal facilitative process and an informal or self-organized one (Mirata, 2005; Spekkink, 2015) permeating the observation that interactions during the IS emergence process are much more diverse than thought initially. The same observation can be made when analyzing the IS emergence process in the Aalborg East port industrial area through the Sustainable Synergies project. As presented in section 6.4., the IS emergence process through Sustainable Synergies project included interactions aiming at identifying potential resources, matchmaking specific companies, and coordinating initiatives, among other interactions.

Furthermore, the findings from the IS emergence process in the Aalborg East port industrial area stays in contrast to the multi-stakeholder processes described by the Mortensen et al. (cf. under review #3) and IS literature based on approaches of IS programs around the world (Park et al., 2018; Park et al., 2016; Paquin & Howard-Grenville, 2012; Mirata & Emtairah, 2005). Instead of facilitating IS through multi-stakeholder engagement in various workshops and interaction activities, the facilitative team of the Sustainable Synergies project seems to have applied a goal-directed approach (Paquin & Howard-Grenville, 2012) defined by the project aims and objectives. This is not to say that one approach is better than the other, as the variation of approaches and interactions within an IS emergence process are embedded within a specific (geographical and institutional) context with a specific degree of capacity that shapes the approaches to the emergence process.

This can be explained further by the findings of Mortensen et al. (cf. under review #3). In contexts where a tradition and culture for, and healthy habits of, collaboration exist among actors and these "*breathe with IS*" (Interview 1 Malmö, 2018) interactions are thought to have the potential of leading to identification of symbiotic potentials, symbiotic agreements, and thus to IS emergence. Actors within such contexts can have same frames of reference, shared norms and values, and aligned strategic aspirations and organizational goals. In contexts where such capacity does not yet exist, "*by engaging in interactions, actors [first] shape the institutional capacity, available to them in the future*" (Spekkink, 2015, p. 136). In one of the cases studied by Mortensen et al. (cf. under review #3), for example, there was a need to use various mobilization techniques and organize a series of events across several years with the aim of formulating a shared vision, prior to specific events aiming directly at matchmaking potential symbiotic partners. In the context of the Aalborg East port industrial area, there was a need to map the potential resources available for symbiotic relationships prior to matching events. As companies in the Aalborg East port industrial area were found to possess certain levels of knowledge and relational capacity, as mentioned in section 6.4.1., interactions aimed directly at increasing these were missing at this stage of IS emergence. The facilitation team was the actor building the knowledge capacity for companies engaged in the IS emergence process through the Sustainable Synergies project. The facilitation team was also the actor that bridged the relational links between the potential symbiotic partners.

Analyzing IS emergence processes in different port contexts, Mortensen et al. (cf. under review #3) find that interactions among actors can have a strategic and operational character and can be part of a focused and sustained process. These findings can be confirmed by the IS emergence process in the Aalborg East port industrial area, where Environment^{++} can be perceived as activating a group of actors in a continuous strategic process, supported by frequent partner meetings focused on building a fruitful institutional context for IS emergence, i.e. a strategic shared vision, creation of relevant political and regulatory environment fostering IS, and coordinating efforts across projects, initiatives, and programs. Sustainable Synergies, on the other hand, focused mostly on applying a facilitative approach to identifying the possibilities in the port industrial area in Aalborg East and using these in contributing to the emergence of specific inter-firm symbiotic linkages; thus, activating mostly at an operational level.

While Mortensen and Kørnøv (cf. 2019 #1) do not specify the relationships among such groups of actors, Mortensen et al. (cf. under review #3) find that these groups of actors enter collaborative relations based on professional relationships to form partnerships, as represented in Figure 20. Such **partnerships** are dynamic in their nature, evolving from existing relationships (i.e. antecedents to collaborations). The aim of such partnerships is found to revolve around "*the desire to produce economic, environmental, and social impact in the region where industrial symbiosis takes place*" (p.17). The actors in a partnership for IS emergence can form a core group of leading actors who can play coordinative and facilitative roles/functions. Peripheric groups of actors are found to join/leave the partnerships when relevant during the process specific to each symbiotic relationship. The relationships among the collaborative partners are based mostly on "*informal…verbal agreements, common interests…mutual trust… [and] economic and strategic interests*" (p. 15). However, as such these relations are not based on personal relationships, but rather are of "a professional" nature, that often are defined by "*project applications… joint mission statements, and mutual letters of intent*" (p. 15). Moreover, relations within such partnerships can take on the character of joint ventures and/or Triple Helix collaborations. The function of such partnerships is found to be 1) developing strategic and operational activities, and 2) attracting new actors in the partnership and the symbiotic connections.

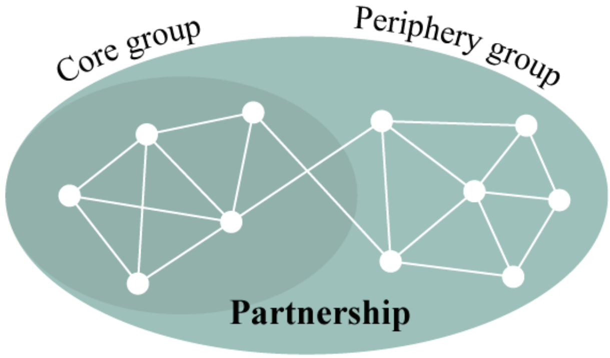

Figure 20: Representation of a partnership understanding. Developed by author based on Mortensen et al. (cf. under review #3).

Furthermore, during the organization for IS emergence, actors can organize into incubation **platforms** that "*could consist of creating and offering a platform or specific interaction spaces*" (cf. Mortensen & Kørnøv, 2019, p. 67 #1), where knowledge, experiences, and information related to IS can be shared, and connections among possible partners can be created. Such platforms are specific collaborative structures that can also attract funding, organize workshops, develop business models and feasibility studies, etc. Mortensen et al. (cf. under review #3) complements the insights in such platforms and argues for them being initiatives fostering multiple partnerships, as shown in the Figure 21, addressing specific issues and/or the interests at stake. Each partnership is formed by a core group of actors and a peripheric one. Actors engaged in such partnerships bring their own capacities to the partnership, develop shared ones, and mobilize these towards emergence of synergistic relations.

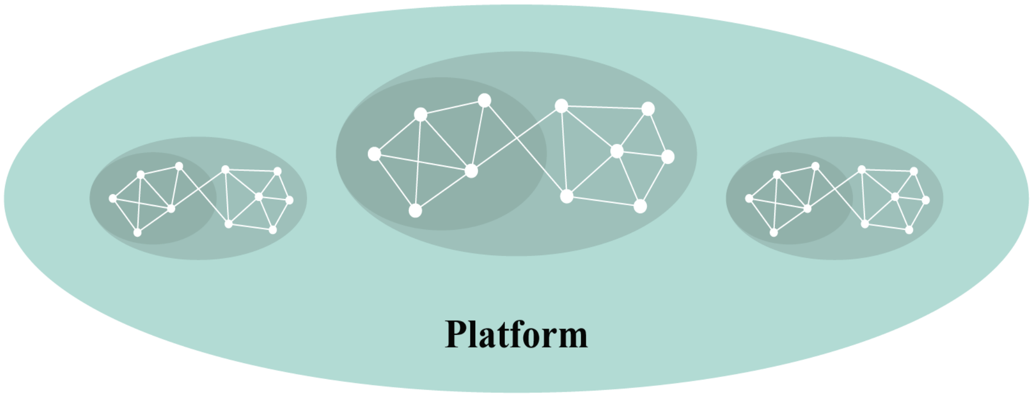

Figure 21: Representation of platforms and partnerships. Developed by author based on Mortensen et al. (cf. under review #3).

Besides being interaction spaces for partnership members, platforms were rather "*a way in which activities supporting partnerships were organized*" (cf. Mortensen et al., under review #3, p. 16). The authors find that activities supporting and encouraging partnerships in port industrial areas can be organized in/through informal networking and/or in more formal structures such as multi-actor associations. The purpose of networking was identified as being "*of aligning visions and interests, and shaping practices of working together*" (p. 16). Within such platforms, the authors find that "*a coordination body assures alignment of visions, missions, and strategies*" (p. 16). An exemplar way of networking was identified by Mortensen et al. (cf. under review #3) through the Malmö example where a Symbiosis Function is created among various actors. The Symbiosis Function "*is not just a group of people*" (Interview 2 Malmö, 2018), it is a specific way to work collaboratively with various partners, keep a continuous dialogue, and meet on the basis of the case and necessity. The interviewees in Malmö explained further that "*depending on what the case is, we collect persons, contacts from the city, system owners …and also depending on the case, it could be an expert in waste water or industry that have waste energy expertise, or something specific for that case…and we try to connect all these people, to sit down together and find [a solution]*" (Interview 2 Malmö, 2018).

The multi-actor associations, in contrast to networking, are formal structures, "*a specific juridical entity focused on a collective approach to industrial symbiosis facilitation*" created with the aim of "*improving competitiveness and synergies among the participants*" (cf. Mortensen et al., under review, #3 p. 16) and partnerships. The organizational structure of such associations revolves around a board, thematic working groups, and a coordination body. Thus, organizing platforms supporting partnerships for IS emergence can have a formal or informal character. What is true for both is that these require the presence of a coordination body and that these support activities at both strategic (through the core groups of actors, be these an association board or a Symbiosis Function) and operational level (through working groups and/or adding peripheric actors into existing partnerships).

Within such platforms, port authorities are found by Mortensen et al. (cf. under review #3) to often play a coordination role. As such, port authorities are identified to develop commitment among the actors in the partnership and to establish technical infrastructure necessary for symbiotic relations, within which data regarding the resource potentials could be collected, administered, and used to match possible partners. Moreover, the port authorities bridged the public and the private sector. A port representative at an interview expressed that "*it was a bit of explaining that the private sector works like this, that we cannot think like that*" (Interview 1 Malmö, 2018).

Insights from IS emergence processes in other port industrial areas present a framework for understanding and provide inspiration for further development of the collaborative structures facilitating IS emergence in the Aalborg East port industrial area.

8.2.2 Understanding Port of Aalborg's role for IS emergence.

Connecting the findings of Mortensen et al. (cf. under review #3) to the role of the Port of Aalborg within IS emergence in the Aalborg East port industrial area through the Sustainable Synergies project, it can be observed that both the Port of Aalborg and the ports studied by Mortensen et al. (cf. under review #3) are found to present important geographical, technical, and logistical resources and infrastructures that can support symbiotic flows.

Port of Aalborg's industrial spaces accommodate, as presented in section 2.1.2., hundreds of diverse (business) organizations from a variety of sectors within a geographical proximity. Functioning as a landlord and accommodating a critical mass of companies and organizations clustered at the port perimeter and its hinterland, Mortensen et al. (cf. under review #3) find that ports have the possibility to influence and generate shared norms and values through alignment of sustainability visions and ambitions.

Moreover, the ports are found to develop specific (environmental) requirements for companies at the port system, especially for planned industrial areas, as in the case of Malmö Industrial Park (Malmö Industrial Park, n.d.). Port of Aalborg, as presented by Mortensen et al. (cf. 2020 #2), introduces the voluntary environmental codex for both the companies at its perimeter and at its hinterland. Such initiatives can potentially attract companies with the needed profile and thus encourage the process of IS emergence. Furthermore, these can assure environmentally responsible action and creation of a greener profile of the entire port system. However, such initiatives are found to be voluntarily at Port of Aalborg or even perceived as reactive by the port itself (cf. Mortensen et al., 2020 #2). Being voluntarily and perceived as reactive can point to little involvement from either the port or the companies' sides. In such case, benefits from such initiatives can to be low. For Port of Aalborg to be able to collect benefits from such initiatives, a pro-active attitude towards environmental codex implementation and pro-active leadership is needed in this process. This might involve a stricter and more formal procedure for accepting companies at the port industrial area. The port of Aalborg might use its position in the Business Network 9220 and its involvement in Environment^{++} to strongly encourage and maybe even make a coalition with companies in the network to support and respect the environmental codex. By this, environmental profile of the Aalborg East port industrial area can be strengthened and promoted. This initiative might have potential for contributing to creating a common ground for companies to collaborate for environmental reasons and is thought to lead to a strengthened collaboration among network members and a stronger community spirit.

The Port of Aalborg covers an area of about 4,2 mill m^2 and aims to increase to 10 mill. m^2 in 2050 of available land for further industrial development. Being a multimodal transport center, it provides logistical solutions through global (shipping, truck, and railways) connections. Besides the waterways, road, and railways available, pipelines and infrastructure for electricity, wastewater treatment, etc. are available in the Aalborg East port industrial area. Mortensen et al. (cf. under review #3) refer to these as the infrastructure that can facilitate implementation of potential symbiotic linkages among companies and that can connect the port area with the city, region, and/or trans-nationally in urban and trans-national symbioses. In the case of Aalborg, advantage has not yet been taken of the infrastructural conditions, but plans exist to include these in the development of a new industrial area through symbiotic flows at the port's hinterland.

Through its logistical activities and functions, the Port of Aalborg has access to and is connected with a variety of (local, regional, national, and trans-national) actors across geographies. Such connections can provide important potential for symbiotic relationships across geographical localities (cf. Mortensen et al., under review, #3). However, Port of Aalborg has not yet embraced this possibility and fully accepted its own role for promoting and encouraging IS emergence across geographical boarders and within the globalized supply chain network, as have other ports studied by Mortensen et al. (cf., under review #3). For example, the North Sea Port in The Netherlands, beside focusing on creating symbiotic relationships among companies at the port system, also looks for opportunities to create symbiotic relations across national and trans-national boundaries between the industrial areas it comprises in The Netherlands and the one in Belgium. (cf. Mortensen et al., under review #3) Port of Aalborg, in its turn, through Environment^{++}, seems to focus mostly on IS emergence at the local level, within its perimeter and direct hinterland. While such possibilities are important for showing examples of symbioses to other companies in the area and to inspire local authorities to take more pro-active attitude towards IS emergence, I also find it important for the port to investigate possibilities that might lie across local geographical proximity (be these at the national or trans-national level) intentionally and pro-actively. These could contribute to the further IS emergence and the port's future engagement with IS emergence. The SipAAL initiative could present a relevant platform to accommodate trans-boundary synergistic relationships.

Such specific geographical characteristics make ports natural habitats for IS emergence processes, as also argued for in the section 7.2. Moreover, ports are also found both by Mortensen et al. (cf. under review #3) and during the Sustainable Synergies project to be institutional habitats with large potential to bridge contact among various actors locally, nationally and trans-nationally. With a "double" (public-private) identity, the Port of Aalborg can act as a company and as an authority. As a company, it can enter symbiotic relationships, acquire first-hand experience and knowledge with these, and provide inspiration for other companies in the port system to take pro-active action and enter symbiotic linkages. As an authority, the port can take pro-active action in establishing stronger partnerships and platforms for encouraging IS emergence. Being a member of various networks and partnerships, the port can actively engage with its role as a bridging actor and strategically could establish connections between initiatives, projects, and actors for the benefit of IS emergence. In this way, the port could shape a common ground for the various initiatives in the region. Moreover, the port, with its financial possibilities, could support the establishment of a specific platform aiming at facilitating and coordinating IS emergence. Within this, the Port of Aalborg could take a coordinative role, being a leader for various initiatives and projects, and practice its integrator role.

Within Sustainable Synergies project the port was bridging contacts between the facilitation team and the companies, spread the offers and communicated the results of the project and Environment^{++} initiative to other potential partners, and lobbied for IS emergence at the political level. With its various resources and capacities accumulated over the last decade, the port could have had a more pro-active attitude and could have taken a stronger leadership role within the project. While Port of Aalborg was mostly bridging contacts locally, the other ports studied by Mortensen et al. (cf. under review #3) also bridged contacts across geographical spaces, due to the ports' logistical connections and possibilities identified. For example, in the case of Biopark Terneuzen, studied by Mortensen et al. (cf. under review #3), North Sea Port authority led and coordinated activities, in contrast to Environment^{++}, where the Port of Aalborg took the initiative to establish and support the facilitation team. Port of Aalborg could thus take inspiration from the other cases provided by Mortensen et al. (cf. under review #3) and consider 1) engaging pro-actively with the IS emergence by intentionally looking at entering symbiotic action with other companies and taking an active lead and pro-active action in facilitation process of IS emergence; and consider 2) the opportunities that may lie across geographical boarders.

While the new port strategy refers to a greater role and involvement of the Port of Aalborg in the future initiatives supporting IS emergence and to other sustainable actions oriented towards port and hinterland development (Port of Aalborg, 2020), specific ways on how to anchor these already within the present Environment^{++} initiative and own organization must be explored.

8.2.3 Understanding the role of the Environment^{++} initiative

Analyzing Environment^{++} through the findings of Mortensen et al. (cf. under review #3), an observation can be made: the initiative functions as a partnership between Port of Aalborg, DCEA, Aalborg Municipality, Reno Nord, and the Aalborg (Energy and Water) Utility companies, while also being a platform that accommodates a number of sub-projects such as the Sustainable Synergies project (which can be seen as another partnership among a group of business companies, facilitation team, and the other actors involved in specific symbioses, such as individuals and consultancies). Thus Environment^{++} functions, as represented by the Figure 22, both as a platform and as a partnership.

Figure 22: Environment++ as both platform and partnership. Developed by author.

Environment^{++} as a partnership. The (participant) observations made throughout this PhD project, as well as my integrated position as an insider within Environment^{++}, permitted me to observe that the Environment^{++} partnership has evolved over time. With the Port of Aalborg and DCEA as initiators, the partnership enlarged in the three last years with the addition of other actors beyond existing relations with the local municipality, Reno Nord waste incineration plant, and Aalborg Utility companies. These can be perceived as the core group of actors in the partnership, while the companies involved in the Sustainable Synergies project make a peripheric group of actors.

While the partnership functioned mostly on voluntary basis, similar to the findings of Mortensen et al. (cf. under review #3), relations among partners were based on professional relationships. Moreover, the relationships among the core group actors were not defined by any project application, mission statement, or other documents, but by the strategy and the vision of the initiative. The relationships with the peripheric group of actors were rooted in the Sustainable Synergies project application and the signed partnership agreements. Sustainable Synergies actors were mostly connected to the facilitation team, without having a direct relationship to the other partners of Environment^{++} initiative. The core group of actors within the Environment^{++} partnership lobbied for IS strategies at the political, regulatory, and collaborative level, advocating for a fruitful regulatory context and communicating IS to the networks in the region in order to raise their awareness and interest in IS benefits and to attract more actors to the partnership, while the companies were involved directly in operational activities such as matchmaking and joining symbiotic relationships.

The study of IS emergence through the Sustainable Synergies project permitted identification of the **Sustainable Synergies project as a partnership** between DCEA, Port of Aalborg, and House of Energy, which can be said to function as the core group of actors in the partnership formalized by the project application. The project engages a multitude of companies in a facilitative process and these can be considered as the peripheric group of actors in the partnership of the Sustainable Synergies project. DCEA, being one of the initiators of Environment^{++} and the operators for the Sustainable Synergies project, is in a bridging position between the strategic activities fulfilled by the Environment^{++} partnership and the operational activities seeking to create symbiotic linkages between companies at port industrial area in Aalborg East through the Sustainable Synergies project. The partnership between the core group actors is formalized in the project application, while the relationships with companies are formalized by partnership agreements when symbiotic possibilities are found and companies express motivation for entering symbiotic relationships. Various companies have been found to join and leave the project before formal partnerships are signed. Thus, the project confirms the findings of Mortensen et al. (cf. under review #3) pointing at the dynamic nature of partnerships.

Environment^{++} as a platform accommodated a number of projects as described in the section 2.1.2. among which are this PhD project and the Sustainable Synergies project. As a platform, Environment^{++} offered economic incentives and functioned as a prerequisite to these. Furthermore, it accommodated and financially supported research activities such as this PhD project. Building on the findings by Mortensen et al. (cf. under review #3), Environment^{++} can also be seen as a way to organize activities that support the partnership among the actors. The insights into the Environment^{++} initiative point out that Environment^{++} functions as a platform based on collaborations among actors. No formal structure and agreements exist among the core group of actors in the partnership. As mentioned above, the initiative ends by December 2020 and thus partners in the initiative are searching for ways of organizing a continuation of Environment^{++} as a platform.

The insights from Mortensen et al. (cf. under review #3) can provide inspiration for further organization of Environment^{++}:

Organizing Environment^{++} as a network implies the establishment of a collaborative structure that aims at creating mutual agreements among actors, aligning their visions and interests, and shaping actors' practices. A coordination body is needed to assure the shared agreements, visions, and mission, and to implement the network's strategy. Such a network could function based on shared interests and mutual trust. Financially, such a network can function based on projects funded by European Commission, municipal, and private funds. Furthermore, a membership fee from the network members can finance the network's activities.

Within such a network, a core group of actors can be involved in strategic activities and a peripheric group of actors can be mostly involved in operational ones. The actors involved in the Environment^{++} partnership could be perceived as engaging in strategic activities, lobbying for the initiative with regard to persuading other actors in the collaboration to provide (financial, political, etc.) support of the initiative. Following the example of Symbiosis Function in Malmö (cf. Mortensen et al., under review #3), Environment^{++} can be organized to have a core group of actors to set a strategic direction for engagement with IS emergence, lobby for it at political level, assure the financing of IS-aiming initiatives, attract relevant actors in the network, and engage actors in relevant activities. Then the network can focus on relevant projects that will revolve around specific symbiotic ideas, symbiotic resources, societal issues, and/or other opportunities that might occur. Projects such as Sustainable Synergies could perform operational activities. Based on these opportunities, multiple actors can be involved as peripheric actors to bring their expertise in the process and contribute to IS emergence.

Within a network, actions should be shared among the actors, meaning that, for example, the functions and roles of a facilitator, as found during the Sustainable Synergies project and presented in section 6.4.2., would be shared among the actors. For example, researchers can function mostly as developing business models and assessing the (environmental, economic, and social) feasibility of symbiotic ideas, generating and sharing knowledge, disseminating results, raising awareness of potentials for IS, and facilitating connections. Municipal bodies can function as regulators, policy makers, legalization and permit issuers for symbiotic activities, and providers of public and political support to symbiotic initiatives. These can also provide funding, coordinate activities, disseminate knowledge, and create connections among actors. Business companies can be activated in different projects based on various symbiotic ideas and can take leading roles in relevant projects. Furthermore, based on the findings from the Sustainable Synergies project, Port of Aalborg and Business Network 9220 are to be actively involved in the network.

A coordination body would however still be needed to secure the communication and balance between the strategic and operational level, organizing events where actors from these two levels meet and interact. This is confirmed by the findings on the multiple functions of the facilitation team in the Sustainable Synergies project, presented in section 6.4.2. These point to the importance of a facilitation and coordination body despite the involvement of each actor and the playing of specific roles. In the case where Environment^{++} can be organized as a network, the coordination body is to be a team of various members with multiple (professional and personal) competences. Such a team will work in close collaboration with the other actors and agrees to mutual roles. A coordination body could e.g. maintain continuous communication with the companies and the core group, assure the companies' motivation in the projects, screen for symbiotic possibilities, manage the data and identify new symbiotic ideas, and coordinate among actors' roles, projects, and initiatives in the network and outside, while the core group of actors could provide strategic activities to shape a fruitful (institutional) context for the emergence of symbiotic linkages.

Collaborative structures based on networks point to the need for a certain level of commitment, as actors function without formal agreements and instead rely on shared interests and mutual trust.

Organizing Environment^{++} as an association refers to establishment of a formal structure functioning through a formal agreement among multiple actors. The purpose of the association can to be agreed upon consensus among various actors establishing the association. An association statute or formal agreement among the association members formally establishes the vision and mission of the association. The association would have a board and an executive body. The executive body will be made of a coordination body and multiple working groups (established according to the various issues and/or possibilities arising).

A coordination body is needed to assure coordination among the working groups (functioning on specific symbiotic projects), and the communication between the working groups and the board of the association. The board of the association will take care of strategic activities (working for establishing a fruitful institutional context for IS emergence), while working groups will engage in activities making IS emergence operational at the company level. A coordination body will organize events to engage actors in interactions that permit sharing knowledge, creating connections, sharing experience, identifying new symbiotic possibilities, developing project applications, attracting funding, etc. Furthermore, the coordination body will establish contact with relevant actors and attract new members into the association.

Financially, the association, like other networks, can work based on projects supported by European funds, while a membership fee can also be administered to cover the work of the executive body, assure the facilitation of symbiotic possibilities, and organize various activities. Both strategic and operational activities will be supported by the executive body, within which continuous communication of results is needed to keep the members motivated and committed to the activities within the platform.

The Port of Aalborg has a special role within platforms supporting IS emergence. The Port of Aalborg can actively engage and take a pro-active lead within such platforms. Besides taking initiative and according financial support for platforms such as Environment^{++} and bridging the contacts between actors, the port can take further inspiration from the ports studied by Mortensen et al. (cf. under review #3). The authors find that the ports often functioned as interaction platforms. As such, ports organized workshops, breakfast-meetings, site visits, etc. to support knowledge, information, and experience sharing and relational capacity building. A port established a specific entity with a group of employees at the port to work specifically with facilitating and coordinating IS-aiming processes. The same port entered a joint venture with other companies to establish and maintain the necessary infrastructure for the IS initiated at the port’s territory (Spekkink, 2015).

The Port of Aalborg, however, has not yet proven its full potential for facilitating IS emergence. Through its position within Business Network 9220, the port is the co-founder and driver for local (business) networks and acts as a knowledge, relational capacity building, and a mobilization platform for various actors. Through organization of various network activities and its participation at different network meetings, Port of Aalborg could bridge contacts and communication across actors in various sectors and facilitate the coordination of various initiatives. However, with its resources, potentials, and ambitions regarding various IS-aiming initiatives, the port could and would need to take more pro-active action. The port needs to contribute actively and directly (not only by supporting other's actions but engaging itself) in the establishment of a network or association as a platform fostering facilitation of IS emergence. As such, the port could take a leading position in IS emergence processes acting as an interaction platform by establishing specific stakeholder engagement systems and procedures that will permit it to engage actively with the companies at its perimeter and its hinterland, communicating with these regularly and reporting back to these. Moreover, the port needs to acknowledge its position as an intermediary for knowledge and information sharing within various networks and the multiple initiatives of which the port is part, and start taking responsibility for raising awareness and interest in specifically encouraging IS emergence within these.

Such recommendations are in line with the previous research conducted on the Port of Aalborg and the Aalborg East port industrial area, as presented in the section 2.1.2. The previous studies mention that the Port of Aalborg has the capacity for establishing interaction platforms, being itself a facilitator for IS emergence and leading such processes in the port industrial area (Roesen et al., 2016). However, this capacity needs to be mobilized through multi-actor processes where various actors could be engaged by the port through various interactions and collaborative processes (Roesen et al., 2016; Mortensen, 2016). The previous studies did not provide inputs on how to mobilize this capacity but encouraged the Port of Aalborg to establish a shared platform for communication, a knowledge, experience, and information exchange, and networking events and relation formation (Milani et al., 2017). The port can be an important contributor to the establishment of a tradition for collaboration because of its involvement in Business Network 9220, and the establishment of fruitful conditions for IS emergence thanks to its multiple resource and capacities.

Furthermore, the high ambitions of the Port of Aalborg to provide inspiration and support to other companies in the region that seek engagement with IS, and to initiate IS-aiming initiatives such as Environment^{++}, the Green Test Center, and SipALL (Port of Aalborg, 2020), encourage the port to take a higher role in IS emergence and ask for more pro-active action by appointing specific (human, financial, etc.) resources in the future. There is a need for institutionalization of IS emergence mobilization.

How exactly this can happen? What can bring along the institutionalization of mobilization actions? And how can a platform that can promote a fruitful context for IS emergence be established? The next section wraps up the findings and builds on these and the theoretical insights to discuss ways through which platforms for facilitating IS emergence can be mobilized.

8.2.4 Mobilizing action for establishing a platform for enabling the industrial symbiosis emergence in Aalborg East port industrial area

Entering partnerships was identified by Mortensen et al. (cf. 2020 #2) as being a way to institutionalize sustainability actions through collaborative action. The authors observe that the various environmental actions that the port took over the last decade had a dynamic movement across quadrants. They specify that "*the reactive and internally oriented actions have been made for several decades and have now been well standardised. The proactive and internally oriented actions also have a long history and have recently been standardized in management systems and strategies. The reactive and externally oriented actions are historically newer and have been systematised in a codex. The proactive and externally oriented actions are still developing in nature and format*" (cf. Mortensen et al., 2020, p. 14 #2). Such an observation points to the fact that the port's (internal and external, reactive and proactive) actions passed through several dynamics: first the actions were initiated with a focus on its own organization or oriented towards its hinterland, then these became systematized and standardized through internal procedures and management systems. At last, these became institutionalized through partnerships. This dynamic is observed to be time-dependent, i.e. as longer time passed, the farther the actions were in this dynamic. When considering the actions regarding engagement with IS emergence, the port's actions were perceived as "*still developing in nature and format*" (cf. Mortensen et al. 2020, p. 14 #2) meaning that these were most probably at the initial stage, even before the systematization and standardization, and thus not internalized within Port of Aalborg's organization.

Systematization and standardization, based on the findings of Mortensen et al. (cf. 2020 #2), implies the presence of some routines created internally in the organization, such as implementation of the environmental management system and the environmental codex. While standardization involves existence of a standard procedure that needs to be monitored and repeated periodically (such as the environmental management system[15]), systematization of the environmental codex supposes only the existence of a procedure that is not necessarily standardized yet. Standardization seems to involve internalization of procedures into the port's own organization, while systematization seems to be an acknowledgement and application of a voluntary system (in the case of the environmental codex).

Thus, acting in partnerships such as Environment^{++} has organizational consequences for the port but also for the other partners, as IS emergence is a multi-actor process. Acting in partnerships presupposes participation of a multitude of actors within

[15] The port goes through an evaluation procedure every second year that allows to get a new ISO 140001 certification.

interconnected relationships where each party brings valuable resources and takes on shared responsibilities for achieving common benefits in a continuous manner. Partnerships imply a specific way of collaboration among partners based on co-optation, co-regulation, delegation, and self-regulation. (Schuppert, 2011) Thus, acting in partnerships implies adjustment of action among actors and within actors' own organizations.

Actors collaborating in partnerships need to be able to share, collaborate, and bring their own contribution to common benefits in the form of intentional support for IS emergence. When entering partnerships, the partners need to redefine the self-understanding of their own roles and identity, assess and acknowledge their own capacity, and consciously mobilize these. In the context of the Environment^{++} partnership, the partners—DCEA, Port of Aalborg, Aalborg Municipality and Aalborg Utility companies—need to redefine their self-understanding, acknowledge and make their own interests clear over for each other, and rephrase their future engagement and roles within further platforms fostering IS emergence. Thus, there is a need to internalize the collaborations with various actors within their own organization for achieving well-functioning partnerships. Organizational routines, systems, and standards that can anchor symbiotic strategies and IS values, norms, and visions within their own organizational strategies and internal systems need to be developed prior to and along with the development of common collaborative structures fostering IS emergence. Moreover, specific (financial, human, etc.) resources need to be allocated to work specifically towards achieving IS emergence. The lack of these can pose challenges for longevity of partnerships and achieving IS emergence.

For example, the port needs to allocate not only financial resources, but also human resources that could specifically focus on the facilitation of IS emergence and/or coordination of various partnerships, assuring that the port's strategic vision concerning partnerships for sustainable port and hinterland development is achieved. DCEA, one of the co-founders of the Environment^{++} initiative and part of the facilitation team within the Sustainable Synergies project, is acting both at the strategic and operational level and is the bridging actor between the two levels, keeping a considerable amount of (facilitation) capacity acquired through its experience within the Sustainable Synergies process and coordinating activities across various initiatives. In a future platform fostering IS emergence, facilitators are crucial (as learned from the studies developed during this PhD project) and therefore DCEA needs to re-consider its future role: Can and will DCEA continue to be a facilitator, or should the facilitation capacity be transferred to an association (with a formal board and working groups) that will facilitate the emergence of symbiotic linkages based on specific issues and opportunities or to a network of actors who share the commitment and the roles and responsibility for IS emergence?

8.2.5 Formation of collaborative structures—institutionalization of IS emergence

The actual challenges regarding the organization of Environment^{++} and the disagreement of roles and rather split interests among the Environment^{++} partnership members, as observed during the PhD project, seem to confirm not only the need for internalizing IS emergence within its organizational routines, but also the need for redefinition of the entire partnership, its role, and its shared vision, norms, and rules. The commitment and participation of the other partners, beyond DCEA and Port of Aalborg, in Environment^{++} and thus towards IS emergence, appear to be weak. The partners seem to approach the partnership as protecting and following own interests. Although it seems that the initiative's vision is a shared one, the partners do not present enough commitment and do not take enough initiative to equally participate in the IS emergence.

While the DCEA was the facilitator for IS emergence, the Port of Aalborg could have been a connecting point and important bridging actor among various initiatives in the area. The other partners did not play a role within the facilitation process through Sustainable Synergies. This can be because of the Port of Aalborg and DCEA being initiators of Environment^{++} as a platform fostering IS emergence and therefore the other actors might have had difficulties assuming ownership of this. Moreover, the particular activities aimed at IS emergence were established mostly within the Sustainable Synergies project application, and not agreed to among the partners of Environment^{++}. The Sustainable Synergies project did not engage the partners within Environment^{++} into the facilitation process, and the Environment^{++} did not engage the actors involved in Sustainable Synergies project into a common process for solution finding to IS emergence.

Moreover, this can also be an expression of the fact that the two initiatives (the Sustainable Synergies project and Environment^{++}), even though strongly related, have in practice not been integrated within each other. Environment^{++} was the initiative acting mostly at the strategic level and only through its specific projects at the operational level. The core partners in the initiative have acted mostly at the strategic level. From these, only DCEA (and in a much weaker degree the Port of Aalborg) was acting at the operational level. DCEA being thus the bridging actor between the two levels and an actor that holds a significant level of capacity acquired through the facilitation process within the Sustainable Synergies project and the coordination of activities across other initiatives in the area.

This can have influence on the flow of capacity built during the various initiatives' implementation. As section 6.4.3. presents, the facilitation team used and acquired increased capacity for facilitation of IS emergence. At the beginning, the facilitation team was inexperienced, and during the project, built knowledge on (energy, water, by-product, and other material) resources available and their potential flows and developed relational resources. Such capacities are not fed back into Environment^{++}

because of their “in silo” development. If this capacity to be further used in the processes of fostering IS emergence, there is a need for it to be fed and anchored into larger initiatives that aim at long-term interventions for IS emergence (such as SipAAL and The Green Test Center) and not kept only at the project level. Projects, such as Sustainable Synergies, are normally of shorter duration and IS emergence risks failure when the project ends.

Furthermore, the facilitation of IS emergence risk to not be systematized and institutionalized, and thus the facilitation process risk ceases when Sustainable Synergies project ends. The presence of a facilitator was perceived by the companies as a crucial factor for IS emergence, and the reproduction study of emerging symbioses through Sustainable Synergies (see Appendix II) show a strong dependency of IS emergence on facilitators. If a facilitation body and a facilitation process cease to exist at the end of the Sustainable Synergies process, the emergent symbiotic network is at risk of terminating before even established once the project ends. This can be first because, the emergence of symbiotic linkages was strongly bounded in the Sustainable Synergies project description, which aimed at only identifying IS possibilities, and not implementing these, i.e. not to establish physical flows. Secondly, because after the end of the Sustainable Synergies project, no official facilitation body exist in the Aalborg East port industrial area that can ensure the physical establishment of the synergies.

Moreover, the trust within the emergent synergies and among symbiotic partners is found to go through the facilitation team. The contacts and communication go through the facilitation team. The knowledge of potentials and resources available are detained by a facilitation team. The experience accumulated during the process is held by a facilitation team. Thus, a large responsibility and importance is laid on facilitators. The lack of facilitative bodies can thus challenge the trust among symbiotic partners, the communication among these, and the identification of further synergistic possibilities. The lack of these challenge the social embeddedness of emerging IS (Boons & Howard-Grenville, 2009), which is able to encourage IS emergence and development, and thus challenges IS emergence.

Thus, the facilitation team was not only important and crucial during the Sustainable Synergies project, but it remains equally important after its termination. This then triggers us to think of the need for a collaborative structure, such as Environment^{++}, to consider a holistic approach to facilitation that is not only applied to specific projects like Sustainable Synergies, but also to the entire platform. Such facilitation structures may take the form of coordinating or orchestrating (Park et al., 2018; Paquin & Howard-Grenville, 2013) structures that could include facilitation structures, which can offer operational activities and support based on various specific projects. Thus, deliberate coordination and facilitation bodies need to be established that will secure the mobilization of existing resources, capacities, and actions, and the development of further capacity. Such structures could bridge the strategic and operational level, assure the sharing of knowledge across sectors, and contribute to the relational capacity building among the actors. They can keep track of data accumulating along an IS emergence process and can connect potential symbiotic partners. Simultaneously, they can learn from their own experience and accumulate capacity for further IS emergence and development, institutionalizing IS emergence deeper within the Aalborg East port industrial area. Such coordination and facilitation structures should consider other IS emergence and development dynamics than the one taken in the Sustainable Synergies project by taking a more holistic approach to IS emergence and development. For example, the IS emergence could be considered through both development of bilateral connections and the network formation, through connecting the existing symbiosis network in Aalborg with the ones emerging through the Sustainable Synergies project, and considering how the existing IS network can contribute to the reproduction and emergence of the new ones.

To establish a collaborative structure as an institution that can accommodate coordinative and facilitative bodies for IS emergence, the Port of Aalborg as the main initiator of Environment^{++}, can start an institutionalization process of the partnership aiming at IS emergence and encouraging establishment of a collaborative platform. Acknowledging that the partnerships, as institutions, require establishment of a high collaboration culture, the port could initiate a collaborative process aimed at developing a shared vision, commitment, norms, and rules through engagement of relevant actors.

Spekkink (2016, p. 226) finds that "*visions do not only function as forward-looking devices. They also offer means to consolidate the common ground that has already emerged, thereby providing a bridge between the building blocks for collaboration, and the collaboration itself*." Within IS emergence processes in the port industrial area in Malmö, for example, several years and multiple interactions within various platforms where needed to develop a shared vision. In the case of the port industrial area in Aalborg, the vision stated within Environment^{++} was articulated through the promotion of the partnership at the initiative of the Port of Aalborg and DCEA, being further developed within the Business Network 9220 as a vision for Aalborg East. Thus, the Environment^{++} vision was not built from collaborations among actors within the initiative, but instead was the articulation of the common ground built among a few specific actors, while the other actors in the partnership thus remained uninvolved. This can be problematic and poses challenges for the further collaboration process. As one of the respondents in Malmö expressed "*the process builds on an unstable basis*" (Interview 2 Malmö, 2018), i.e. without a shared vision and commitment, collaboration processes for IS emergence risk to collapse and being unsuccessful in the long run. Thus, Environment^{++} partnerships can direct their efforts towards building a common vision and commitment through engaging various actors in its articulation to assure the success of a future platform fostering IS emergence.

Engaging various actors from the design phase of such an institution aiming at IS emergence could not only create shared vision and commitment, but also give to the platform fostering IS more structure, direction, and operational focus. To obtain this, there is a need to formalize the shared commitment and the shared norms and visions among the partners in the initiative. Specific collaboration rules, and regular and continuous interactions need to be agreed among partners.

Such an institution can take the form of a network, an association, or another type of organization with institutional characteristics (see section 3.2.). Such an institution can act as a governance structure fostering the partnerships aiming at enabling a fruitful institutional context and at symbiotic linkages and network emergence. Such a governance structure could mobilize the existing capacity and resources in the area and build further capacity securing the development of a fruitful institutional (political, regulative, etc.) environment through strategic actions while simultaneously operationalizing IS emergence through emergence of inter-firm networks.

For the creation of a collaborative structure as an institution fostering IS emergence, de-institutionalization (Peters, 2012) of Environment^{++} and creation of a new collaborative institution through engagement of various actors might be needed. A new collaborative structure shaped in partnership through collaborative agreement, shared vision, norms, values, and rules could increase the ownership and commitment of the engaged actors towards IS emergence. The experiences and capacities acquired within Sustainable Synergies on one hand and Environment^{++} on the other, could serve as lessons learned for design of further actions directed to institutionalization of IS emergence. A process of mapping the lessons learned to this point could help identify strengths, weaknesses, and existing capacity that further processes will build on. Then, activities aiming at integration of knowledge and relations acquired during the Sustainable Synergies project and Environment^{++} (i.e. a process of capacity building) must be set in place and supported by the collaborative structure.

9 CONCLUSIONS

Industrial symbiosis, a systemic approach to organizing industrial systems by using otherwise underutilized by-product materials, energy, and water, is perceived as an important strategy to achieve sustainable industrial development. Its application within various geographical contexts proved to bring economic, social, and environmental benefits. Modern ports, which accommodate important industrial areas at their perimeter and hinterland, are engaging increasingly with IS strategies for both port and hinterland sustainable development.

IS became a strategy for the Port of Aalborg and its hinterland sustainable development. The port, together with the Danish Center for Environmental Assessment at Aalborg University, initiated Environment^{++} in 2016 as a focused initiative towards IS emergence. Being engaged in IS-aiming initiatives since around 2011, the Port of Aalborg lacked the experience and understanding of how symbiotic linkages emerge and what factors can facilitate them. With the initiation of Environment^{++} and its sub-project, Sustainable Synergies, aiming at facilitating the emergence of industrial symbiotic linkages in the area, the possibility of learning from real-time focused processes arose. Both the Environment^{++} initiative and Sustainable Synergies project provided relevant platforms for data gathering on IS emergence and the factors that facilitate it in real-life context.

IS literature refers to geospatial, technical, economic, human and organizational, informational, institutional, and social factors as important for IS emergence and development. The contexts that foster these factors are perceived as having a specific level of institutional capacity (i.e. knowledge, relation, and mobilization) that can encourage IS emergence. However, these factors are not identified to be specific to IS emergence. Furthermore, while the IS research provides common ground for understanding IS emergence as an evolutionary process going through various phases, the IS emergence phase remained unclear. Few studies focused directly on IS emergence and differentiating it from IS development so that specific characteristics and factors facilitating it could be identified. Moreover, contextualized and empirical insights from specific contexts are necessary for understanding and fostering IS emergence in that specific context, as IS emergence proves to be embedded within geographical and institutional contexts (Boons & Howard-Grenville, 2009) and thus dependent of their characteristics.

Building on the gap identified in IS literature, the challenges with IS emergence in practice, and the opportunities offered by the Environment^{++} initiative and Sustainable Synergies project, this research asks:

How can industrial symbiosis emerge and what factors can facilitate the industrial symbiosis emergence in the Aalborg East port industrial area?

By answering the main research question the present research sought the following:

- To explore and analyze the process through which IS emerges and identify the specific factors that can enable IS emergence. The first two sub-research questions addressed these objectives:
    - RSQ 1: *How can industrial symbiosis emerge*?
    - RSQ 2: *What are the factors that can facilitate industrial symbiosis emergence?*

- To identify the contextual characteristics and capacities that the Aalborg East port industrial area presents for fostering IS and identify how IS emergence can be further facilitated in the Aalborg East port industrial. The last two research sub-questions further guided the research:
    - *RSQ 3: What are the specific contextual characteristics and capacity of the Aalborg East port industrial area that can facilitate IS emergence?*
    - *RSQ 4: How can the IS emergence be further facilitated in the Aalborg East port industrial area?*

The research aim was thus two-fold: 1) to provide insights into and a deeper scientific understanding of the IS emergence phase through identifying specific factors facilitating it, and 2) to contribute to practice of IS emergence in the Aalborg East port industrial area through collecting inputs from the on-going IS-aiming initiative Environment^{++} and provide insights for further mobilization of IS emergence.

An embedded case strategy is adopted where the IS emergence process in the Aalborg East port industrial area was used as the main case, while other secondary cases contributed to enriching the empirical findings and to conceptualizing IS emergence in port industrial areas. The four academic studies developed during the PhD became sub-units of specific chapters of this thesis, and each elucidates specific aspects that feed into one or more of the research sub-questions. Moreover, the research presented within this thesis binds the studies made during the PhD project together and applies their findings on the IS emergence in the Aalborg East port industrial area. Thus, the research also provides direct inputs to practice in the Aalborg East port industrial area while developing theoretical insights on IS emergence.

Addressing the research questions, an engaged scholarship (Van de Ven, 2007) research process was conducted. As a researcher, I shifted among various modes of research. These implied various approaches to *doing* research and *being* a researcher, which in turn implied further reflective considerations on researcher positionality, roles, and values.

The main assumption made within this research was that symbiotic linkages can produce considerable benefits to environment, economy, and society without being an actual subject of concern. While the Sustainable Synergies project continuously assessed the environmental effects of the emerging IS linkages assuring their sustainability, these are not considered by default within this research. Thus, conclusions within this thesis must consider this aspect and the application of the insights from this thesis must be complemented by consideration of the sustainability assessment aspects.

Furthermore, reading the thesis conclusions must take into account the methodological considerations regarding conducting case studies, observations, and interviews with various respondents, and the theoretical lenses I used to process the data collected. While it is argued that generalization from case studies is possible (Yin, 2018; Flyvbjerg, 2006), further research and application of the insights from this thesis must consider the specificities of context and the theoretical lenses applied to understand them.

The following sections present conclusions regarding the research sub-questions that together form an answer on the main research question. These must be read with the above-mentioned considerations in mind.

9.1 HOW CAN INDUSTRIAL SYMBIOSIS EMERGE?

The present research provides insights into and a deeper scientific understanding of IS emergence by developing a conceptualization of IS emergence and identifying the factors that facilitate it, thus making a direct scholarly contribution to the IS field. Exploring the state of the art, it was argued that while the IS research provides common ground for understanding IS emergence as the initial phase within the IS evolution, the understanding of IS emergence remains unclear as much of the existing knowledge refers to both IS emergence and development, without a clear distinction between these. Moreover, the literature is based on various empirical cases from various contexts, which present various dynamics through which IS emerges and develops (Boons et al., 2017). However, while this poses a challenge to understanding IS emergence, contextualized and empirical insights from various contexts are still necessary as IS emergence and development is embedded within such contexts (Boons & Howard-Grenville, 2009) and their unfolding will strongly depend on contextual characteristics.

Exploring the conceptualization of IS emergence, answers to these specific questions were sought: *How can IS emergence be defined?* and *What are IS emergence characteristics, boundaries, and dynamics?* The following sections conclude on the findings related to these and discuss them in relation to the existing IS literature pointing at the scholar contribution of this research.

IS is a social dynamic process. The disparate understanding of IS emergence within IS literature based on multiple cases challenges the common understanding of IS emergence among IS researchers. The present research builds on biological terminology related to the germination of seeds leading to the plant emergence and to coral reproduction to understand IS emergence. Moreover, various empirical cases provide insights into emergence processes that permit the initial conceptualization of IS emergence to form. The real-time empirical cases enrich the initial conceptualization with insights from port industrial areas. The conceptual and empirical findings point at *IS emergence being a highly dynamic social process that unfolds through multi-actor collaborative processes based on systematic and continuous interactions within various platforms, which mobilize and build further the existing capacity within the context and lead to the emergence of inter-firm symbiotic relations. Within such processes a coordinative and facilitation body is necessary.* A specific pre-emergence phase, characterized by the presence of specific contextual conditions, present the initial (physical and institutional) conditions or antecedents for an IS emergence process. The physical establishment of symbiotic flows marks the start of their development and thus the post-emergence phase of IS.

This conceptualization is based on the process-oriented approach introduced by Boons et al. (2014) and is in line with conceptualizing it as the coming about of symbiotic relations, and as the "gestation period" (Van de Ven, 1999, p. 25) of innovation processes (Mirata & Emtairah, 2005; van Berkel et al., 2009) within which "*people engage in a variety of activities that set the stage for innovation*" (Van de Ven, 1999, p. 25). Wang et al. (2017) similarly conceptualizes the process of inter-firm symbiotic relationships coming about through processes that take place within IS-aiming collaborative networks. Similar to Spekkink (2016), IS emergence within this thesis is conceptualized as a collaborative process leading to collaborative symbiotic business models, within which actors share value creation and proposition. While Spekkink (2016) conceptualizes the emergence process as an IS, the present research makes a distinction between the IS and its emergence—defining IS as the inter-firm flows of by-product resources, energy, liquids, etc., and IS emergence as the social process that leads to the emergence and establishment of such relationships.

IS emerges from bilateral linkages towards network development. While, it seems still to be helpful to keep the sharp conceptualization of physical establishment and implementation of a symbiosis as their emergence point, the delineation between the emergence of bilateral linkages and IS network formation does not need to be sharp. Evidence for connectivity and dependency between existing (emerging) and new (emerging) symbiotic relationships is examined and the research argues more for conceptualizing the IS emergence boundaries as fluid and dynamic. In practice, the emergence of bilateral symbiotic linkages happens simultaneously as an IS network emerges, due to the interconnectivity among symbiotic linkages encouraged by bridging symbionts, facilitation bodies, and knowledge diffusion. IS emergence is thus a more complex phenomenon than the emergence of bilateral connections. It transcends the bilateral flows and implies the initial network formation as also specified by Paquin and Howard-Grenville (2012). Thus, the present research contributes to the definition of IS, by confirming the one developed by Boons et al. (2017). The authors define IS as a network of at least three interconnected actors exchanging (material, energy, by-product, etc.) resource flows where the bilateral relation is the precursor to IS, while an IS network still emerges.

IS emergence has specific characteristics. Besides of being dynamic, IS emergence is a social process involving multiple actors. The range of actors that engaged in the IS emergence process was variate. Each of these contribute to the process with a specific set of (individual, organizational) characteristics and capacities, that activate and shape various roles along the IS emergence process. Individuals, organizations, and networks are found to act as change agents taking roles as champions, bridging actors, facilitators, and coordinators. Among these, facilitators prove to be the most important change agents. Through their actions and mobilization techniques, change agents can provide incubation platforms for symbiotic relationships, shape the formation of a (strategic) symbiotic network, build actors' further capacity, and shape the necessary institutional conditions for IS emergence.

The emergence of symbiotic linkages and an IS network is thus a phenomenon emerging from the social interactions among a multitude of actors who activate their multiple capacities and learn new capacities in this process to help them see different opportunities for symbiotic relationships and to make decisions on their actions. Such a conceptualization is in line with Boons and Spekkink (2012) referring to IS emergence and development as an interaction between the actors' and the institutional capacities.

Among the actors involved in an IS emergence process, ports present significant resources and capacities that make the port industrial areas natural habitats for IS emergence. Moreover, the (environmental) evolution of ports have prepared these for taking pro-active action towards becoming catalyzers for IS emergence processes for port and hinterland sustainable development. However, for resources and capacities to be beneficial and lead to IS emergence, there is a need for collaborative processes that can mobilize and further build these. Port industrial areas prove to be significant arenas where actors across sectors engage in collaborative processes for IS emergence.

IS emerges through a mix of dynamics. The present research builds further on IS dynamics to develop the initial conceptualization of IS emergence. It then develops the IS reproduction model, which unfolds a new dynamic leading to IS emergence: reproduction. Such a dynamic was not previously described in the IS literature and thus constitutes a novel contribution to this. While the other dynamics revolve around actors that engage in specific events, the reproduction dynamic builds on the interconnectivity between the existing and new symbiotic relationships. The IS reproduction model that was developed proved to apply to both existing networks and emerging ones and is able to explain IS emergence.

While the cases studied, and on which this thesis is built, point mostly at the facilitative dynamic (Boons et al., 2017) being conducive to IS emergence, the other dynamics cannot be cast away. Just as Boons et al. (2017) mention, it is found that emergence of symbiotic linkages and networks do not necessarily follow one single dynamic, but rather present traits of a mix of these. The empirical studies included in this thesis present the facilitation dynamic making use of reproduction modes to promote IS emergence. Moreover, facilitation proves to be a successful way of activating various dynamics to obtain different benefits that can lead to promoting IS emergence; findings that support and complement Paquin and Howard-Grenville (2012).

Moreover, intentional focus on and application of anchoring activities proposed by Sun et al. (2017) could be integrated within facilitative processes, having focus on activities as mobilization techniques (for activating the existing resources and capacity for IS emergence). Integration of different dynamics in the facilitative processes for IS emergence could increase the mobilization of the existing institutional capacity and could build it further. This could trigger a higher rate of success with IS emergence and network formation. Thus, IS does not necessarily emerge and develop through one single dynamic, but is best understood through multiple ones. Understanding and applying these dynamics intentionally to future processes could enrich the understanding of IS emergence and network development.

9.2 What are the factors that can facilitate industrial symbiosis emergence?

Contextual factors. Regarding the factors facilitating IS emergence, the IS literature refers to geospatial, technical, economic, human and organizational, informational, institutional, and social factors as enabling IS emergence. While the present research acknowledges the importance of these various factors for both IS emergence and development, it finds that contexts with specific levels of institutional capacity (i.e. knowledge, relation, and mobilization) can function as fruitful soil for fostering IS emergence. In contexts where a tradition and culture for, and healthy habits of, collaboration exist among actors and where actors share common visions, norms, values, and degree of commitment, interactions seek to operationalize IS through identification of issues, challenges, and possibilities, and through identification of a pool of available resources that can be transformed into the potential for IS. In contexts where such capacity does not yet exist or are weak, interactions will need to be aimed first at shaping a fruitful context, a healthy collaboration culture, shared visions, and commitment among actors, prior to and/or along with the interactions aiming for specific inter-firm connections. The empirical studies confirm the findings of Spekkink (2016) and Mirata (2005), which stress the importance of contextual characteristics and institutional capacity for IS emergence.

Port industrial areas are found to be geographical, logistical, and infrastructural resource-rich habitats and contexts with high capacity for IS emergence. Institutionally, ports are often special entities with double identities: functioning as both a public and private entity. As such, ports, besides offering important financial support to IS-aiming initiatives, can bring actors from across sectors together. Ports also provide interaction spaces and an incubation platform that can facilitate knowledge, information, and experience sharing, building new and strengthening existing relationships, and fostering actor engagement systems and procedures. Ports can take a leading position in encouraging IS emergence through activation, mobilization, and building further the existing institutional capacity.

Geographically, ports prove to be beds for industrial co-location, accommodating considerable amounts of diverse business organizations. The presence of an agglomeration of business organizations at a port industrial site, or the industrial parks at the ports perimeter and its hinterland proves to facilitate IS emergence, which supports the IS scholars' argument for geographical proximity as an enabling factor (see e.g. Chertow et al., 2008). Geographical proximity and co-location of companies within industrial parks can be resource effective, minimizing (by-product, material, liquids, energy, and water) resource transportation time, and facilitating easier knowledge, information, and experience flows, conducive to new symbiotic ideas and potential new relationships. However, geographical proximity is found to be insufficient. Involvement of business organizations beyond the geographical area of the Aalborg East port industrial area was necessary in order to assure resource efficiency and minimization. Thus, this research also acknowledges and supports the other IS scholars who argue for a less important role of geographical proximity (e.g. Jensen et al., 2011).

Geographical proximity and co-location is not a necessity but a factor that can enable the emergence of symbiotic relationships. Emerging at the bilateral level, symbiotic relationships connect to form an emerging IS network. When established, these can gradually add up and transform the existing industrial parks into eco-industrial parks. While this is the result that is the aim in the Aalborg East port industrial area, this context is not the only one. Numerous other examples of contexts where IS is applied as a strategy for transforming industrial sites into eco-industrial parks are described in the IS literature (Korhonen, von Malmborg, Strachan, & Ehrenfeld, 2004). These present evidence for contexts where industrial symbiosis initiatives are continuously cultivated and where these add gradually up to an emerging regional industrial ecosystem (Susur, Hidalgo, & Chiaroni, 2019). Within such contexts, as this research proves and IS literature describes, capacity seems to build and contribute to further IS emergence. However, little evidence exists on how exactly capacity builds and how communities with shared norms, visions, and values form. The studies of Spekkink (2013; 2015) are some of the few studies identified describing capacity building for IS emergence in a few cases in The Netherlands. In order to understand how capacity for IS emergence builds, there is a need for more research on capacity building in various contexts. Understanding dynamics of capacity building could increase the understanding of the mechanisms leading to emergence of regional eco-systems.

The present research did not focus specifically on capacity building for IS emergence, but its findings point out that **institutional capacity** in the Aalborg East port industrial area is building on various arenas and with the participation of various change agents. The environmental evolution of the Port of Aalborg seems to have brought the port to increasingly engage and initiate partnerships aiming at IS creation. The presence of Business Network 9220 (and other business networks) in the area prove to be important for the support and building of knowledge and relational resources. The presence of skillful and strongly capable researchers at DCEA (Aalborg University) was crucial for the IS emergence as they were acting as facilitators and coordinators for the facilitation process.

Also, the individual (i.e. human) and (business and public) organizations' dimensions prove to be important for IS emergence. The presence of individuals that could take active actions and play roles of champions, facilitators, coordinators, and bridging actors was crucial for the emerging symbiotic relationships. Individuals and organizations that have specific (environmentally motivated, symbiotic mindsets, pro-active attitude, willingness, etc.) characteristics prove to be actively involved in IS emergence processes and shape them.

With its findings, the present research expands the understanding described by Cohen-Rosenthal (2000) two decades ago, referring to the human dimension being important for establishment of symbiotic relationships: Knowledge, information, experience sharing, and other mechanisms can only provide the means for identifying synergistic potential "*but this does not link them: decisions by people do" (*p. 246*)*. The human dimension proved, in the process of IS emergence in the Aalborg East port industrial area, to also be highly important in the identification of possibilities, establishment and maintenance of connections with companies for identifying potential flows, facilitation of the process, coordination across initiatives, etc. Where willingness to share knowledge and information, openness towards new possible partners, and actors with specific facilitative skills and capacities exist, the IS emergence was fostered. Thus, not only is the human dimension important for the physical establishment of the synergistic flow, but it is equally important for the process of IS emergence, before these are established. The present research supports thus researchers advocating for the importance of the capacities of individuals involved in an IS emergence process (see e.g. Mirata, 2005). While the human dimension is found important, it remains under researched within the IS literature (Walls & Paquin, 2015). Walls and Paquin (2015) call for more research on the role of individuals' IS cognition, skill sets, experience, their value orientations, motivations, and preferences, as antecedents and enablers for IS emergence; the findings of the present research support this call.

The port industrial areas, which accommodate co-location of diverse organizations that dispose of infrastructural, logistical, financial, etc. resources, where individual and organizational actors have pro-IS characteristics and capacities and these act as change actors, can be seen as fruitful contexts for IS emergence. However, such factors are not conducive to IS emergence by default. A need for mobilization processes, techniques, and actors as facilitators that can activate, mobilize, and develop further these characteristics and capacities is identified through this thesis' research.

Mobilization processes as intentional facilitation of IS emergence can raise the awareness and interest in IS by identifying and mapping the potential of underutilized resources, which can function as flows within symbiotic relations. These can also provide arenas for reaching out to potential partners and exploration of possibilities to develop new symbiotic partnerships. Through facilitative processes, potential partners can be matched in symbiotic relationships and the sustainability effects can be calculated and monitored. Communication across initiatives resulting in symbiotic relationships can be coordinated.

The insights from IS emergence in port industrial areas provide evidence for the need of **formal facilitative structures**. Intentional and formal facilitative structures need to exist if IS emergence is to be successful in these contexts. This finding confirms other findings in the IS literature addressing the importance of facilitation, coordination, and orchestration of IS emergence and development (e.g. Paquin & Howard Grenville, 2012; 2013; Paquin et al., 2014; Park et al., 2018). Such facilitative structures appear, in both port industrial areas and other contexts described in the IS literature, to undertake strategic functions such as lobbying for a fruitful (political, regulative, etc.) context for IS emergence, and operational functions such as providing support to business organizations, matching these into specific symbiotic relationships, and communicating benefits and results of mobilization actions. However, **s**pecific (systemic, analytic, technical, coaching, project management, and personal) **skills are necessary for facilitating the IS emergence** in port industrial areas. Facilitation requires, for example, engagement and agency, responsibility, commitment, neutrality, and capacity building skills through knowledge and information creation and sharing. Moreover, facilitation requires patience, persistence, and empathy, specific analytical and technical skills, and coaching skills to facilitate the matchmaking among organizations.

These findings point at the fact that such structures are better fulfilled not only by one single actor, as often presented in the IS literature, but by a collaboration of actors across sectors that can take the form of collaborative networks (Spekkink, 2016; Wang et al., 2017). Such collaborative structures fostering IS emergence in port industrial areas can take the form of partnerships fostered by collaborative platforms that support a focused (intentional) process aiming at IS emerging as important conditions for IS emergence.

While the IS literature is rich in setting focus on facilitative bodies, it remains scarce on describing collaborative processes and platforms supporting IS emergence and how these can build institutional capacity for further IS emergence. Spekkink and colleagues' work (see Spekkink, 2016) in this regard is the most considerable. The present research makes thus a contribution to understanding of such platforms and partnerships facilitating IS emergence. Actors across sectors engage in collaborative processes that focus on societal issues and existing symbiotic flow potentials. Core and peripheric groups of actors characterize partnerships for IS emergence. Various partnerships can organize within an IS-aiming platform that can function as informal collaborative networks and/or formal associations.

Collaborative platforms aiming at IS emergence and partnerships provide mobilization arenas that can foster continuous interactions among actors. There seems to be an agreement among IS scholars and the findings of this research that interactions are "*the source of change*" (Spekkink, 2015, p. 136) through which contexts activate and build their institutional capacity. It is especially the facilitated interactions with an intentional character that are found to be most fruitful for IS emergence in port industrial areas. These have the potential to mobilize and activate the present (institutional) capacity and to build it further.

The presence of IS-aiming initiatives at port industrial areas prove to function as platforms fostering and incubating IS emergence. The insights from Aalborg East port industrial area point out however at such initiatives must be thought of within larger strategies and initiatives if the capacity built through the former processes are to be integrated within further initiatives and processes. Intentional and focused IS-aiming programs are thus thought to be necessary for assuring the longevity and the emergence of symbiotic linkages and networks. IS literature presents multiple examples of such IS aiming programs. While IS literature refers in many cases to national initiatives, examples are found within practice that describe ways in which ports engage with industrial symbiosis (LOOP Ports, 2020). Inspiration could be taken from both scholar literature and practice to be implemented at local levels within other port industrial areas. They function based collaborative processes engaging a multitude of actors from various sectors in both IS emergence and development. Application of a similar strategy for the Aalborg East port industrial area, where an intentional IS-aiming program to be developed in collaboration among various actors in the area, could build further on both existing IS network (Schlüter & Milani, 2018) and the emerging one. IS facilitation and reproduction dynamics could be used to further support and enable IS emergence in the area.

Mobilization capacity in a port industrial area context is therefore thought to be probably the most significant factor that enables IS emergence. Such a finding supports and builds further on Boons and Spekkink (2012), who find that the mobilization capacity was the most important institutional capacity for IS emergence and development.

Institutionalization. The initiation and raise of collaborative structures, and facilitative entities that can foster and encourage mobilization of institutional capacity, can be viewed and understood as signs for institutionalization of IS (Chertow & Ehrenfeld, 2012). While Chertow and Ehrenfeld (2012) mention the importance of facilitative structures, informational resources, technical assistance, and the engagement with various actors as important for IS emergence and development, the present research adds to these by setting focus on the need for institutionalization of IS emergence through initiating multi-actor processes intentionally aiming at IS emergence and engaging various actors across sectors in continuous (strategic and operational) interactions where actors can play various facilitative roles. Such processes can be incubated by specific platforms that can accommodate various partnerships according to the (environmental) issue and/or possibility identified.

In the context of the Aalborg East port industrial area, IS sprouted long ago and the existing IS network was recently uncovered. IS-aiming initiatives were implemented and collaboration structures for further application of IS strategies formed to further support and foster IS emergence in the area. While institutionalization proves to be crucial for activating and mobilizing existing capacity and enabling IS emergence in the port industrial area, it continues to build the institutional contextual capacity even further. What Chertow and Ehrenfeld (2012) stated years ago remains true and relevant for Aalborg East port industrial area:

"*it seems very likely that institutionalization (...) may be the best way to further the norms of resource sharing*" (p. 24)

9.3 What are the specific contextual characteristics and capacity of the Aalborg East port industrial area that can facilitate industrial symbiosis emergence, and How can industrial symbiosis emergence be further facilitated in the area?

Besides understanding the actual IS emergence, identifying its characteristics and factors that facilitate it, the present research has provided insights into the characteristics of the Aalborg East port industrial area. The empirical study on the IS emergence process in this area and the observations effectuated during the PhD project allowed identification of specific contextual characteristics of the Aalborg East port industrial area, which facilitated the current IS emergence process and can facilitate further processes.

IS emergence in the Aalborg East port industrial area is found to benefit from the presence of logistical possibilities, the infrastructure in the area, and geographical co-location of various (business) organizations at the Port of Aalborg's perimeter and in its hinterland. While the most emerging symbiotic relationships are found to be possible between local organizations, some relationships are possible with partners across geographical borders. Furthermore, the presence of the port and its engagement with IS, researchers such as DCEA with specific facilitative capacities and relevant environmental expertise and pro-active attitude, and pro-active companies in the area with symbiotic mindsets, willingness, and openness for new collaborations and sustainability ambitions provide a fruitful institutional context for future IS emergence. Such characteristics of the area present its capacities for further support and facilitation of IS emergence. However, in order for such capacities to be activated, mobilized, and built further, there is a need for both the port and the other actors to internalize their own organization of partnerships, with systematization and standardization; i.e. they need to allocate specific (human, financial, etc.) resources to create specific organizational structures and systems in order to assure the desired effects of partnerships for IS emergence. Research analyzing the possibilities and ways to support IS emergence in the Aalborg East port industrial area exist, while the further IS emergence could benefit from research focusing on how the actors involved in collaborative processes could establish such organizational structures and systems to support future IS emergence processes and partnerships for these. Moreover, research monitoring the institutional capacity building through the collaborative processes could bring further insights in the IS dynamics and their effects on IS emergence.

The current IS emergence process in the Aalborg East port industrial area appears to have benefitted from the presence, not only of the Port of Aalborg, but also the Environment^{++} initiative. Environment^{++} is found to function both as a partnership and a collaborative platform fostering strategic and operational activities facilitating IS emergence. Future IS emergence processes could further benefit from similar collaborative structures. Two ways of organizing such collaborative structures are explored by this research. Moreover, the Port of Aalborg currently supports several other initiatives that could function as platforms accommodating future organization of Environment^{++}. To assure positive effects of these and assure the future of the Environment^{++} initiative, it is found that institutionalization of such processes is needed, as mentioned above. Specific collaborative structures with shared rules, norms, and visions are necessary to be established. Within these, actors may take various (leading) roles, among which champions, facilitators, and bridging actors are necessary. Without such entities, IS emergence risks not to happening and the capacity built during Environment^{++} initiative may remain passive and not mobilized.

Intentional establishment of a collaborative structure can secure the facilitation of collaborative processes. However, intentional and focused facilitative processes are necessary to be initiated and unrolled. Establishing a focused facilitative process and a specific facilitative entity can encourage focused (strategic and operational) activities directed specifically towards IS emergence. These in their turn can assure continuous interactions, engaging multiple actors across sectors activating and mobilizing their existing institutional capacity, while building it further.

While the present research points at potential screening and mapping, matchmaking activities, development of business models, communication, and coordinative activities through which an IS network forms and institutional capacity builds, further inspiration on facilitative and capacity mobilization techniques can be taken from IS literature (see Mirata, 2005, Spekkink, 2015). Although IS literature presents several studies pointing at specific activities that could act as mobilization techniques and activities for building the institutional capacity for IS emergence further (e.g. Park et al., 2018; Paquin & Howard-Grenville, 2012, Sun et al., 2017; Wang et al., 2017), it remains scarce in studies presenting a methodological contribution to how IS emergence can be facilitated through mobilization techniques. Thus, further research on these aspects is necessary. Following, monitoring, and evaluating the current and future processes of IS emergence in the Aalborg East port industrial area could shed light on further facilitative activities that work on IS emergence. Research collaboration on identifying facilitative actions across IS emergence cases and contexts could make an important contribution to the IS field, as, as this research finds, researchers play an important facilitative role within IS emergence processes. This raises questions and the need for further consideration of the role of researchers, universities, and science in the transition towards sustainability.

Concluding, it can be stated that the present research, by identifying the specific characteristics of the Aalborg East port industrial area and the factors that facilitate IS emergence in this context, and elucidating specific characteristics of IS emergence processes, has pointed at the existing capacities in the area, and the capacities that needs to be built through further processes. Institutionalization of IS emergence through collaborative structures and processes that can mobilize and build further the institutional capacity in the area are necessary.

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Appendeces

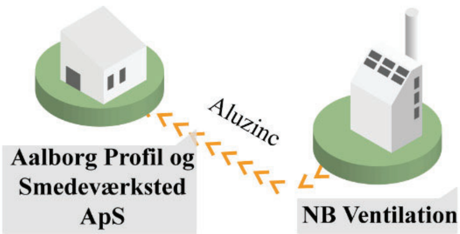
APPENDIX I

INDUSTRIAL SYMBIOSES EMERGING THROUGH SUSTAINABLE SYNERGIES PROJECT

Industrial symbioses based on material flows

In November 2018 the facilitation team established the contact with a ventilation system producer, NB Ventilation A/S. After continuous interactions with the company, it was screened for potential resources that could be utilized as resource flows. Several by-products from own production were identified as being discarded and presenting resource potential for possible symbiotic flows, among which were defected professional electric tools, Aluzinc and plastic sheets. The company then became one of the partners within several symbioses.

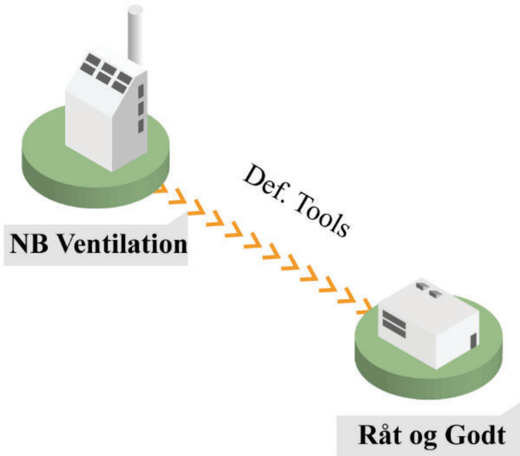
Symbiosis 1: Reuse of Aluzinc sheets



Aluzinc is a galvanized steel sheet which is corrosion resistant and durable. The ventilation system producer, NB Ventilation A/S is a company located in Aalborg East, established in 1973 and a management change in 2016, with ca. 40 employees. The company produces and sells ventilation units that range from small residential units to larger comfort systems for larger units. The company is interested in saving from discarding the Aluzinc plates as by-products from own production and engaged in the Sustainable Synergies project by signing the partnership agreement in January 2019. The facilitation team started to develop the business idea for the symbiosis and looked for potential partners. A blacksmith company, Aalborg Profil og Smedeværksted ApS, was identified in March 2019 to be a potential receiver of the Aluzink plates that could be used in own production. The company was contacted by the facilitation team and the two companies were matched by May 2019. The symbiosis is based on the reuse of Aluzinc by-products from the ventilation system producer by the blacksmith company that uses them to replace virgin Aluzinc plates produced and purchased in China and divert the by-products as waste disposal.

From May to June 2019 the potential business model of the symbiosis for both companies was developed and approved by the companies in August 2019.

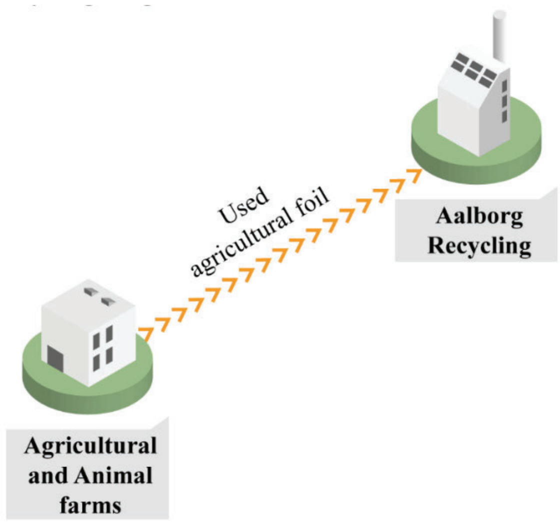
Symbiosis 2: Reparation of professional electric tools



The same ventilation systems producer, NB Ventilation A/S and the socio-economic organization Råt & Godt, seek to enter a symbiotic relation based on reparation of professional electric tools. Råt & Godt engages socially vulnerable young people in various handicraft activities which aims strengthen their professionalism and education possibilities. The organization focuses on reusing discarded materials to produce design furniture, household objects for private use, institutions and companies. The socio-economic organization will collect from the ventilation system producer defected professional electric tools that otherwise are to be discarded. The socio-economic company will then repair as many tools as possible and will sell them to other companies in the area (inclusively NB Ventilation). The symbiotic linkage was not present at the time of data collection back in May 2019 but emerged between May 2019 and January 2020. Despite the fact that Råt & Godt was screened for potential symbiotic possibilities back in January 2019, the development of the business model did not happen before July 2019, when it was possible to match the two companies together. In this time the business idea was developed for both companies and environmental effects were calculated. The symbiotic business models were approved by Råt & Godt in September 2019, while NB Ventilation approved it in January 2020.

Interacting with companies has permitted for the facilitation team to identify several societal challenges with specific materials that are discarded in a condition that permits the material to be recycled and/or reused. Such waste materials are e.g. used agricultural foil, defected washing machines, used spin belt material and cardboard tubes, and plastic sheets. The following symbioses revolve around the flow of these materials.

Symbiosis 3: Recycling of agricultural foil



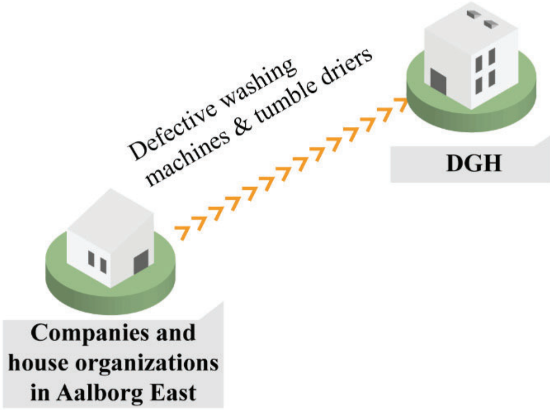
Within this industrial symbiosis, the waste management company, Aalborg Recycling ApS, aims at collecting the used agricultural foil from the agricultural and animal farms in the area. Then the company seeks to clean it, cut it in smaller pieces, melt and produce pellets from recycled plastic. Then later it seeks to implement more machinery to make new foil. The company is originally specialized in collecting and cutting iron and metal scrap and provides container services to companies. During the last years the company was enlarged to fine- cut glass fibre from scrapped wind turbine blades and produce noise reduction walls. No companies exist in Denmark that can recycle the agricultural foil, therefore the symbiotic business model seems to be promising.

The company was screened for potentials back in November 2018, but the development of the symbiotic idea took time. The facilitation team, learning about the company's ambitions with the collecting and recycling of agricultural foil, simultaneously as they learned about the societal challenges with it, got the business idea. By May 2019 initial thoughts and ideas for this symbiotic flow were initiated, while by August 2019 they developed a business model and calculated possible (economic and environmental) effects.

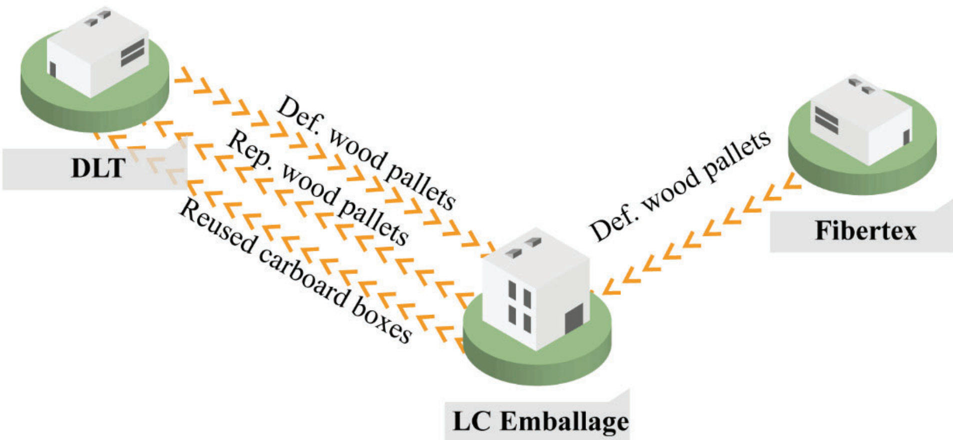
Symbiosis 4: Recycling of defective washing machines and tumble driers

De Grønne Hvidevarer (DGH) is a one-man company located in Nørager, outside Aalborg East. The DGH's owner, after succeeding in repairing and reselling the defective machines collected from Aalborg Renovation, established the company in 2016. DGH repairs the machines, ensures their quality and resells them with a warranty to a broad variety of companies. Within this symbiosis, DGH will collect the defective washing machines and tumble driers from companies and real estate agencies in Aalborg East port industrial area, will repair them, quality secure and resell them (hopefully in the same area).

In June 2018 the facilitation team became aware of the societal problem with the defected machines and tumble driers that were discarded. The contact to DGH was established and the company was screened for possibility of joining the project. Learning about the possibilities the company had, the facilitation team engaged with the company in developing the business model and in providing consultancy possibilities until June 2019. The business model of the symbiosis was developed by August 2019 and potential environmental benefits are calculated.



Symbioses 5 & 6: Re-use of wooden pallets and cardboard boxes



Re-use of wooden pallets

The screening for potential resources during 2018 in the port industrial area allowed the facilitation team to identify multiple companies that had specific amounts of wooden pallets that were discarded. Seeing it as a possibility for IS initiation, the facilitation team explored the possibility of a common initiative of collecting the

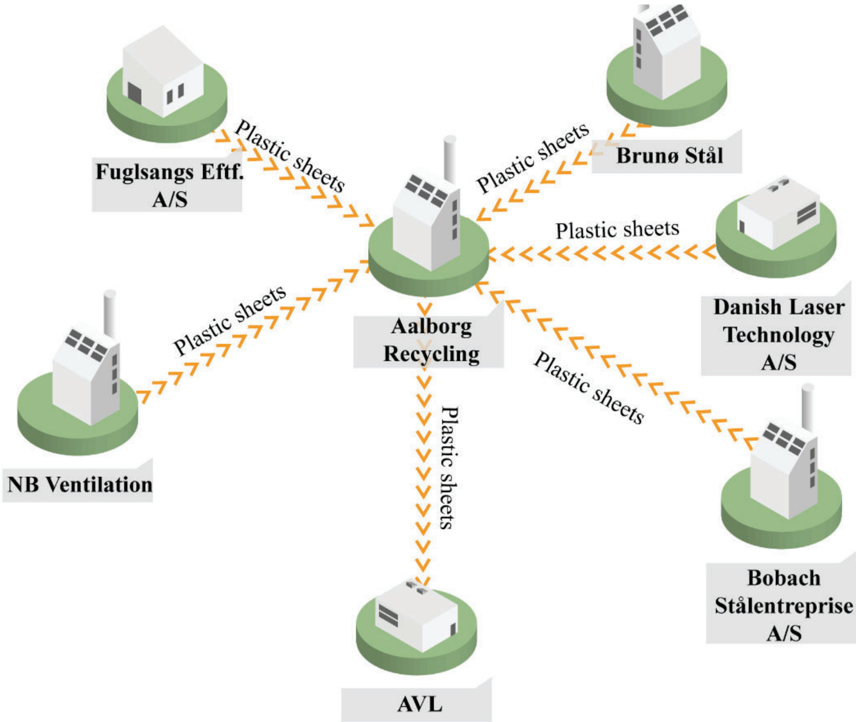
wooden pallets and transporting them to the waste management company, LC Emballage situated in Hobro, outside the port industrial area to be repaired and reused. LC Emballage is a company which deals with disposable pallets, pallet frames and cardboard boxes, which are sorted, repaired and resold. The company was screened for possibilities in February 2019 and partnership was signed in March 2019. Since then, possibilities of identifying companies that could send pallets to LC Emballage were explored. Several companies in Aalborg East area were identified as having specific amounts of wooden pallets as a waste material before May 2019. However, only two companies became interested in collaboration on this symbiotic flow. One of the two companies is Danish Laser Technology A/S. Danish Laser Technology A/S is a company located in Aalborg East with ca. 50 employees. It is a supplier to other companies in the area. The company manufactures metal parts by laser or water cutting plates, pipes, etc. Danish Laser Technology A/S was screened for potentials in March 2019 and entered the symbiotic partnership with LC Emballage in April 2019. The second company joining the symbiosis (after May 2019) is Fibertex Personal Care A/S. The company is part of Fibertex Personal Care Group with 740 employees around the globe. The company has a production site located in Aalborg East where it produces supplies of non-woven fabric for hygiene products. As Fibertex Personal Care A/S is a large company it did not comply to the requirements of the Sustainable Synergies project that focused on small and medium sized companies. Thus, Fibertex Personal Care A/S did not become a formal partner in the project but involved in the IS emergence through the Environment^{++} initiative.
Symbiotic business models were developed and approved by the (two formal partners in the project) companies by July 2019.

The (defective) wooden pallets are to be collected from Danish Laser Technology A/S and Fibertex and transported to LC Embalage, where these can be repaired and sold further to other companies, and part of them can return to Danish Laser Technology A/S.

Re-use of cardboard boxes

Danish Laser Technology A/S uses a considerable number of cardboard boxes for packaging and sending of production materials to its customers. Today the company uses new cardboard boxes. LC Emballage is specialized in reselling cardboard boxes in good condition to other companies. Identification of the symbiosis concerning the reuse of wooden pallets also identified a new symbiotic relation between the two companies. Within this, Danish Laser Technology A/S will buy recycled cardboard boxes from LC Emballage to replace the new ones in their production. By May 2019 several companies that wanted to send used cardboard boxes to LC Emballage were identified but only Danish Laser Technology A/S joined the partnership. The companies signed the partnership with the facilitation team in March – April 2019. After May 2019, companies were matched, the business plan was developed, and potential effects were calculated.

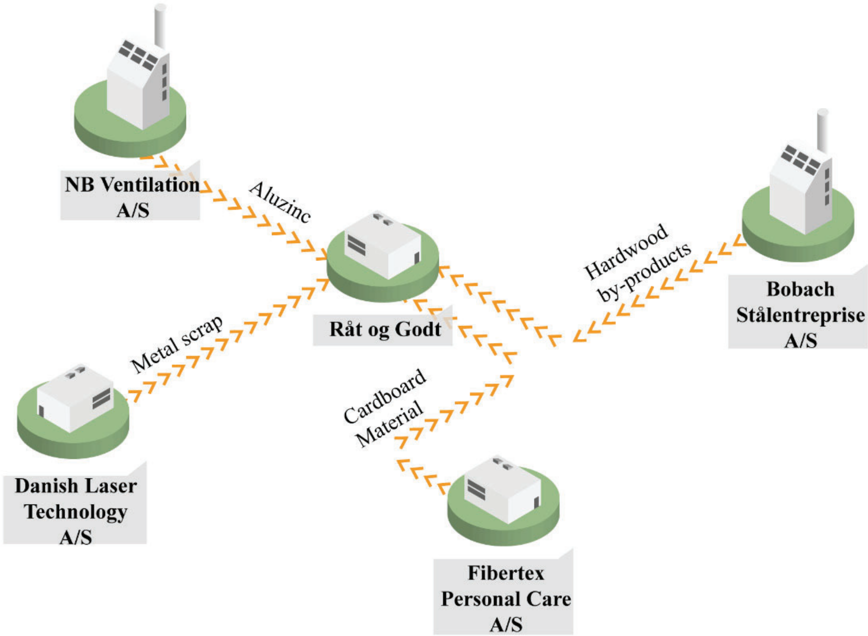
Symbiosis 7: Recycling of plastic sheets



Plastic sheets as by-products or waste fraction (used to separate metal plates during transportation) were identified as a potential resource for symbiotic flows at various companies' screenings at the end of 2018 and beginning of 2019. As a small amount was identified at several companies, a common initiative was necessary. From March to August 2019 the symbiotic idea was developing, and potential partners were explored. By May 2019 five companies that receive steel sheets to be used in their production were identified to possess significant amounts of plastic sheets that could be transported to Aage Vestergaard Larsen A/S (AVL). By that time the initial contact with the plastic management company was established and continuous negotiations were taking place. By September 2019 the companies in the symbiosis were identified and business models were developing by January 2020. Currently, the symbiosis is emerging between AVL and Bobach Stålenterprise, Brunø Stål ApS, NB Ventilation, Danish Laser Technology A/S, and Fuglsang Eftf.A/S.

Within this symbiosis, the plastic sheets are to be collected from multiple companies in the Aalborg East area and stored in Aalborg East at RGS Nordic until 2-5 tons are collected. Then, these are to be transported to AVL. RGS Nordic will function here as an intermediary company. In this way plastic sheets can be transformed into plastic granules and reused instead of being discarded. AVL is Scandinavia's largest plastic recycling company located in Mariager (outside the Aalborg east). Established in 1972, AVL has today more than 50 employees. The company is specialized in recycling, grinding, and compounding of various kinds of plastics.

Symbiosis 8: Design of recycled materials



From May 2019 to January 2020 a new symbiosis was developing between the socio-economical organization, Råt & Godt and four other companies: the ventilation system company NB Ventilation A/S, Bobach Stålenterprise A/S, Fibertex Personal Care A/S, and Danish Laser Technology A/S. The symbiosis is based on the collection of by-products (wood, cardboard tubes, spin belt material, Aluzinc and metal) by Råt & Godt and upcycle these into design furniture made by Råt & Godt.

Råt & Godt is socio-economic organization that engages socially vulnerable young people in various handicraft activities which aims at strengthening their professionalism and education possibilities. The organization focuses on reusing discarded materials to produce design furniture, household objects for private use, institutions and companies.

Within this symbiosis five types of materials are to be recycled: *Cardboard tubes* of high-quality material are to be collected from Fibertex Personal Care A/S. Today the tubes are recycled but have potential for being reused due to their clean and strong quality; *Spin belt material* is to be collected from the same company Fibertex Personal Care A/S. The spin belt material is a net of a high and strong quality. The spin belt material together with the cardboard tubes can be used as main materials in the new designed lamps.

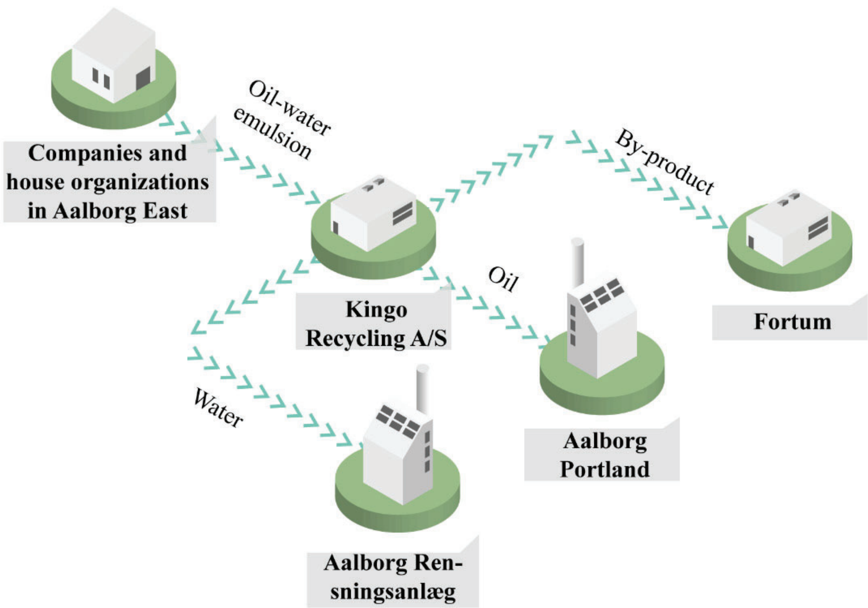
Hard wood by-products are to be collected from Bobach Stålenterprise A/S. Bobach Stålenterprise A/S is a forging and engineering company located in Aalborg East. The company is a supplier for new construction and renovation of balconies, stairs, handrails, guardrails, and load bearing structural steel. The company gets hard wood by-products from its production especially from building balconies. As the material is of good quality, this can be reused in by Råt & Godt in building design tables. *Aluzink by-products* of smaller measurements from NB Ventilation A/S are to be collected by Råt & Godt to be used in the design furniture such as tables and chairs. Råt & Godt will collect also *metal by-products* from Danish Laser Technology A/S. Danish Laser Technology A/S has steel scraps that can be used in the production of new designed furniture such as tables.

The symbiotic idea started to developing in March 2019. However, it was in the facilitator's attention longer before that, as the facilitation team started developing the idea already in March 2018. Through multiple iterations between companies, facilitation team and Huse Design, a designer company to develop the design for the new furniture the symbiotic idea developed, and companies were matched by June 2019. The first to join the symbiosis with Råt & Godt was Bobach Stålenterprise A/S. Then, gradually, more companies were matched up during the facilitation process. Danish Laser Technology A/S joined the symbiosis at last contributing with the last elements for the design tables. The business models for each company were developed by the facilitation team by November 2019 and approved by January 2020.

Industrial symbioses based on liquid flows

While the above symbioses are based on re-use and recycling of otherwise discarded materials, the following symbiosis revolve around flows of liquids: oil-water emulsion as a by-product.

Symbiosis 9: Separation of oil from water within oil-water emulsions discarded

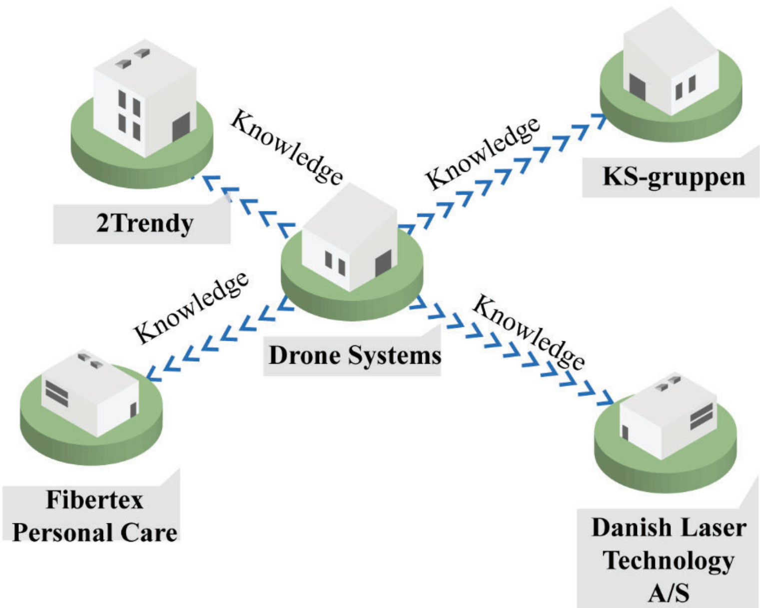


This symbiosis revolves around several potential partners. The waste management company, Kingo Recycling, located in Aalborg East and established in 2017 as a branch to Kingo Karlsen A/S located in Silkeborg, is a pro-active small company that develops method for recycling and recycles primarily by-products from construction sector. Within this symbiosis, Kingo Recycling would like to collect oil-water emulsion as a by-product from various companies in Aalborg East (e.g. ships, car and buss wash areas, construction machinery cleaning, surface run-off storages, etc.) and, through various processes, it seeks to separate the oil from water. The oil is then to be transported to the local cement factory, Aalborg Portland that can use it as a fuel within the cement production. The water is to be transported to the local water treatment company, Aalborg Rensningsanlæg, for further cleaning. The by-product of this separation process which cannot be used, since it is possibly hazardous waste/by product, is to be transported to Fortum, a company outside the area. The symbiotic idea was identified back in June 2018 when the waste management company was screened by the facilitation team. In October 2018 the company joined officially the project and involved in the further development of the symbiotic idea. By May 2019 the symbiotic idea was clearly defined, while potential partners (Aalborg Portland, Fortum and Aalborg Rensningsanlæg) were not yet identified. The exploration of various potential partners from May to January 2020 permitted identification of these. By July 2019 the symbiotic business model was developed, and up to November 2019 the company got involved with a consultancy company to aid the development of the water cleaning process and competencies within the company. Also, a student project was initiated, which led to Kingo Recycling now being able to process another type of by-product watery emulsion. The symbiotic plan was approved, and the expected environmental effects were calculated by the facilitation team.

Industrial symbioses based on knowledge flows and shared service

At the group interview with the facilitation team in May 2019 two possibilities for initiation of knowledge and shared service symbioses were identified. Following-up on these, in January 2020, two other symbioses based on knowledge and shared service flows were emerging. Furthermore, a new symbiosis regarding furniture design from recycled materials was identified. The following presents the emergence of the symbioses as identified in January 2020.

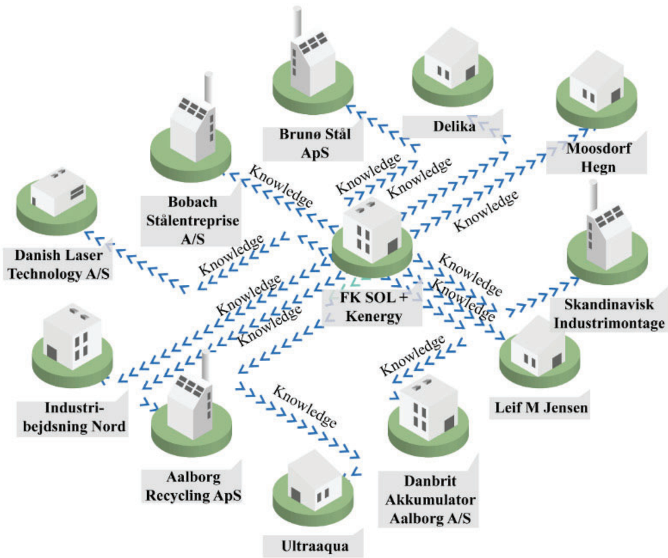
Symbiosis 10: Knowledge and shared mapping service symbiosis on energy and heat loss



This symbiosis revolves around Drone Systems, a consultancy company specialized in drone- and thermographic measurements, that offered a group of co-located companies free screening and mapping of the energy loss from corporate buildings.

By March 2019 the offer was sent out to the companies through the Business network 9220 and a number of companies, among which five became partners in the Sustainable Synergies project, joined the symbiosis before summer 2019. These are KS-gruppen, Fibertex Personal Care, Danish Laser Technology A/S, 2Trendy, and Tri Trail. The facilitation team developed the symbiosis idea from March to October 2019, while also screening the potential partners for resources potentials. Drone Systems flew with drones over the buildings of the companies involved and mapped the heat loss from these. The data collected by the drone were then processed and analyzed by another consultancy company, Brix & Kamp who joined the symbiosis to conduct feasibility studies of different energy efficiency initiatives. A meeting between several actors (the facilitation team, Aalborg Heat utility company and Drone Systems) was held to explore possibilities for future improvements. The companies involved obtained a complete overview of the heat loss from own buildings and, after Brix& Kamp analyzed the data, they got an overview of the investments necessary for energy efficiency possibilities regarding heat loss from own buildings. Thus, the knowledge resulting from the shared mapping service back in May-June 2019, could be used for identifying possibilities for energy efficiency improvements at each company level in January 2020.

Symbiosis 11: Knowledge and shared mapping service symbiosis on feasibility of installing solar panels



Several companies that were screened back in November 2018 by the facilitation team pointed at a large amount of energy consumption. At that time, the facilitation team could not identify any potential symbiotic relation that could address these possibilities. However, by November 2019 an offer to the companies in the port industrial area of Aalborg East was sent through different channels, including the Business Network 9220. The offer contained the proposal of joining a common initiative where a consultancy company, FKSol, offered free screening services for mapping the potentials and feasibility of installing solar panels on the roofs of corporate buildings. A group of twelve small and medium companies that have a large amount of energy consumption joined the symbiosis (Danbrit Akkumulator Aalborg A/S, Ultraaqua A/S, Delika A/S, Industribejdsning Nord, Brunø Stål ApS, Danish Laser Technology A/S, Aalborg Recycling ApS, Leif M Jensen, Skandinavisk Industrimontage, Moosdorf Hegn, Bobach Stålentreprise A/S, and Elektro Gruppen). Many of these were already among those screened back in November 2018 – February 2019. The facilitation team developed business ideas and models and obtained partnership agreements from companies joining the symbiosis by November 2019. After the companies received the screening from FKSol for potential and rentability of investing in solar panels and under what conditions, eleven of these were identified to have considerable potential and another consultant company, Kenergy joined the symbiosis to calculate the feasibility of the different potential possibilities. The individual results for each company will be collected and knowledge and experience will be disseminated to the entire Aalborg east port industrial area.

Several other by-products such as big bags, textiles, and glass fiber, were identified from company screenings. Some of these constituted resource flows within symbioses identified as emerging through data collection in May 2019, and which terminated by January 2020. For example, the symbiosis based on recycling of textiles collected from a laundry in Aalborg East, the knowledge symbiosis between a utility company and a production company in Aalborg East, the symbiotic relationship between a waste management company glass fiber producer company based on recycling of glass fiber, the symbiotic relation between Fibertex Personal Care A/S and a festival arranging company based on recycling of spin belt material and cardboard tubes.

APPENDIX II

REPRODUCTION OF INDUSTRIAL SYMBIOSES EMERGING THROUGH SUSTAINABLE SYNERGIES PROJECT

Introduction

The aim of this appendix is to present the study of the previously emergent symbiotic linkages' role for the emergence of newer ones, and thus to examine the reproduction of symbiotic linkages emerging through Sustainable Synergies project.

The IS reproduction model developed by Schlüter et al. (cf. 2020 #4) is applied to the emerging industrial symbiosis (IS) network through Sustainable Synergies project. Doing that it is necessary to specify that the initial symbioses are not established ones, as in the case studied by Schlüter et al. (cf. 2020 #4), but still emerging ones. While this is an important difference, it is not perceived as affecting the understanding and application of the IS reproduction model. This is because a consecutive order of emergence between the initial and the following symbioses still exists. Application of the reproduction model to the emerging IS network through the Sustainable Synergies project is thought to be able to offer insights into how the different dynamics (of facilitation and reproduction) are connected. Subsequently, a discussion of differences in reproductive modes of self-organized and facilitated IS can be made.

Methodological clarifications

In order to apply the IS reproduction model to the emerging symbioses, a closer methodological clarification must be made. When presenting the IS reproduction model, Schlüter et al. (cf. 2020 #4) describe each IS reproduction mode as having specific characteristics. These, in their turn, present indices for classifying the mode through which symbiotic linkages reproduce. Table 1 summarizes the reproduction modes' characteristics. These refer to the type of knowledge diffused (targeted, untargeted) and the degree of interdependency between symbiotic linkages as enabler for the reproduction mode. Also, these functioned as parameters for identification of the reproduction mode among the emerging symbioses. The emergent symbiotic linkages were analyzed in accordance with these characteristics and the specific reproduction mode was identified.

Table 1:Characteristics of reproduction modes presented by the IS reproduction model developed by Schlüter et al. (cf. 2020 #4)

Reproduction process		**Classification indices**
Budding	Reproducing	Targeted/untargeted knowledge diffusion Direct and purposefully exerted influence of a previous symbiosis Dependency on the previous symbiosis Can clone Can settle
Broadcast spawning		Untargeted knowledge diffusion (usually by symbionts) Independency between symbiotic linkages Can clone Can settle
Brooding		Targeted knowledge diffusion (usually by symbionts, facilitators, etc.) Independency between symbiotic linkages (with a closer connection between these) Can clone Can settle
Staying attached	Settling down	Dependency between symbiotic linkages Connected through shared partners, material markets, facilitators Emergence relying or controlled by the older symbiosis Can settle as independent
Budding off		Settling of IS Independency between symbiotic linkages
Cloning		An impetus (reproducing modes) makes the symbioses emerge at the same time Dependency /independency between symbiotic linkages
Settling		Physical establishment Commercially viability is assured Relationships established by contracts
Colony formation	Growing larger	Through continued budding
Further reproduction		Through broadcast spawning or brooding Through active implication of symbiotic actors
Colony division		Colony formed can intentionally/unintentionally divide

A closer look at the emerging IS network through the process of the Sustainable Synergies project allowed to observe that while some symbioses emerged before May 2019, some others emerged after this date. While some companies only participate in one symbiosis, other companies are shared symbionts within several symbioses, and while some symbioses have bilateral linkages, some others resemble what Schlüter et al. (cf. 2020 #4) might call 'a colony'. Moreover, analyzing the business model reports developed by facilitation team, connections between particular symbioses could be identified. This encouraged application of the reproduction model to four symbioses that:

1. Emerged after May 2019
2. Share common symbionts
3. Have more than two bilateral linkages

The Table 2 presents four symbioses selected. These serve as four cases on which the model is applied.

Table 2: Overview of symbioses analyzed for reproductive processes of emergence.

Symbiosis	Sender	Resource	Receiver
Case 1: ***Design of recycled materials***	NB Ventilation A/S	Aluzink	Råt &Godt
	Bobach Stålentreprise A/S	Hard wood by-products	
	Fibertex Personal Care A/S	Cardboard tubes spin belt material	
	Danish Laser Technology A/S	Metal pieces	
Case 2: ***Recycling of plastic sheets***	Danish Laser Technology A/S	Plastic sheets	AVL RGS Nordic
	Brunø Stål ApS		
	NB Ventilation A/S		
	Bobach Stålenterprise A/S		
	Fuglsangs Eftf. A/S		
Case 3: ***Knowledge and shared mapping***	FKSol Kenergy	Knowledge	Danbrit Akkumulator Aalborg A/S
			Ultraaqua
			Delika
			Industribejdsning Nord

service symbiosis on feasibility of installing solar panels			Brunø Stål ApS
			Danish Laser Technology A/S
			Aalborg Recycling ApS
			Leif M Jensen
			Skandinavisk Industrimontage
			Moosdorf Hegn
			Bobach Stålentreprise A/S
Case 4: ***Re-use of wooden pallets and cardboard boxes***	Danish Laser Technology A/S	Defective wooden pallets	LC Emballage
	LC Emballage	Repaired wooden pallets	Danish Laser Technology A/S
	LC Emballage	Re-usable cardboard boxes	Danish Laser Technology A/S

The emergence through reproduction of the symbioses selected is explained below.

Case 1: Design of recycled materials.
The design symbiosis is an appropriate case to be studied as in its end state it resembles a small network of several synergies connected through Råt & Godt as a shared symbiont. Most of these synergies seem to emerge from the experiences of previously emerging symbioses. The Figure 1 presents an overview of the symbiotic linkages within the IS network. Five types of materials – metal, cardboard tubes, spin belt material, Aluzinc by-products and hard wood, are to be collected by Råt & Godt from 4 companies – Danish Laser Technology A/S, Fibertex Personal Care, NB Ventilation, and Bobach Stålentreprise. These flows of materials make the four synergy within the symbiosis:

Synergy I: Bobach – Råt & Godt (hardwood)
Synergy II: Fibertex – Råt & Godt (spin belt & cardboard tubes)
Synergy III: Danish Laser Technology A/S – Råt & Godt (metal)
Synergy IV: NB Ventilation – Råt & Godt (Aluzinc sheets)

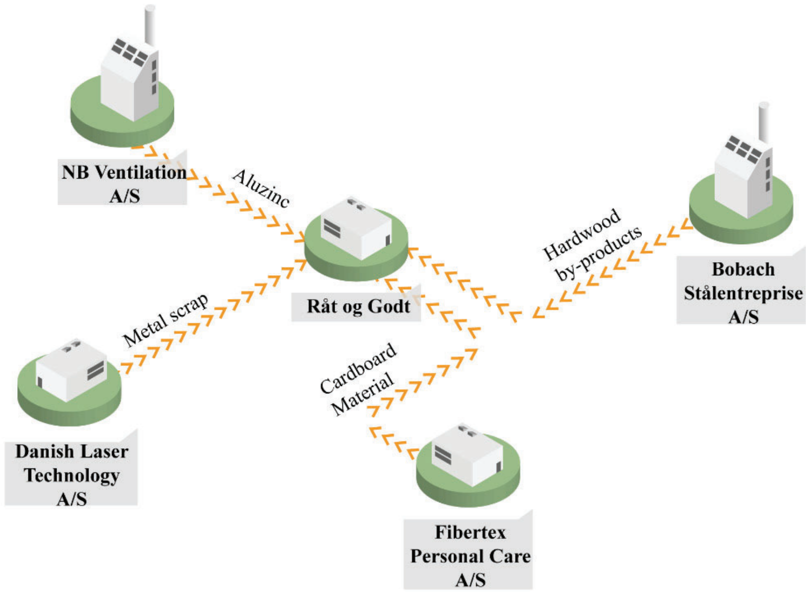


Figure 1:Symbiosis based on the design of recycled materials

The symbiosis - Design of recycled materials **-** emergence through reproduction is reminiscent of a *(2c) cloning process,* as the synergy I, between Bobach Stålentreprise A/S and Råt & Godt, encouraged the emergence of the other synergies simultaneously. Moreover, dynamics of *budding (1a)* and *brooding (1c)* are identified as impetus for the cloning process and later to colony formation. The companies entering this symbiosis were initially partners in other emergent symbioses, while the facilitation team simultaneously tried to identify possibilities for Råt & Godt. Thus, the emergence of this colony builds on reproduction dynamics of each symbiotic linkage.

Synergy II: Fibertex Personal Care – Råt & Godt (spin belt & cardboard tubes)

The linkage between Råt & Godt and Fibertex Personal Care (FPC) evolved from the endeavor of trying to make another symbiotic linkage emerge: between FPC and a festival-organizing company. By May 2019 the amount and material properties of the spin belt material and the cardboard tubes were identified and possibilities for its reuse were explored. Interactions among several groups of actors unfolded, including designers and a design workshop was organized to explore the possibilities for their reuse. Specific possibilities were identified as promising such as e.g. the reuse of spin-belt material for designing new products as e.g. festival carpets for the festival-organizing company, Nibe Festival, and/or playground facility. However, by January 2020 the connection between the large company and the festival-organizing company were not developed. In contrast, the materials were directed to Råt & Godt and the connection between FPC and Råt & Godt was established. This is reminiscent of *budding* (1a) as the knowledge was targeted and diffused towards Råt & Godt. Moreover, the emergence (or rather non-emergence) of the previous synergy (between FPC and Nibe Festival) exerted a direct influence (through its non-emergence) on the emergence of the new synergy.

The IS reproduction model presents budding dynamic as one where the two synergies (the previous and the new one) are dependent on each other. However, in this case, where the non-emergence of the previous synergy leads to the emergence of a new one is rather reminiscent of the 'Phønix effect'. Schlüter et al. (cf. 2020 #4) find a similar situation within one of the cases studied. The authors explain that "*looking back to our biological equivalents, in some species of corals we can observe an unusual habit of forming buds primarily when the parent is moribund or injured" (p. 12).* This explanation refers to the new synergy emerging from the death of an established synergy. In the case of the synergy between FPC and Råt & Godt, the synergy evolves not from an established synergy but from a previous one whose emergence terminated before even it settled. The dependency between the two synergies (the one terminated, and the one emerging) is low. This is because the amounts of materials available at FPC are high, and the Råt & Godt's opportunities are limited. Thus, other symbiotic linkages with the same material flows can emerge without affecting drastically this synergy.

Then another difference between the IS reproduction model and cases studied by Schlüter et al. (cf. 2020 #4) is that in the case of synergy between FPC and Råt & Godt it is not the symbiotic partners that diffuse the knowledge, but the facilitator. The knowledge available from earlier processes was made in purpose available for another synergy by the facilitation team during the Sustainable Synergy project. The presence of facilitators and participation in the project made the identification of specific material (i.e. spin belt material and cardboard tubes) to be used by Råt & Godt possible. Such factors enabled the reproduction of the synergy related to spin belt material and cardboard tubes.

Synergy III: Danish Laser Technology A/S – Råt & Godt (scrap metal)
As the figure 2 shows, the synergy based on the flow of metal scrap from Danish Laser Technology to Råt & Godt emerges as reproduced from another emergent symbiosis – the re-use of cardboard boxes and wooden pallets.

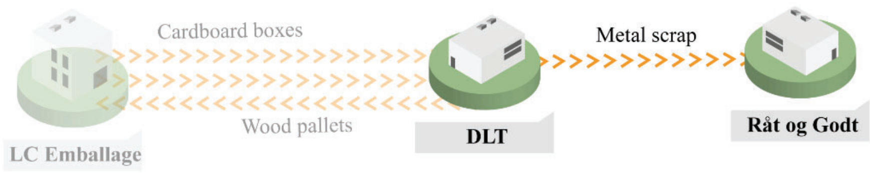


Figure 2:Emergence of synergy between DLT and Råt & Godt.

Danish Laser Technology A/S was involved in a previous symbiosis concerning the reuse of cardboards boxes and wooden pallets. While developing these synergies, the company was found to have some other materials as by-products from their production/services – scrap metal. This material became then a resource for Råt & Godt and an impetus for the new synergy between Danish Laser Technology A/S and Råt& Godt. Råt & Godt, as a socio-economic organization, could take smaller amounts of materials that otherwise could not get into a recycling flow. One of the facilitation team representatives specify that "*the [scrap metal] material was the reason to meet but ended up being secondary to the plans of close collaboration. Almost a token. Danish Laser Technology A/S would get money for recycling it, but now give it to Råt & Godt for free to consolidate the collaboration on human resources (jobs), and the working together on the design table. Danish Laser Technology A/S making legs, designed especially for their production, from their scrap materials, and selling them to Råt & Godt for the production costs*" (Follow up discussions, 2020)

The reproduction of this synergy, based on the previously emerging symbiotic flows of cardboard boxes, and reuse of wooden pallets, resembles the *brooding* (1c) reproduction mode. This classification is based on the observations that knowledge on the existing scrap metal material (from Danish Laser Technology A/S) was in-purpose made available by the facilitation team to another possible symbiont (Råt& Godt). The emerging synergy between Danish Laser Technology A/S and Råt & Godt is independent from the previously emerging synergies based on the flows of cardboard boxes and wooden pallets. Only the engagement of companies in the Sustainable Synergies project and the having Danish Laser Technology A/S as a shared symbiont seam to connect the synergies, and the further establishment and development of the previous synergies seam to not affect the settling and development of the new emerging synergy.

Synergy IV: NB Ventilation – Råt & Godt (Aluzinc sheets)

The synergy between NB Ventilation and Råt & Godt based on recycling of Aluzinc sheets, as depicted in Figure 3 emerged as reproduced from the connection between an earlier emerging synergy in which NB Ventilation is sending Aluzinc to Aalborg Profil og Smedeværksted ApS.

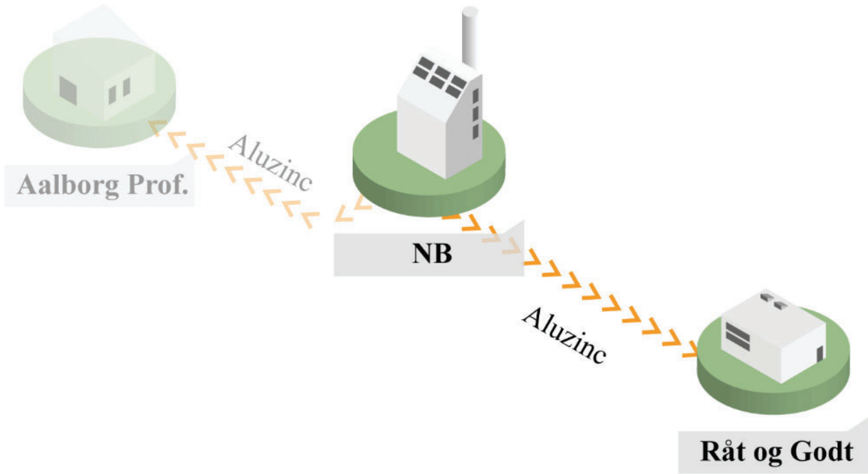


Figure 3: Emergence of the synergy between NB Ventilation and Råt & Godt

The second synergy emerges from the knowledge that this type of material exists at NB Ventilation (while developing the first synergy) and the knowledge of which amounts could be used at Aalborg Profil og Smedeværksted ApS. Thus, the knowledge that particular amounts and fractions of this material could not be used by Aalborg Profil og Smedeværksted ApS, and the knowledge of facilitators on the possibilities that lied in Råt & Godt, permitted the targeted diffusion of knowledge and to match the NB Ventilation with Råt & Godt. Moreover, the presence of a facilitator to connect the knowledge and direct it towards a new symbiotic linkage formation was crucial. Thus, the explicit knowledge was spread by symbionts in the facilitation system, and this, used directly by facilitators encouraged the emergence of symbiotic linkages. The emergence of the synergy between NB Ventilation and Råt & Godt is an example of *brooding (1c)*. Although, the material that shapes the synergies is Aluzinc in both synergies, the two synergies emerge independently from each other. The Aluzinc pieces collected by Råt & Godt seem to be of a smaller measurement than the Aluzinc sheets collected by Aalborg Profil og Smedeværksted ApS. Thus, the two synergies, although they share NB Ventilation and the same type of material, are independent from each other.

Summary and possibilities for further reproduction

Thus, reproduction modes of budding and brooding appear to be the impetus for the cloning of the first synergy. The participation of companies in the Sustainable Synergies project and the presence of a facilitation team seems to be the most important factors that encourage the emergence of new synergies. The facilitation team made the knowledge and materials available in purpose for a new symbiotic partner. The new emerging synergies appear to be independent from previous ones. However, the new emerging synergies appear to be dependent on each other, as they contribute to the design and development of the same furniture series. If the synergies *(2d) settle,* the design symbiotic network can be expected to engage into *colony formation (3a)* where the various materials (plus other materials identified on the way and those that companies would like to donate, as e.g. the steel and iron profiles and aluminum pieces from Danish Laser Technology A/S and other by-products from Bobach Stålentreprise A/S offered as extra material to Råt & Godt) can feed into the production of the same or a new design furniture series by Råt & Godt. As Råt & Godt is a socio-economic organization, more companies in Aalborg East might like to contribute with by-products, therefore the colony formation is deemed quite realistic.

Case 2: Recycling of plastic sheets symbiosis

Five synergies based on collection of plastic sheets from Danish Laser Technology, Bobach Stålentreprise A/S, NB Ventilation A/S, Brunø Stål ApS, and Fuglsangs Eftf. A/S, make the symbiosis based on recycling of plastic sheets, as also pictured in Figure 4. This makes it resemble a small symbiotic network.

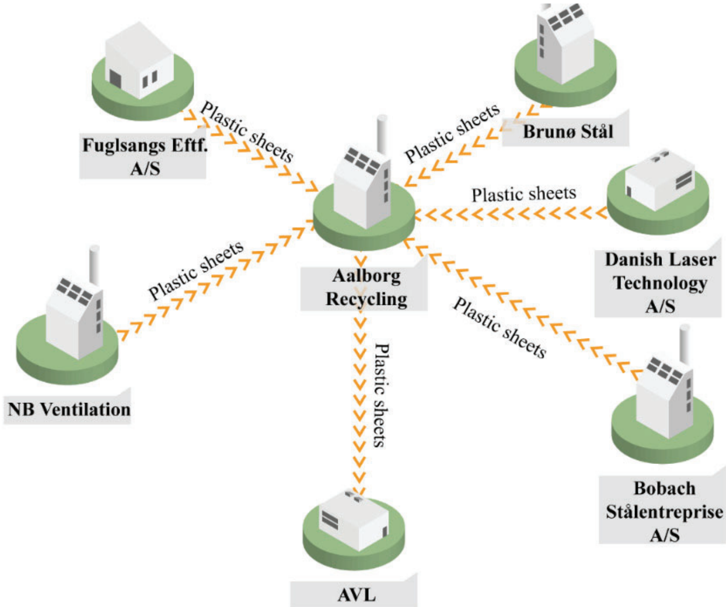


Figure 4: Recycling of plastic sheets symbiosis.

Th emergence of this symbiotic network seems to be reminiscent of *cloning (2c)* where the reproduction mode of *brooding* (*1c)* was the impetus for cloning process.

While symbioses that emerged through a cloning process in the design symbiotic network appear to be dependent on one another based on the materials serving as input resources for the same series of furniture, the symbiotic linkages within this symbiotic network seem to be dependent on each other based on the amounts that AVL needs to collect. A high degree of dependency between the cloned synergies exist as a specific number of synergies have to emerge as a specific amount of plastic is needed for AVL to accept joining the symbiotic network.

Brooding reproduction mode seems to characterize the emergence of the synergies within this symbiotic network. Several companies within this symbiosis entered the project (and other symbioses) before the emergence of this symbiotic network. For example, NB Ventilation engaged in the symbiosis reusing Aluzinc offcuts with Aalborg Profil og Smedeværksted ApS, Danish Laser Technology A/S engaged in several symbiotic synergies, as e.g. reuse of wooden pallets and cardboard boxes, who was a symbiont, Brunø Stål ApS engaged with the project for an energy efficiency solution calculation, Bobach Stålentreprise A/S entered the design symbiotic network, and Fuglsangs Eftf. A/S entered the project due to an earlier knowledge symbiosis with Aalborg Energie Teknik (that is not emerging anymore), etc. Through the process of emergence of these previous symbiotic synergies, the knowledge of plastic sheets existence at these companies became available for the facilitation team. This one, targeted it towards the emergence of a new symbiotic network based on recycling of plastic sheets. The facilitation team became then the connecting link between the knowledge available and new opportunities that could emerge. Thus, knowledge diffusion was strongly targeted specific companies. The new emergent synergies in the symbiotic network of recycling the plastic sheets emerge independently from the previous emerging symbioses that brought the companies in the project.

Possibilities for further reproduction

The symbiotic network presents potential for further development, as AVL has potential for receiving more plastic arcs and it is assumed that besides these companies could exist at least 3-4 other companies in Aalborg East that could have plastic sheets as by-products. While the symbiotic linkages described above emerge simultaneously, with support from the facilitation team, the subsequent symbioses will not emerge in the same time, as these will join later. These will be budded onto the actually emerging plastic sheet symbiosis. If the symbiosis emerges and establishes then it can develop into a *colony formation* (3a) with place for development.

Case 3: Knowledge and shared mapping service symbiosis on feasibility for installing solar panels.

This symbiosis, as pictured in Figure 5 resembles as well a small symbiotic network shaped by the synergies based on FK Sol and Kenergy providing knowledge mapping services to a series of companies: Danish Laser Technology A/S, Bobach Stålentreprise A/S, Aalborg Recycling, Brunø Stål ApS, Leif M Jensen, Skandinavisk Industrimontage, Moosdorf Hegn, Industribejdsning Nord, Delika, Ultraaqua, and Danbrit Akkumulator Aalborg A/S.

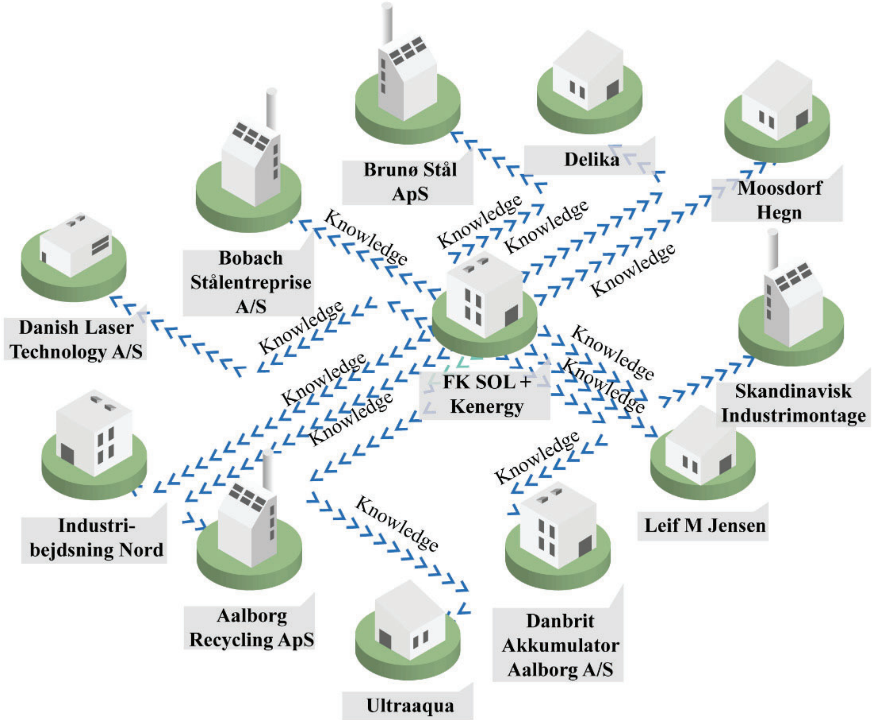


Figure 5: Knowledge and shared mapping service symbiosis on feasibility for installing solar panels.

The emergence of the symbiotic network based on knowledge and shared mapping service on feasibility for installing solar panels seems to be partly through *brooding* (1c) reproduction mode and partly, facilitated by the facilitation team, leading to *cloning* (2c).

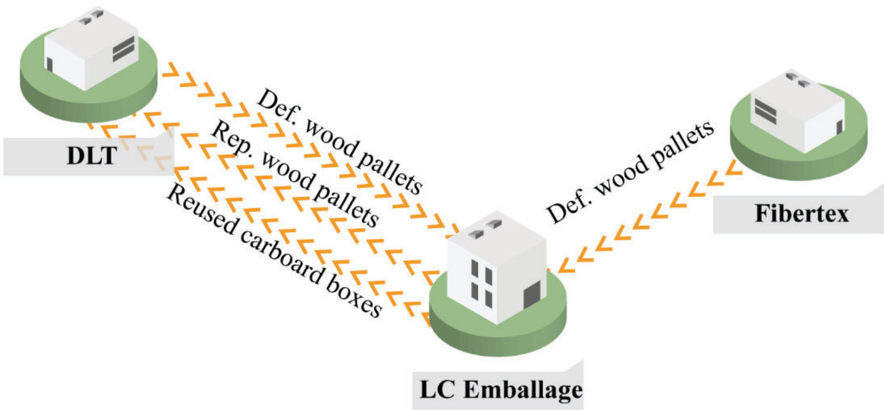
From the 11 companies to join the mapping of solar cells/panels feasibility, 4 companies (Danish Laser Technology A/S, Bobach Stålentreprise A/S, Aalborg Recycling, and Brunø Stål ApS) were involved in previous symbioses, three companies (Leif M Jensen, Skandinavisk Industrimontage, and Moosdorf Hegn) were screened by the facilitation team in the end of 2018 and these joined the project without engaging within a specific symbiosis. The rest of companies (Industribejdsning Nord, Delika, Ultraaqua, and Danbrit Akkumulator Aalborg A/S) were identified when the business idea for this symbiosis arose.

Through the process of emergence of previous symbiotic synergies and the screening of new companies the knowledge of the necessity of such a symbiosis and the companies' desire of becoming more energy efficient by installing renewable energy sources at the production site became available for the facilitation team. This one, targeted it towards the emergence of a new symbiotic network based on knowledge and shared mapping service on feasibility for installing solar panels. Like in the case 2 of the recycling of plastic sheets symbiotic network, the facilitation team became the connecting link between the knowledge available and the new symbiotic possibilities, engaging new companies in the project and symbiotic network. The knowledge diffusion was strongly targeted by the facilitation team towards specific and new companies. Emerging as independent from previous symbiosis and involvement in the project, the emerging synergies within this case shared the same impetus: the facilitator. The facilitation team's ambitions capacities and skills to grab the possibilities existing in the context and transform them into a new emerging symbiosis seem to have been crucial for the emergence of synergies.

Possibilities for further reproduction

The facilitation team mentioned in the business models reports related to this case that such a symbiotic network can help identify possibilities of energy efficiency solutions by installing solar panels at the production sites and then spread the knowledge of benefits from these to other companies in the region, thus attracting new members to the network. These can thus be budded onto the actually emerging network and a *colony* can be *formed* (3a). *A colony division (3c)* can be thought to occur between the companies that chose to implement the solutions that are identified through the knowledge symbiosis and the companies that chose not to invest and implement the solutions proposed after it settled. However, these might depend on the availability of a facilitator to e.g. enable the implementation process, to look for and attract funding for financing the solutions identified. Here, the presence of facilitative structures and an incubation platform are necessary. On the other hand, other factors such as national regulations and financial incentives to renewable energy solutions installation might provide impetus for further colony development.

Case 4: Recycling of wooden pallets & cardboard boxes symbioses. Two symbioses constitute the case 4: one revolves around the recycling of wooden pallets and the other one of cardboard boxes, as pictured in the Figure 6.



Connected through the same symbiotic partners, Danish Laser Technology A/S and LC Embalage, the emergence of the two symbioses seem to be reminiscent the reproduction mode of *budding (1a)*. Besides sharing the same symbionts, the symbioses develop around the same time. While the symbiotic idea regarding the reuse of wooden pallets came from the facilitation team in March 2019, the symbiotic idea concerning the reuse of cardboard boxes arose in April2019. The business models were as well developed simultaneously and in dependence with one another through June and July 2019. The facilitation team, who collected the knowledge on the availability of pallets and cardboard boxes for reuse, targeted it through the facilitation process from one company to another. Thus, the two symbioses emerge through a strong interconnectivity and dependency. Moreover, the ambitions of Danish Laser Technology A/S and their engagement with sustainability, as they experience increasing requirements on sustainability throughout their supply chain, also contributed to the company's engagement in both symbioses and thus presents an important impetus for interconnectivity of the two symbioses.

Possibilities for further reproduction

The document analysis of the business models reports allowed to observe that there is potential for other small and medium sized companies join these types of symbioses (i.e. sending pallets to LC Emballage for recycling, and/or receiving pallets and recycled cardboard boxes from LC Emballage). If this happens, then, with the time, the symbioses could *bud off (2b)* and eventually lead to *cloning (2c)* (i.e. the same concept is applied by other companies) and further reproduction.

Discussing the findings from applying the IS reproduction model to the emerging symbiotic network

Applying the IS reproduction model to the facilitated symbiotic network emerging from the process of Sustainable Synergies project reflect the relationships between the different dynamics (of facilitation and reproduction). While the symbiotic linkages arise through facilitation, and as a result of facilitation process, the emergence of the symbiotic network seams to arise from reproduction dynamics. Within this, previous symbiotic linkage bud and brood to clone into other synergies and can, after their settling, lead to colony formations, and thus to the network development. If in the cases studied by Schlüter et al. (cf. 2020 #4) most of the synergies arose through self-organization. In those cases, budding happened by information and knowledge made available mostly by the symbionts. Reproduction mode of broadcast spawning was found to also lead to cloning and then further development. In the case of facilitated synergies, broadcast spawning was not observed. This can be because the knowledge diffusion in the case of synergies emerging through Sustainable Synergies project was effectuated by the facilitator (and not the symbionts themselves as characteristic for broadcast spawning) and was targeted towards specific opportunities observed by the facilitator. Thus, the facilitator was the most important impetus that made the information and knowledge available targeting specific companies and mobilized these to enter new symbiotic relations.

The knowledge, relational and mobilization capacity of facilitators seems to raise with the time. One of the facilitation team's members expressed at the second group interview in May 2019 that "*in the start we followed the process step by step, while at a later stage, we knew already the companies, we knew their needs and possibilities*" (Group interview 2, 2019). Through the facilitation process, companies were screened for resource potential and information on resources available, companies' possibilities, desires and needs were collected. Relation to each company involved in the process was built through continuous interactions, face-to face meetings, dialogues, etc. A sense of trust and commitment develops among the facilitation team and the companies involved in the process. The knowledge, relations and trust formed between companies and the facilitation team can, when mobilized, lead to the same companies entering new symbioses through reproducing emerging synergies.

To conclude, it can be stated that although self-organized and facilitated processes can lead to IS network formation through reproducing existing or emerging synergies, the facilitative dynamic seems to be productive in identifying emergent possibilities, as these depend mostly on facilitator and its built capacity during a facilitation process.

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