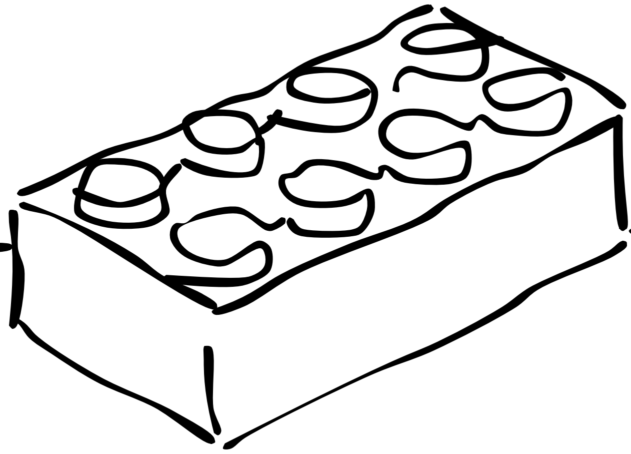
Building a Shared Vision for Industrial Symbiosis



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Exploring Value Retention from Wood Residues in Nordic Wood Industries

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Abstract:

Addressing environmental challenges in the construction sector, particularly high resource consumption and waste generation, this thesis explores the potential for industrial symbiosis (IS) in Nordic Wood Industries (NOWI). IS provides a collective approach to address these challenges, but its application within corporate groups and wood residues remains underexplored in the construction sector. Therefore, this thesis examines how NOWI can enhance value retention from wood residues through IS. A single embedded case study was conducted using a mixed-methods approach, with an emphasis on qualitative methods. The thesis adopts an abductive approach, guided by the institutional capacity building (ICB) framework. Wood residues were mapped, revealing a potential for IS, but current practices prioritise energy recovery, limiting value retention. To address this, a workshop inspired by the LEGO® Serious Play® methodology was held to co-create a shared vision for managing wood residues, resulting in a model for increasing value retention. A subsequent qualitative survey assessed the ICB for sustaining IS efforts, and findings illustrate that ICB has increased, supported by stakeholder engagement and facilitation efforts. The thesis proposes several recommendations, including a sustainability assessment of the proposed IS model, a roadmap for further IS development and improved data collection. This thesis recommends theory development to advance the ICB, emphasising further research on implementation aspects like facilitation and economy.

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Preface

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Reading instructions

In this thesis, citations follow the Harvard referencing style, denoted by (Author, Year). The first mention of abbreviations and glossary-defined terms is accompanied by an asterisk (*). Figures and tables are referenced by chapter number and sequential order, such as (Chapter #. Figure/Table #).

Abbreviations

- **CE:** Circular Economy
- **DTE:** Dansk Træemballage
- **EIP:** Eco-Industrial Park
- **GHG:** Greenhouse Gas
- **IC:** Institutional Capacity
- **ICB:** Institutional Capacity Building
- **IS:** Industrial Symbiosis
- **LCA:** Life Cycle Assessment
- **NOWI:** Nordic Wood Industries

Glossary

- **C24:** Coniferous trees are sorted based on their strength according to DS/EN 14081-1 (Andersen 2024). C24 is a common strength class used in buildings.
- **Circular Economy:** Defined as: *"[CE] an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models" (Ellen MacArthur Foundation 2013a)*
- **Co-creation:** Defined according to Cambridge Dictionary (N.A.): *"to make or invent something new together with one or more other people".*
- **Construction Sector:** Defined as a sector consisting of many different stakeholders providing various services and products related to construction, such as building, maintaining, and renovating buildings (Dansk Industri N.A.). This definition does not include infrastructure.
- **Facilitation:** It is defined as a process in which external or internal facilitators support new possible collaborations by creating a space for interactions where knowledge can be shared and trust can be built (Park *et al.* 2018).
- **Industrial Ecology:** Defined as: *"Study of flows of materials and energy in industrial and consumer activities, the effects of these flows on the environment, and the influences of economic, political, regulatory, and social factors on the flow, use and transformation of resources" (Allenby* and *Richards 1994)*
- **Industrial Symbiosis:** Defined as: *"Industrial symbiosis is the sharing of surplus resources between two or more companies, such as materials, energy, by-products, and water. It can also be common solutions*

in logistics, facilities, and expertise. Companies can be located close to each other or far from each other and they can be in the same industry or widely different"(Kørnøv *et al.* 2020a)

- **Institutional Capacity and Institutional Capacity Building:** IC is defined in IS literature, as the ability of actors to collectively find solutions to enhance the development of IS (Mortensen 2023). Institutions are defined as structures in society, whereas capacity refers to the acquired competences and resources such as knowledge, relations and the ability to mobilise (Mortensen 2023). ICB refers to the continuos development of IC within an organisation.

- **LEGO® Serious Play®:** Defined as: *"a mode of activity that draws on the imagination, integrates cognitive, social and emotional dimensions of experience and intentionally brings the emergent benefits of play to bear on organizational challenges"* (Roos *et al.* 2004, p. 563).

- **Network:** Defined as *"a structure involving multiple nodes, i.e. agencies and organisations with multiple linkages, working on cross-boundary collaborative initiatives.[...] A network brings together the knowledge experience of the component organisations to attempt to align their actions with the network goals"* (Wang *et al.* 2017).

- **Roadmap:** Defined according to (Seet N.A.), a roadmap is more specific than a strategic plan, as it describes precise actionable tasks within a shorter time frame.

- **Sustainability:** Defined according to World Commision on Environment and Development (1987): *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*

- **Systems Perspective:** Is defined as *"A systems perspective enables the decision maker to understand interactions among smaller systems within the larger system and identify potential synergies or harms that should be explored before implementation"* (Kumanyika *et al.* 2010).

- **Value Hill and Value Retention:** Value hill is a conceptual framework, describing how materials gain value through the processing to products, with the highest value obtained at the user (Achterberg *et al.* 2016). After end of use, several strategies can be applied to retain value, with repair and maintenance providing the highest value, and recycling providing the lowest measures of value retention (Achterberg *et al.* 2016). Value retention thus refers to the circular strategies ensuring that products retain their value as high as possible (Haupt and Hellweg 2019)

- **Wood Residues:** Residues refer to specific leftovers of e.g. wood, which still hold potential value for further use through e.g. circular strategies (Grebner *et al.* 2022). When the residue is used by another, it becomes a resource, and what is defined as waste, residues, or resources thus depends on the perspective (Greer *et al.* 2021).

Dansk Resume

Byggebranchen står for en betydelig del af de globale miljøpåvirkninger, hvorfor branchen har et stort ansvar for at gentænke eksisterende praksisser og derigennem bidrage til den bæredygtige udvikling. Koncernen Nordic Wood Industries (NOWI) ønsker at bidrage til den bæredygtige udvikling gennem deres arbejde med træbaserede byggeelementer og er herigennem interessede i at undersøge potentialer for industriel symbiose (IS).

Konceptet IS betegner et symbiotisk system mellem flere virksomheder, der deler fysiske og vidensbaserede ressourcer. Det er ofte affald eller overskudsressourcer, der kan anvendes af andre virksomheder, og der sikres mest cirkulær værdi, når produkter anvendes så tæt på deres oprindelige form og funktion som muligt. Dette kan bidrage til øget økonomisk og cirkulær værdi.

I byggebranchen har IS primært været fokuseret på ikke-fornybare ressourcer såsom metal og cement, samt store strategiske industriparker. Der har derfor været et begrænset fokus på, hvordan IS udvikles og implementeres i koncerner, samt på træbaserede produkter. Forankret i dette forskningsbehov, samt interessen fra koncernen, undersøger dette speciale derfor følgende problemstilling:
Hvordan kan Nordic Wood Industries øge værdibevarelsen af resttræ gennem industriel symbiose?

Dette undersøges gennem et eksplorativt single embedded case studie af NOWI, med de fire selskaber Scandi Byg, Roust Element, Palsgaard Spær og Lilleheden som underenheder. Specialet er udarbejdet gennem en socialkonstruktivistisk tilgang, og tager derudover afsæt i teorien institutionel kapacitetsopbygning. Dette muliggør undersøgelsen af, om NOWI har kapacitet til at fortsætte arbejdet med IS. For at undersøge potentialet for IS i NOWI anvendes både kvalitative og kvantitative metoder, og gennem denne metodetriangulering styrkes resultaternes validitet.

Resttræet i NOWI blev kortlagt gennem kvantitativ affaldsdata, observationer og interviews i produktionshallerne. I 2024 havde NOWI en mængde på ca. 4.500 tons resttræ. Dette består primært af svensk gran og opstår især i forbindelse med tilskæringsprocesser, udendørs opbevaringsløsninger og designvalg. 72 % af det samlede resttræ afbrændes med henblik på energiudnyttelse.

Gennem en workshop, inspireret af LEGO® Serious Play® metoden, byggede virksomhederne en LEGO® model, som er et resultat af de indledende ideer om en fælles vision for håndtering af resttræ i NOWI. De konkrete løsninger, beskrevet i modellen, bidrager til værdibevarelse gennem forskellige cirkulære strategier, herunder genbrug og genanvendelse.

Et kvalitativ spørgeskema blev udarbejdet for at vurdere workshoppens indflydelse på den institutionelle kapacitet. Herigennem blev det identificeret, at workshoppen havde bidraget til øget viden om resttræ og forbedret relationerne på tværs af virksomhederne.

Det kan således konkluderes, at der er tilgængeligt resttræ, som kan anvendes til symbiotiske løsninger for at øge værdibevarelsen, og at der ligeledes er opbakning til at fortsætte udviklingen af IS i NOWI. Specialets eksplorative karakter begrænser dog mulighederne for direkte implementering af initiativerne fra workshoppen, hvorfor en række anbefalinger er udarbejdet til NOWI.

Det anbefales, at der skabes bedre dataindsigt om resttræ i NOWI, da dette påvirker validiteten af kortlægningen. Med bedre data vil det være muligt at minimere mængden af resttræ ved kilden, hvilket er væsentligt for at undgå, at IS initiativer legitimerer processer der skaber resttræ. Derudover er det vigtigt, at der udarbejdes bæredygtighedsvurderinger af initiativerne, for at undgå suboptimering. Desuden anbefales det, at der identificeres nye kompetente facilitatorer, da specialet hidtil har haft denne rolle. Disse aspekter er fundet mangelfulde i den anvendte teoretiske ramme, hvorfor dette speciale identificerer et behov for teoriudvikling, der fokuserer på, hvordan IS initiativer faciliteres og implementeres.

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Chapter 1

Introduction

The construction sector* contributes significantly to global environmental impacts, including emissions, resource extraction, and waste generation (Stylianou *et al.* 2024). In 2021, the construction sector accounted for approximately 30% of global solid waste (Soto-Paz *et al.* 2023) and 37% of global carbon emissions (United Nations Environment Programme 2022). Additionally, 59 billion tonnes of materials, approximately 55% of the total global material demand, were linked to the built environment and mobility (United Nations Environment Programme 2024). This highlights the urgent need to rethink current patterns of resource consumption in the construction sector to improve sustainability*.

Wood is often promoted as a sustainable material due to its regenerative nature and has therefore gained increasing attention (Thybring N.A.; Maier 2022). However, wood use also raises concerns related to land use and biodiversity, and increasing climate change affects the quality of wood (Bekin 2023; Pretzsch *et al.* 2014). Thus, a shift to biobased materials alone is insufficient to ensure sustainable practice (Jensen 2023; Pedersen *et al.* 2021).

Global and European policy initiatives, such as the Paris Agreement and the European Green Deal, highlight the need for a transition to a circular economy* (CE), with the construction sector playing a central role (United Nations 2015; European Commission N.A., 2024, 2020). One approach supporting this transition is industrial symbiosis* (IS), a collaborative strategy that rethinks resource use and waste generation without compromising economic viability (Mulrow *et al.* 2017; Neves *et al.* 2020). IS has been studied since the 1990s and is rooted in the fields of industrial ecology* and CE (Baldassarre *et al.* 2019). Symbiosis refers to organisms coexisting and mutually benefiting from one another (Chertow 2000). Inspired by this, IS builds on the principle that one company's waste is another's resource, creating more collective value than can be achieved individually (Chertow 2000; L. Kørnøv, personal communication 2025; Wang *et al.* 2017). However, this definition has faced criticism for focusing too narrowly on closing resource loops (Mirata 2005). Utilising waste to produce unnecessary products cannot be considered sustainable (Schlüter *et al.* 2023a). However, IS can result in more than closing loops (L. Mortensen, personal communication 2025). Recent developments in IS have expanded the concept to include shared expertise, logistics, and strategies for value retention* beyond recycling (Kørnøv *et al.* 2020a). The following literature review will explore current research on IS in construction, highlighting opportunities for further investigation.

Chapter 2

State of the Art: Industrial Symbiosis in Construction

This chapter presents the key findings from the systematic literature review, focusing on trends, challenges, and research gaps related to IS in the construction sector. The methodology behind the literature review is described in Section 4.2.1. The subsequent section will build upon grey literature to position the thesis in the context of the Danish construction sector.

2.1 Key Findings from the Literature Review

Based on the literature review, it was evident that research on IS in construction has existed for over 20 years, with a noticeable increase in publications since 2010. Yu *et al.* (2014) describe how the research on IS has evolved from practical examples to broader systemic theory building research. This is also reflected through this review, where it was evident that the literature generally divides into two main groups, where one focuses on an operational IS which examines specific materials (e.g., cement) and secondly, strategic IS focusing on broader eco-industrial parks* (EIP). As the main focus of this study is wood, the studies on cement were noted, but not further assessed in the analysis. It was found that the EIPs generally were strategic and broad in their scope, consequently not solely focused on the construction sector. This may be a result of the IS concept not being isolated to a single sector, but being able to cover multiple sectors. Therefore, this review is based on the 22 articles that were read in full text. Findings are structured into subsequent aspects of focus: benefits and barriers, existing examples, success factors, institutional capacity* (IC), and the identified research gap.

Benefits and Barriers

Several publications highlight IS benefits, particularly in minimising resource depletion, greenhouse gas* (GHG) emissions, and waste generation (Chen *et al.* 2022; Putra *et al.* 2025; Cudecka-Purina *et al.* 2024; Zhu and Ruth 2014; Teh *et al.* 2014). Park *et al.* (2018) further stress that IS provides the involved companies with a competitive advantage, as the IS mechanisms lower the costs related to the purchase of products and waste treatment. Economic benefits are recognised as a key driver for IS development (Yedla and Park 2017; Domenech *et al.* 2019). Additionally, several publications argue that collective benefits created through IS collaboration are greater than what the companies could achieve individually (Yedla and Park 2017; Romero and Ruiz 2014). Consequently, Baldassarre *et al.* (2019) position IS as an important aspect of transitioning to a more sustainable world.

Besides the potential benefits from IS, there are also several publications highlighting barriers and challenges such as Ling Zhang *et al.* (2010), who stress that a major barrier for the environmental benefits of IS is that many EIPs tend to focus on just closing loops and hereby neglect the primary CE-strategy of reducing waste and resource consumption at the core activity. Other barriers relate to economic challenges due to limited funding, geographical proximity challenges, but also a limited engagement from companies (Ling Zhang *et al.* 2010; Schlüter *et al.* 2023b; Yedla and Park 2017). de Abreu and Ceglia (2018) stress that lock-in mechanisms generate an institutional problem when trying to change linear systems through IS, and through this, they argue that without political engagement and regulatory changes, most waste would still be sent to landfill, as this remains the cheapest. Another barrier identified by Yedla and Park (2017) is that the benefits of engaging in an IS collaboration are company specific and can vary, which can create significant challenges in the negotiation process when forming a partnership. Furthermore, Romero and Ruiz (2014) highlight that the interactions between participating companies can pose challenges in the practical implementation of IS.

Success Factors

One of the first examples of IS is the Danish Kalundborg case (Park *et al.* 2018; Domenech *et al.* 2019; Zhu and Ruth 2014). The model has developed through the last 50 years, and contains more than 20 different streams, such as water, energy, and materials, between 17 companies (Kalundborg Symbiosis 2025). However, existing literature also highlights examples of EIPs from China, for instance the EIP case of TEDA (Wang *et al.* 2017). TEDA is one of the first and largest EIPs in China, and mentioned in several publications in the review (Liu *et al.* 2018; Wang *et al.* 2017; Putra *et al.* 2025). Furthermore, China has the highest number of publications related to IS, largely due to its long-standing top-down policy approach to resource efficiency (Liu *et al.* 2018). Apart from Denmark and China, IS cases are found in other countries such as the US, Australia, UK, Finland, Japan, South Korea, Sweden, Norway, Iceland and the Netherlands (Boons *et al.* 2017; Zhu and Ruth 2014; Schlüter *et al.* 2022).

Park *et al.* (2018) describe how existing examples of IS have made researchers try to identify what made these examples a success. Consequently, IS has been widely researched over the years, with several publications focusing on the success factors in various contexts (Schlüter *et al.* 2023b; Putra *et al.* 2025). Putra *et al.* (2025) provide a framework of three phases of EIP evolvement, with a key success factor being the ability to include EIP goals into national or local development strategies. Schlüter *et al.* (2023b) discuss the two diffusion types; replication and reproducibility, as success factors for EIPs, where they provide a framework with four phases for EIP evolvement. Furthermore, Schlüter *et al.* (2023b) stress that empowerment and knowledge diffusion are key factors for EIP implementation success. This is also supported by Zhu and Ruth (2014); Freitas and Magrini (2017). Mortensen *et al.* (2024) also support the aspects of knowledge and political support to be critical factors to success, but also address the importance of having shared visions and a specific roadmap*.

The literature on EIPs generally focuses on physical resource exchange (Chen *et al.* 2022; Park *et al.*

2018; Teh *et al.* 2014), but Yu *et al.* (2014) argue that collaboration and existing relationships between companies are more effective for developing a more sustainable industry.

There is a broad consensus in the literature that replicating successful IS models requires adaptation to local institutional, social, and material conditions (Putra *et al.* 2025; Schlüter *et al.* 2023b). However, studies such as Schlüter *et al.* (2023b), Boons *et al.* (2017), and Park *et al.* (2018) describe this variation in context by emphasising the embeddedness of factors that hinder comparison across IS cases. The context-specific factors such as; trust, attitudes, social factors, material characteristics, and institutional factors emphasise the embeddedness of such factors (Park *et al.* 2018; Yedla and Park 2017). As part of context-specific adaptation, Park *et al.* (2018) argue that facilitation* plays a key role in IS. Their study examines how facilitation impacts various categories, including organisational, technical, and institutional aspects, which is closely linked to the theory of institutional capacity building* (ICB) (Park *et al.* 2018).

Institutional Capacity Building

Mortensen *et al.* (2024) state that ICB is of great importance for the establishment of IS, and several researchers have drawn upon the theory to study the development IS around the world (Wang *et al.* 2017; Park *et al.* 2018). de Abreu and Ceglia (2018) argue that this is because IS requires collaboration between different companies, and that the collaboration is influenced by the IC embedded in the network*. According to de Abreu and Ceglia (2018), ICB plays a crucial role in determining the success of collaborative efforts in IS.

Identified Research Gaps

Despite extensive research on IS in industrial parks and material-specific applications (e.g., cement and metals), little attention has been given to how IS principles can be applied within corporate groups and their subsidiaries. This is particularly relevant for regenerative materials like wood, which hold significant sustainability potential, as this is one of the main waste fractions (Freitas and Magrini 2017). Building on this gap, and the Danish position and experience with IS (Mortensen *et al.* 2024; Kalundborg Symbiosis 2025), the following section explores the current situation of wood waste in the Danish construction sector.

2.2 The Danish Construction Sector and Wood Waste

The identified research gaps are relevant in a Danish context, where wood is gaining attention (Pedersen *et al.* 2021; Indenrigs- & Boligministeriet 2021). Furthermore, Denmark's political commitment to CE principles (Miljø- og Fødevareministeriet 2018; Miljøministeriet 2021), and its leading position in sustainable construction make it a valuable setting for exploring how IS practices can be operationalised within corporate structures (Indenrigs- & Boligministeriet 2021). However, Rådet for Grøn Omstilling (2024) argues that Danish legislation inadequately focus on CE and resource consumption, which does not create an incentive in the sector to reduce resource consumption. The Danish construction sector currently put more emphasis on lowering energy consumption and greenhouse gas emissions, rather than promoting a resource agenda (Rådet for Grøn Omstilling 2024; NIRAS 2024). With the increased focus on greenhouse gas emissions, wooden building elements have gained increasing attention.

The increased use of wood in construction makes it relevant to identify how the waste is handled to ensure most value is retained (Pazzaglia and Castellani 2023). Aho *et al.* (2022) estimated that the Danish construction sector generated 195,000 tonnes of wood waste in 2021, of which 82% were recycled and 18% were used for heating. However, Aho *et al.* (2022) articulate the challenges with generating data related to waste. These data challenges align with Kanafani *et al.* (2023), who find limited knowledge and data gaps to challenge the existing awareness of the construction sector environmental challenges. With new legislative updates to the Danish Building Regulations the generation of waste at the construction sites become mandatory (Social- og Boligstyrelsen 2025). This has the potential to increase the awareness of potential value retaining practices that could optimise the current practice.

Addressing the gap from the scientific literature review along with the tendencies in the Danish construction sector, Nordic Wood Industries* (NOWI) is a relevant case for investigating value retention of wood waste through IS. NOWI is one of the leading manufacturers in Denmark of prefabricated wooden building elements and spans several companies, enabling an exploration of potential synergies across the subsidiaries. As Yu *et al.* (2014) identify relational structures to have great importance for the success of IS development, it is especially interesting to explore if the corporate structure in NOWI can have a positive influence on the ability to develop IS solutions. By exploring the case of NOWI, this thesis provides an empirical case for exploring the research gap of IS in corporate groups with a focus on wood, and hereby enables insights with both academic relevance and practical applicability.

The state of the art and the Danish construction sector's wood waste illustrate an important terminology challenge, as both tend to use the term waste to describe surplus resources. As this is misleading in a CE perspective, this thesis will refer to wood residues* (Greer *et al.* 2021). Through this, the thesis addresses the overall research question:

> *How can Nordic Wood Industries increase value retention of wood residues through industrial symbiosis?*

Chapter 3

Theoretical Framework

To explore whether IS can be established in NOWI, it is essential to assess the IC to collaborate and share resources. However, IS is not solely dependent on physical exchanges (Kørnøv *et al.* 2020a). It also relies on social and relational capacities among the involved actors (Yu *et al.* 2014). ICB ensures the inclusion of these aspects and will therefore serve as the theoretical framework of this thesis. The following section will provide a brief description of the theory followed by a description of how the theory is utilised in this thesis.

3.1 Introduction to Institutional Capacity Building

The ICB theory provides a framework consisting of three main aspects: knowledge resources, relational resources, and mobilisation capacity (Lindfors *et al.* 2020; Boons and Spekkink 2012). Firstly, knowledge resources refer to the quality and depth of actors' existing knowledge, their prior experiences, their shared understanding of challenges, and their ability to acquire new knowledge (Lindfors *et al.* 2020). Secondly, the relational resources are connected to the specific relationships between the actors, the level of trust within the network, and the degree of engagement in collaborative efforts (Lindfors *et al.* 2020). Thirdly, mobilisation capacity refers to a network's ability to integrate additional companies that possess essential characteristics for collaboration. It also encompasses the development of a shared vision and the role of change agents in driving collective action (Lindfors *et al.* 2020; Spekkink 2015).

The theory of ICB has been used in IS research to understand the dynamics involved in the development of IS (de Abreu and Ceglia 2018; Lindfors *et al.* 2020; Mortensen *et al.* 2024; Park *et al.* 2018; Wang *et al.* 2017). For example, de Abreu and Ceglia (2018) investigate how ICB influences IS in the UK by identifying critical aspects related to knowledge, relations and mobilisation through interviews. (Wang *et al.* 2017) also provide an exploration of ICB in the Chinese IS case TEDA, which is also conducted through interviews.

3.2 Institutional Capacity in NOWI

Knowledge about residues is crucial for establishing an IS (Wang *et al.* 2017; Schlüter *et al.* 2023b). Therefore, the first analysis focuses on mapping the wood residues within these companies. This is described as a theory-informed use according to Kørnøv (2014).

Mobilisation capacity plays a key role in enabling stakeholders to recognise potential steps to drive development (Boons and Spekkink 2012). Therefore, the second analysis includes a workshop exploring the companies' opportunities for collaboration. Additionally, potential opportunities and barriers for IS are identified within NOWI. This is characterised as a theory-informed use according to Kørnøv (2014).

In the final part of the workshop, participants completed a detailed qualitative survey designed to assess the IC in NOWI. Since the questions were developed based on the theoretical framework, this phase is considered theory testing according to Kørnøv (2014).

By combining theory informing and theory testing approaches, this thesis aims not only to apply ICB as an analytical tool, but also to reflect critically on its applicability in the context of IS within corporate structures. Potential theoretical limitations and suggestions for further development are therefore addressed in the analytical chapters.

Chapter 4

Research Approach and Methods

The philosophy of science provides the foundation for how this thesis is carried out, impacting the ontology, epistemology, and methodology. This thesis adopts a social constructivist stance, as it aligns with the aim of exploring the possibilities of IS with NOWI. IS is not a universal truth, but rather a socially constructed phenomenon that is dependent on collaboration across companies and actors. Therefore, actors' perceptions and relations are crucial for exploring IS in NOWI. The epistemological perspective in social constructivism, views knowledge as interpretive (Egholm 2014). Consequently, knowledge is constructed by people, and as this thesis applies a workshop methodology, this illustrates how knowledge is co-created* (Roos *et al.* 2004). In relation to ontology, it is assumed that there is no single truth, but that reality is subjective, and is formed by the social context, including both discourses and institutional settings that actors are part of (Egholm 2014).

4.1 Research Design

This thesis is structured around the following research question: *How can Nordic Wood Industries increase value retention of wood residues through industrial symbiosis?* To explore this research question, three sub-questions have been formulated and investigated through a mixed-method approach. The first sub-question : *SQ1: What are the types and hotspots of wood residues generated by NOWI companies over a year?* contributes to the research question by providing information related to what type of residues and quantities the NOWI companies generate. The first sub-question is investigated by applying a mixed-method approach, combining quantitative residue data with qualitative insights from observations and field interviews, to gain a comprehensive understanding of the wood residues in the NOWI companies (Brinkmann and Tanggaard 2015). The approach begins deductively, using a semi-structured guide inspired by the Ishikawa diagram. However, as observations evolve with context and events, inductive elements emerge. Thus, the overall logic for the first sub-question is abductive. The second sub-question: *SQ2: How can a model of industrial symbiosis be designed in NOWI to retain value of wood residues and what are the main challenges?* is contributing to the research question by providing an exploration of how a model of IS could be designed in NOWI. This sub-question is explored through a workshop methodology inspired by LEGO® Serious Play®*, which follows a deductive design. However, the co-creation aspects involve inductive reasoning. As a result, the overall approach to the second sub-question is abductive.

The third sub-question: *SQ3: How has the industrial symbiosis workshop contributed to the institutional capacity building in NOWI?* contributes to the research question by evaluating if the IC is sufficient for proceeding with IS development in NOWI. The evaluation used a qualitative survey with theory-based questions, reflecting a deductive approach. However, inductive reasoning was applied during data analysis to support interpretation. Thus, the overall approach to the third sub-question is abductive.

An overview of the thesis structure is provided in Figure 4.1.

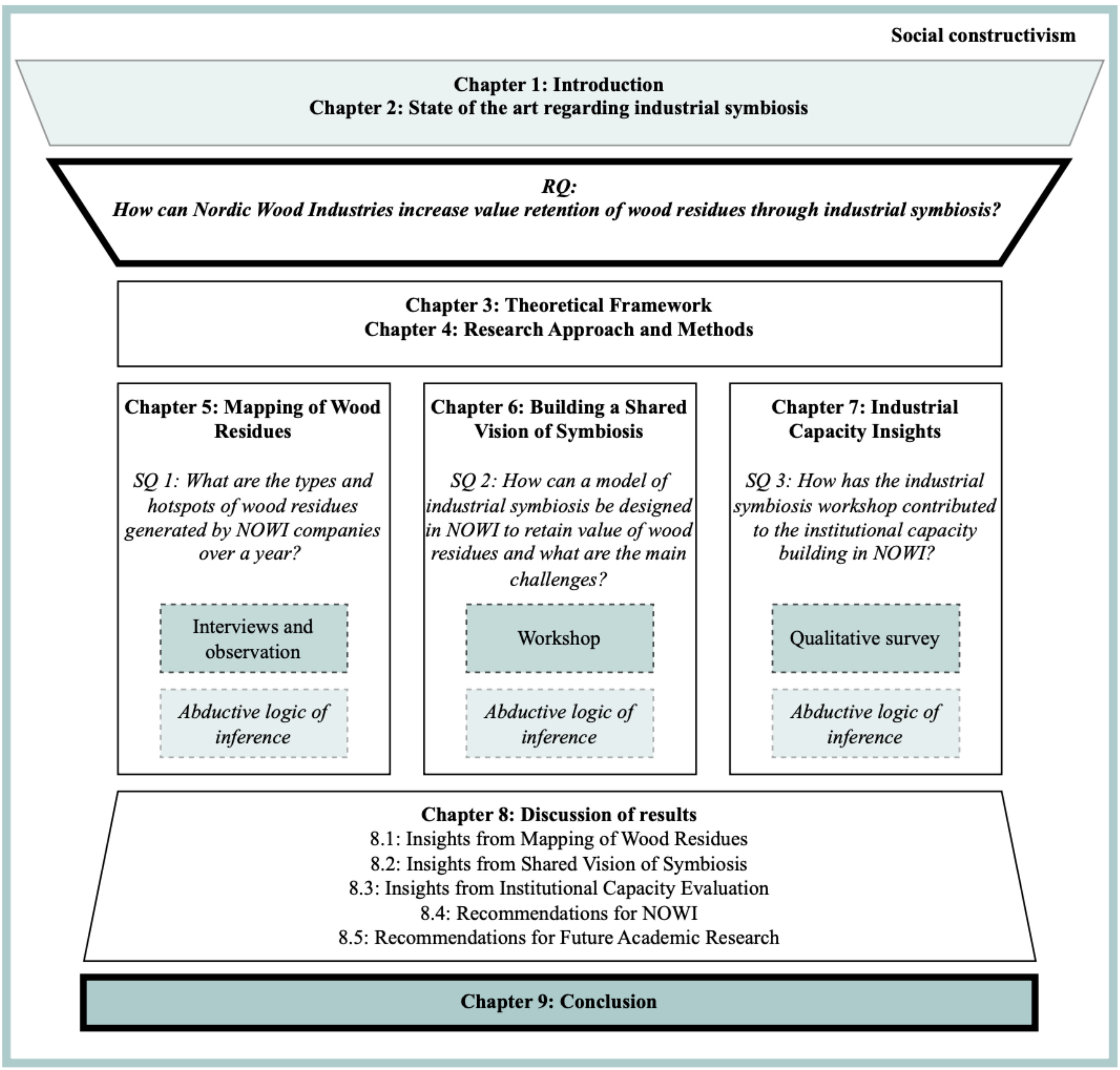

Figure 4.1: Research design

4.2 Methods

The following section outlines how the data for this thesis was collected and analysed. To ensure a comprehensive exploration, this thesis employs triangulation by using multiple methodologies to examine the problem from different angles (Aarhus Universitet N.A.). By combining qualitative and quantitative methods, triangulation offers a more nuanced perspective and helps mitigate the limitations inherent in each approach, serving as part of the validation process supporting the thesis findings (Aarhus Universitet N.A.).

4.2.1 Literature Review Process

To investigate the state of the art in research related to IS in the construction sector, a systematic literature review was conducted. The review was carried out in February 2025 with the aim of mapping and categorising the existing academic literature to identify gaps (Grant and Booth 2009). The review specifically explores how IS has been implemented in the sector, the challenges involved, and the potential sustainability benefits of IS. The review was designed based on the methodological principles presented in Kristensen and Mosgaard (2020); Snyder (2019), and Pautasso (2013). The methodology behind the literature review is illustrated in Figure 4.2. The literature review was conducted in the database Scopus using the following search string:

"industrial symbiosis" AND (construction OR building)

The search string was applied to the title, abstract, and keywords, resulting in 291 publications. Hereafter, three filters were applied to omit irrelevant publications from the search.

1. Subject Area Filter: Limited to Engineering, Environmental Science, Earth and Planetary Sciences, omitting 51 publications
2. Language Filter: limited to publications in English, omitting 15 publications.
3. Document Type Filters: Limited to articles, reviews, conference papers, and book chapters, omitting two publications.

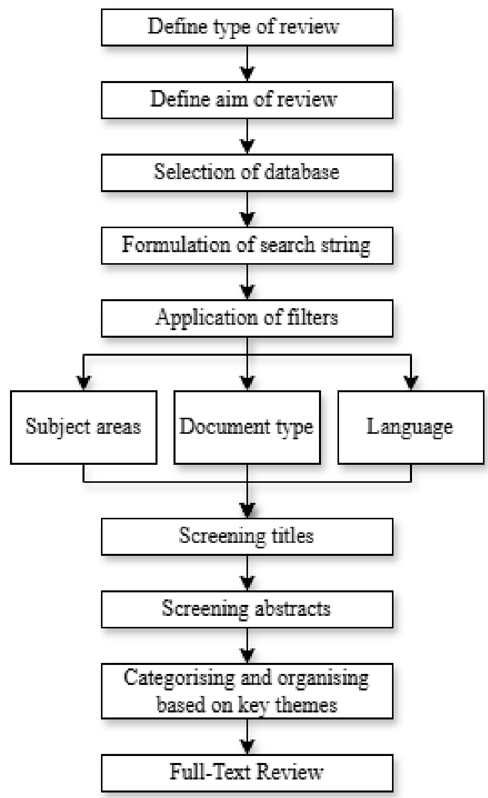

Figure 4.2: Research process for literature review. Author generated with inspiration from (Kristensen and Mosgaard 2020)

The 223 publications were hereafter manually assessed to identify the relevant literature.

1. Screening Titles: Omitted 63 publications (e.g., related to water management and agriculture), leaving 160.
2. Screening Abstracts: Omitting 59 publications not focusing sufficiently on IS in construction, resulting in 101.

During the abstract screening, several key themes emerged, including geographical scope, gaps, challenges and applications (e.g., case studies). Categories were developed based on content analysis. Following this, similar codes were merged (e.g., residue flow mapping and residue flow analysis). Subsequently, a matrix was created with the categories represented by columns and each publication with a row. This matrix structure enabled the identification of tendencies across studies.

Based on the aim of the review, publications were manually selected based on their relevance. Specifically, studies on the implementation of IS, associated challenges and barriers, as well as opportunities, were included for further analysis. This selection process resulted in 22 publications. The literature review is available in the supplementary information titled *"IS Literature Review"*.

4.2.2 Case Study

This thesis employs a single embedded case study approach to gain deeper insights into residue management and IS exploration within NOWI (Tight 2022; Yin 2009). According to the definition of single embedded case study from Yin (2009), this study is appropriate when the aim is to study a phenomenon within the existing context and system, and where multiple sub-units exist within an organisation.

NOWI was selected for its industrial and research relevance, as well as the existing collaborative framework within NOWI, which fosters trust and facilitates IS implementation. Additionally, the geographic proximity of several companies allowed for on-site observations and direct employee interviews, enhancing data collection opportunities, facilitating close engagement with NOWI, and enabling the design and facilitation of a workshop. NOWI was established in 2016, and serves as a corporate group with subsidiaries, specialising in wood-based products. NOWI consists of eight companies, with four having production facilities in Denmark. In this thesis, the case of NOWI encompasses four companies as embedded units; Scandi Byg, Lilleheden, Roust, and Palsgaard. NVIRO is not currently producing products but has shown interest in this thesis and contributed in part by participating in meetings. However, the company was not involved in the analysis activities, such as residue mapping or the workshop. The companies work as independent units. However, within the last year, they have initiated several different networks across NOWI, to share knowledge. This includes sustainability, production, and procurement networks. As these networks are in their early stages and have held limited meetings, collaboration and relationships between companies are still emerging.

An overview of the companies included in this thesis is provided in Table 4.1 and Figure 4.7 illustrates some of the products from the companies.

Company	Lilleheden	Scandi Byg	Roust Element	Palsgaard Spær	NVIRO
Year of establishment	1930	1977	1925	1890	1989
Year of acquired in NOWI	2016	2023	2020	2016	2021
Product overview	Glue laminated timber	Modular wooden buildings	Prefabricated wooden elements	Roof trusses and structural components	Cellulose insulation
Employees	70	175	151	201	17
Location	Hirtshals	Løgstør	Årre	Hampen	Vildbjerg

Table 4.1: Overview of the case companies in NOWI

Figure 4.3: Scandi Byg (Nærheden N.A.)

Figure 4.4: Lilleheden (Lilleheden N.A.)

Figure 4.5: Roust Element (Cj Group A/S N.A.)

Figure 4.6: Palsgaard Spær (Palsgaard Spær N.A.)

Figure 4.7: Examples of NOWI products

Contextual Factors Regarding Scandi Byg

In January 2025, Scandi Byg declared bankruptcy. Although the company has since been restructured and resumed operations, its production is still affected, as fewer people now work there compared to 2024.

4.2.3 Quantitative Data Collection on Wood Residues

To investigate the quantity of wood residues generated by the NOWI companies, it was necessary to collect quantitative wood residue data. The quantity of residues was important to understand the current situation and assessing the potential for IS. The four companies had varying levels of overview over their residues flows. As a consequence, the data was collected in various ways. This is explained in Table 4.2.

Company	Lilleheden	Scandi Byg	Roust Element	Palsgaard Spær
Data collection method	Produced MWh to district heating and invoice to DTE	Waste report from Marius Pedersen	Residue estimate	Invoices

Table 4.2: Overview of the wood residue data collection

Data from the waste report from Scandi Byg and invoices from Palsgaard are given in tonnes. However, data from Lilleheden and Roust needs conversions to identify the estimated quantities. The conversions can be found in Appendix A, and the data related to the residue mapping is available in the supplementary information titled *"Wood Residue Mapping"*.

4.2.4 Observations

Four observations were conducted to examine workflows and residue flows at each of the four NOWI companies. The primary aim was to understand why wood becomes residue and to document the sizes, types, and characteristics of these residues, thereby supporting the quantitative data.

To accommodate the embedded sensitivity in observations, and the risk of cultivating an existing perception, a clear observational framework was necessary. Therefore, a semi-structured observation guide was developed to ensure consistent coverage of key aspects across companies, while allowing flexibility to capture each company's unique characteristics. As described by Wästerfors (2022), this involves balancing the need for a well-prepared and data-rich framework with the flexibility to respond to the specific context and observe beyond predefined aspects.

The guide was developed in collaboration with Simon Wyke, a researcher at Aalborg University, and was inspired by the Ishikawa diagram. The Ishikawa diagram is a well-known framework from studies of cause-effect relations in construction residue (Sagan and Mach 2025), and it provides the ability to define six relevant categories of inspection to find the root cause of a given problem. This offered a flexible structure in which categories could be explored to the extent they were deemed relevant during the on-site observations.

4.2.5 Semi-structured Interviews

Five semi-structured interviews were conducted with researchers, along with four semi-structured field interviews during this thesis period. The interviews serve different purposes in the thesis, as described below. Semi-structured interviews are conversational by intention, but with several questions formulated prior to the interviews, to ensure specific aspects are covered (Brinkmann and Tanggaard 2015). The flexible approach ensures that additional aspects can be discussed as the interview proceeds (Brinkmann and Tanggaard 2015).

Semi-Structured Field Interviews

Four field interviews were conducted during the company visits. A semi-structured approach was used to ensure that key topics were addressed, while also allowing space for new themes to emerge during the visits. The field guide was inspired by the Ishikawa diagram, as with the observations (See Section 4.2.4). The field interviews aimed to provide a deeper understanding of the companies' quantitative residue data by gaining insight into the hotspots of the residue generation. Field interviews were conducted with both the Head of Production and the Head of Development at each company.

Semi-Structured Interviews with Researchers

The five semi-structured interviews were conducted following a semi-structured interview guides. As the four interviewees possess different expertise knowledge, they were utilised in different parts of the thesis. Table 4.3 provides a brief overview of the purpose with each interview person.

Date	Interviewee	Purpose
14-02-2025	Simon Wyke *Researcher, AAU* *Department of Sustainability and Planning*	Insight into research on residue mapping, including the Ishikawa diagram.
28-02-2025	Sara Bjørn Aaen *Associate professor, AAU* *Department of sustainability and Planning*	Insight into LEGO® Serious Play® methodology and feedback on workshop.
18-03-2025	Søren Kerndrup *Associate professor, AAU* *Department of Sustainability and Planning*	Insight into research on workshop facilitation, including feedback on workshop.
07-04-2025	Lucia Mortensen *Head of Research and Education* *GreenLab*	Insight into research on IS and the theory of ICB.
08-04-2025	Lone Kørnøv *Professor, AAU* *Department of sustainability and Planning*	Insight into research development on IS and sustainability assessment of IS.

Table 4.3: Overview of the five semi-structured interviews

4.2.6 Workshop Inspired by LEGO® Serious Play® Methodology

This thesis uses a workshop inspired by the LEGO® Serious Play® methodology to explore IS model design. LEGO® Serious Play® fosters co-creation among participants by enabling them to visualise complex systems through LEGO® bricks (INTHRFACE 2025). By building on shared experiences and iterative model discussions, it can foster a common vision. Consequently, the approach can provide a new way of working with problems, moving beyond solely spoken word or text (Oliver and Roos 2007; Roos *et al.* 2004).

Participant Details and Data Collection

The workshop included 11 participants, representing all four companies. The participants were selected based on their knowledge and decision-making authority, with each company being represented by its head of production and head of development. Additionally, NOWI's sustainability specialist, head of strategy & project management, head of strategic procurement, and Group Operations Manager participated. Scandi Byg was also represented by its logistics manager, since their head of production was new. All models were documented with photos, and discussion rounds were recorded through Microsoft Teams, where they were transcribed automatically. The final discussion on challenges was also documented using post-it notes.

Facilitation and Workshop Design

Successful workshops require careful design and skilled facilitation (Roos and Victor 2018). The workshop was designed through an iterative process in collaboration with three associate professors from Aalborg University, including the thesis supervisor, a certified LEGO® Serious Play® facilitator, and an experienced workshop researcher (See Section 4.2.5). Additional input came from the Head of Sustainability, the Head of Strategy & Project Management at NOWI.

The workshop began with an introduction of its purposes, which were to build shared understanding of residues being resources rather than waste, and to co-create ideas to retain value of residues. This was followed by a presentation of current wood residue flows within NOWI (results obtained from Chapter 5), and the Code of Conduct for the following building sessions. This ensured that participants must participate actively in the model building, listen to presentations, respect different perspectives in discussions, and actively use the models to discuss, rather than being abstract or personalised (Roos and Victor 2018).

Four building sessions took place, with the first being two warm-up activities introduced association-making and storytelling to prepare participants. Secondly, groups, consisting of participants from the same company, built models answering: *"What do your current wood residues look like?"*. Groups hereafter presented their models and answered follow-up questions. Next, groups built models on: *"How can your wood residues have alternative uses if you cannot burn the wood?"*, which were also presented. In the final round, all participants collaborated to build a shared vision for future wood residue handling in

NOWI. This model combined the best ideas from earlier rounds into a collective vision. Participants then wrote challenges or concerns on post-its. These post-its were placed on the model and discussed. Figure 4.12 shows photos illustrating the workshop atmosphere and facilitation.

Figure 4.8: Participants finding LEGO® bricks

Figure 4.9: Participants building their residue model

Figure 4.10: Participants communicating their new model

Figure 4.11: Participants building shared vision model

Figure 4.12: Examples of how the workshop proceeded

4.2.7 Qualitative Survey

A qualitative survey was conducted as the final part of the workshop to evaluate the ICB based on the workshop (Braun *et al.* 2020). The survey contained 15 questions that were formulated based on the theory of ICB. The design was inspired by Wang *et al.* (2017), who similarly applied the theory to evaluate IC. All questions were open-ended to allow in-depth insight into participants' perspectives on IC (Braun *et al.* 2020). However, willingness and trust were assessed using predefined categories (e.g., low, moderate, high) for consistency and clarity. The questions were categorised based on the aspects of knowledge resources, relational resources, and mobilisation capacity. To identify patterns and compare responses, an inductive coding approach was applied through content analysis (Aarhus Universitet N.A.; Bingham 2023). The participants provided their responses in Danish, and coding was carried out in English to align with the language of the thesis. Consequently, the responses were manually translated during the coding process. The questions and coding can be found in the supplementary information file *Evaluation Dataset*.

4.2.8 Validation Meetings

The findings from the thesis were presented at two meetings within NOWI, and one workshop at the Department of the Built Environment (BUILD) at Aalborg University. The aim of these meetings was to generate feedback, and validation of the findings and methodological process. The findings of the thesis were presented at an informal residue workshop hosted by BUILD, where they were discussed with three researchers, who have comprehensive knowledge of construction residues; Simon Wyke, researcher at AAU, the Department of Sustainability and Planning, Lasse Rohde, researcher at BUILD, and Søren Munch Lindhard, associate professor at BUILD. During the workshop, the residue mapping approach was validated as appropriate for the thesis aims, and the researchers confirmed that they face similar challenges related to data gaps and limited residue knowledge in the construction sector.

As part of the validation process, the findings were also presented at two online meetings hosted by NOWI. The first meeting was aimed at top management at NOWI, while the second was held for the workshop participants. Both meetings aimed to validate the research process and results, while also offering an opportunity to collect feedback for continuous learning and future improvement. The meetings further provided insights into IS developments since the workshop.

4.2.9 Generative AI

The OpenAI platform ChatGPT (version 4) was used to identify grammatical issues in the text. This was done using the following prompt: "Identify grammatical errors in the text and write suggestions in parentheses." The output generated by the model was manually evaluated and critically assessed to ensure professional precision. Therefore, the use of generative AI complies with the guidelines outlined in the semester description.

Chapter 5

Mapping of Wood Residues

The following chapter presents the results of the analysis addressing the first sub-question: *What are the types and hotspots of wood residues generated by NOWI companies over a year?* The quantities of wood residues are first presented in a general overview, followed by the results from the observations and interviews, which are presented separately for each company. The results were generated based on a mixed-method approach, which combined quantitative residue data with observations and field interviews, as described in Section 4.2.3 and Section 4.2.4.

5.1 Current wood residues quantities in NOWI

Based on the wood residue data collected from the companies, an overview of the current wood residue quantities in NOWI was generated. In 2024 the total wood residues exceeded 4,466.5 tonnes. These quantities are illustrated in Figure 5.1, along with the residue treatment facility and outcome. The following sections provide a detailed breakdown of the wood residues quantities for each company. Data regarding the residues can be found in the supplementary information *Wood Residue Mapping*.

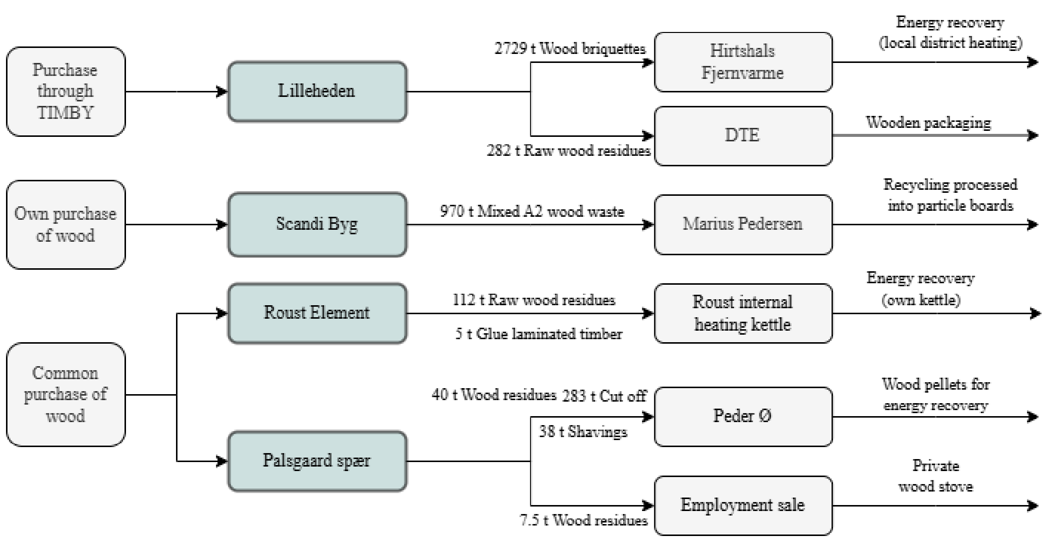

Figure 5.1: Residue streams and management in 2024 for the companies

Palsgaard is the only company with data related to employment sales. However, it is known to occur at both Scandi Byg and Roust, although neither has an overview of the quantities.

5.2 Scandi Byg

Scandi Byg produces modular buildings. They generated 970 tonnes of wood residues in 2024. The wood residues have been discarded as an A2 fraction, which is a mix of materials, such as plywood and raw wood with small pieces of metal or paint. The wood residues from Scandi Byg are collected by the residue management company, Marius Pedersen, and transported to the local facility in Aalborg, where they are processed into particleboard.

Based on the mapping of residues, it was found that incorrect sorting, architectural design, cutting inefficiencies, storage practices, material delivery and single-use pallets are the main hotspots for residue generation.

Incorrect Sorting

The residue generated at Scandi Byg is categorised as mixed A2 wood. However, observations revealed that the majority of these residues could be classified as A1 wood. Due to the presence of a small proportion of incorrectly sorted material, the entire fraction is classified as A2 rather than A1, thus impacting the quality of the classification, processing options, and market value.

Architectural Design, Standard Procurement, and Cutting Inefficiencies

All Scandi Byg's products are project-specific modules, however, they aim to have a general standardised design, resulting in the modules being relatively similar. The modules have a standardised design so that plywood and particleboards can be used in full length across projects. However, the construction beams, referred to as C24*, are cut by a Hundegger cutting machine. The C24 is procured in standard measures, as there is limited time to deliver project-specific measures. This often results in significant cut offs, particularly pieces measuring 30-40 cm.

The C24 is spruce from Sweden, and the employees try to choose the most suitable length of beams before cutting with the machine. The employees follow drawings and measurements from the architects. However, even though Scandi Byg aims to make standardised projects, this is not often the case due to the architectural requirements of the developer.

Storage Practices

The wood is stored outside, wrapped in its original plastic packaging from the sawmill. This storage method results in residue, especially during autumn and winter, when the weather can create high moisture content in the wood and result in fungi. It is possible to treat the wood, but the employees stress that they do not have time and are not allowed to use moisture-damaged wood in the modules. They have a few covers to protect wood pallets stored outside. However, observations revealed that most of the stored wood packages were unprotected.

Material Delivery and Single-Use Pallets

The employees highlight several aspects of transport which generate residue. There can be damages to the wood after transportation, where the top of the wood beam splits. They can cut the damaged part off and use the rest of the wood for something else. Furthermore, there is no take-back agreement on pallets from several suppliers, resulting in many unusable pallets, which end as residues. Figure 5.2 provides an overview of the main wood residue types from Scandi Byg.

Figure 5.2: Overview of wood residue types from Scandi Byg

5.3 Lilleheden

Lilleheden produces glue laminated timber. All products are made from spruce, and the wood residue generation at Lilleheden is estimated at 3,011 tonnes in 2024, where an estimated 282 tonnes were sold to Dansk Træemballage* (DTE), and 2,729 tonnes sold to Hirtshals Fjernvarme. The residues to Hirtshals Fjernvarme are pressed into wood briquettes. However, this contract expires in 2028.

Based on the analysis of residue, it was found that architectural design, cutting inefficiencies, testing material, poor quality, and finger joint challenge are main hotspots for residue generation.

Architectural Design and Cutting Inefficiencies

Glue laminated timber requires beams with uniform length and thickness. This necessitates cutting and planing the beams. Lilleheden's standard 38 mm thick beams are planed down to 33.3 mm for uniformity. Approximately 10 mm is planed off in width. For example, a final width of 90 mm requires raw wood of 100 mm. This process accounts for 20–25% of Lilleheden's residues and is difficult to reduce without sacrificing surface quality.

80% of Lilleheden's production is standard deliveries; 20% is project-specific. Standard products are 24 m beams stored for delivery within 48 hours. Since products cannot be modified, a large stock of finished beams is maintained. Because beams are sold in cut lengths (e.g., 9 m from a 24 m beam cut to 15 m), the cut offs become residue. Project-specific beams (20%) may be ordered at 10.5 m but glued at 10.8 m to ensure even ends. This results in approximately 30 cm of cut offs per beam end.

Lack of Residue Tracking

Lilleheden has limited overview of the quantity of residues generated. Little focus has generally been given residues, as the agreement with Hirtshals Fjernvarme in previous years has been lucrative. Therefore, several data gaps exist in the mapping, and these have been calculated based on estimates described in Section 4.2.3.

Testing Material and Poor Quality

There are three important quality systems at Lilleheden that are crucial for understanding residue generation: strength, knots, and CE-marking[1]. First, the timber must meet specific strength requirements. Half of the timber is strength-graded at the sawmill, typically the widest boards, which are more prone to knots. The remainder is tested at Lilleheden using an in-house grading machine. Timber must be C24 for use in the centre of glue laminated products and C35 at the ends. Timber that falls below these strengths is rejected by the machine and must be discarded, as retesting is not permitted. Rejected beams, typically 24 m long, are sold to DTE.

The second quality control process involves knot identification. A machine identifies all knots, to ensure they are not close to the end of the finger-cutting joint. Knots too close to the end must be cut off. This results in residues of approximately 10-20 cm.

A third quality process, involves tests to ensure that Lilleheden's products comply with CE-marking standards for glue laminated timber. Lilleheden regularly tests both the glue and the strength of finger joints. They conduct around five to ten destructive tests per day resulting in residues.

Finger Joint Challenge

Most of the production at Lilleheden is automated, and mistakes can happen during the finger jointing process. This can result in situations where the glued finger joint must be cut off, after which they can be glued together again. Figure 5.3 provides an overview of the main wood residue types from Lilleheden.

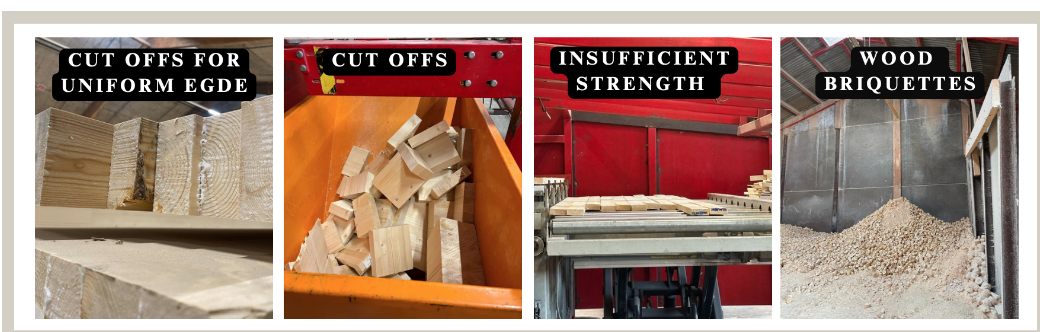

Figure 5.3: Overview of wood residue types from Lilleheden

[1] Conformité Européenne (CE) is a European product standardisation that applies to most products being sold within the European market to ensure its quality, safety, health and environmental performance (European Union 2025; Dansk Standard N.A.).

5.4 Palsgaard Spær

Palsgaard produces structural wooden elements. All the wood used for products at Hampen is spruce imported from Sweden. The production site at Hampen produced 369 tonnes of wood residues in 2024. Wood residues are collected by the waste management company, Palle Ø. They process the residues into wood briquettes, which Palsgaard repurchases for heating.

Based on the analysis of residue, it was found that material delivery, poor quality, architectural design, cutting inefficiencies, and storage practices, are the main hotspots of residue generation.

Material Delivery and Poor Quality

Palsgaard experiences damage to the wood during delivery from the sawmill, which contributes to residue generation. For example, plastic packaging may tear, allowing rain to enter and cause fungal growth. In such cases, the affected wood is manually discarded. Beams that are bent or crooked are also rejected, and both types of rejected wood are stored under cover. These residues can be purchased by locals.

Architectural Design and Cutting Inefficiency

All of Palsgaard's products are project-specific. Therefore, raw wood is selected according to the length required for each project. This process limits wood residues to less than 30 cm in length, with an overall residue generation estimated by the Head of Production to be below 4–5% per project.

Storage Practices

Between the cutting and the assembly station, the wood is stored outside. This can sometimes result in fungi if projects are postponed especially in autumn, with high humidity. However, the storage of raw wood, which arrived from the sawmills, is stored under roof, which ensures that the wood is generally stored dry. Figure 5.4 provides an overview of the main wood residue types from Palsgaard.

Figure 5.4: Overview of wood residue types from Palsgaard

5.5 Roust Element

Roust produces different types of wooden elements, made of swedish spruce, plywood, and chipboard. It is estimated that they generated 112 tonnes of raw wood, and 5 tonnes of glue laminated timber in 2024. Consequently, the total wood residues were an estimated 117 tonnes.

Based on the analysis of residue, it was found that architectural design, cutting inefficiencies, storage practices, and single-use pallets are the main hotspots for residue generation.

Lack of Residue Tracking

Roust currently has no overview of the quantity of wood residue, as they are used for internal heating. They only have information related to residue generation from the Hundegger saws, which indicate a residue rate of 4-5%. This results in large uncertainties linked to the residue data from Roust.

Architectural Design and Cutting Inefficiencies

The residue stemming from the Hundegger saws are generally no longer than 30 cm. One saw is programmed to cut larger cuts offs into small blocks, which support finished elements during transport to the assembly site. Once used, these blocks become residue. This practice helps maintain saw residue at approximately 4–5%. Larger cut offs are collected by local social workshops, while sawdust and smaller pieces are incinerated.

Roust also uses wood for facade planes, and although employees selects the most suitable sizes of raw wood, facades require trimming to ensure a smooth and uniform appearance. This process generates painted wood cut offs, typically around 20 cm in length.

Storage Practices and Single-use Pallets

Raw wood is stored under a roof, reducing the risk of fungal damage. However, if the plastic packaging is torn at the sawmill, moisture exposure may cause fungal growth, resulting in residues. If an entire batch is affected, it is returned to the supplier. Some suppliers use single-use pallets to transport raw materials. These pallets are stored on-site, where employees can reclaim them for reuse. After production, finished elements are typically stored indoors until delivery. If indoor storage is unavailable, the elements are wrapped in stretch film and stored outdoors for up to two months. If customer delays occur, moisture may enter the packaging, and in severe cases, entire elements or sections must be discarded. Figure 5.5 provides an overview of the main wood residue types from Roust.

Figure 5.5: Overview of wood residue types from Roust

5.5.1 Summary of wood residues hotspots in NOWI

Mapping of wood residues in NOWI identified several hotspots for residue generation, which are illustrated in Figure 5.6. The main hotspots include cutting inefficiencies, architectural design, and storage practices. All companies generate wood residues from Swedish spruce, while Roust and Scandi Byg also have residues from facade panels, plywood, and single-use pallets. However, each company also faces distinct causes of residue generation.

Given that wood residues in NOWI exceeded 4,466.5 tonnes in 2024, it is relevant to explore opportunities for utilising these residues with higher value retention. This is explored in the following Chapter.

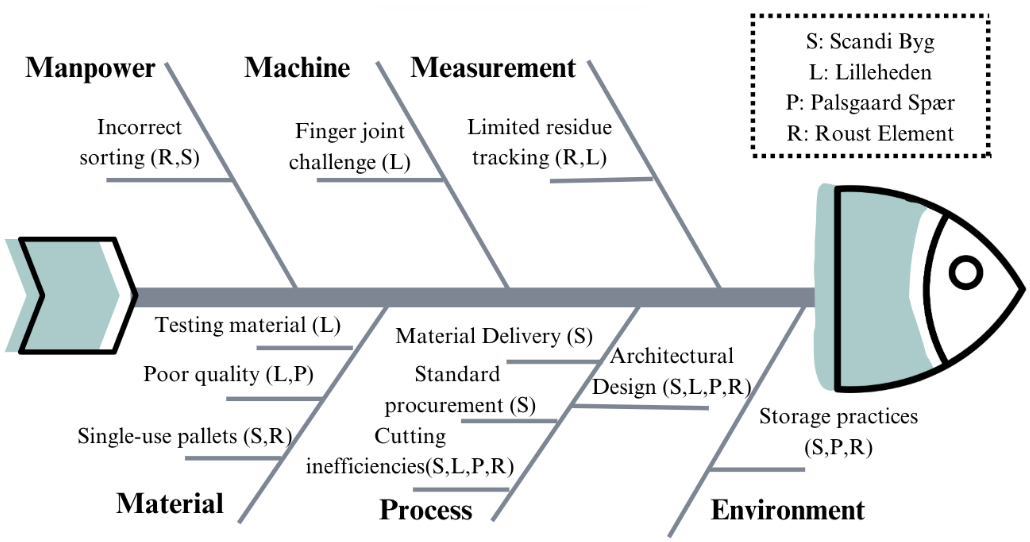

Figure 5.6: Overview of wood residue types from NOWI

Chapter 6

Building a Shared Vision of Symbiosis

This chapter presents the results of the analysis addressing the second sub-question: *How can a model of industrial symbiosis be designed in NOWI to retain value of wood residues and what are the main challenges?*. The results are based on a workshop methodology described in Section 4.2.6.

6.1 Description of the Proposed IS Model in NOWI

During the final workshop session, the participants developed a model illustrating their shared vision for wood residue management in NOWI. The model visualises the exploratory process participants engaged in to arrive at a shared vision. The model should therefore be viewed as a strategic starting point rather than a final, fully feasible solution. This section presents a description of the model, based on the participants' input during the workshop. The model is illustrated in Figure 6.1.

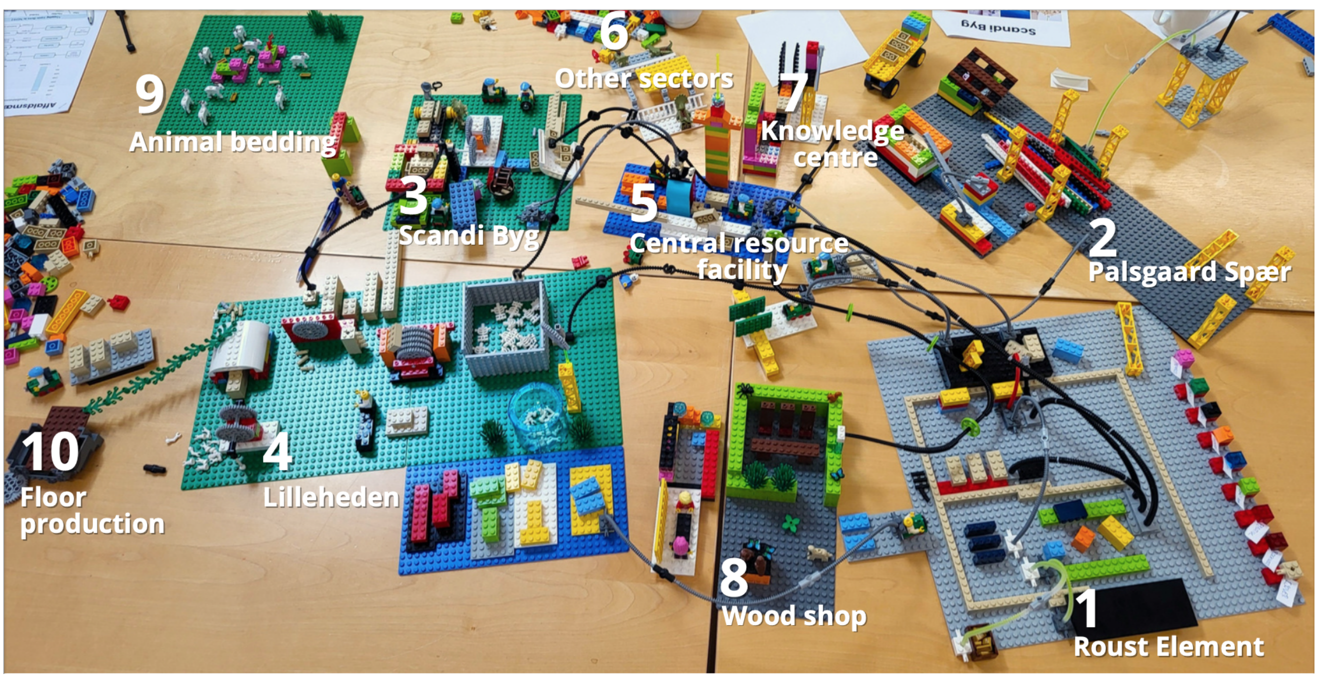

Figure 6.1: Overview of final IS model in NOWI

The figure illustrates ten main elements of the IS model. Four of these elements are companies: Roust (1), Palsgaard (2), Scandi Byg (3), and Lilleheden (4). As part of the new vision, NOWI could establish a central resource facility (5), to provide a shared space for handling residues. The facility could also import wood residues from other sectors (6). To support innovation in the sector, the resource centre could be complemented by a knowledge centre (7). A wood shop (8) could also be established along the central resource facility. Additionally, they could produce various products, including floors (10). Sawdust could be sold as animal bedding (9).

In addition to the common resource facility, each company has identified internal optimisation as their primary priority to minimise residue generation. In the model, Lilleheden, Roust, and Palsgaard have stopped incinerating wood residues and have proposed switching their heating supply to incorporate wind and solar energy. As Lilleheden and Roust are located at the coast, they also identify the potential to use wave energy. The participants highlighted that the resource facility could be coupled to a knowledge centre for testing new residue solutions. This will be described below.

Innovation with Knowledge Centre

The NOWI companies could combine the central resource facility with a knowledge centre. The combination of the central resource facility and the knowledge centre ensures the ability to function as a test facility, exploring the potential of new ideas and fostering collaboration with, for example, other sectors. Such collaboration could position NOWI as a frontrunner in the sector, and potentially also contribute to a changing mentality within the organisation; from a mentality of business as usual to becoming an innovative organisation taking important steps for the sector as a whole. The mentality could contribute to NOWI viewing itself as both part of the problem in residue generation and a part of the solution, by being willing to try alternative products and building practices.

Take-back Agreement

Besides this, Lilleheden could have a take-back agreement, where products are brought back and repaired, after which they could be re-certified as construction timber and reused.

Longer Beam with Lower Strength Cut to Trims

The resource facility could handle larger pieces of wood residues, such as beams that do not fulfil the quality or strength requirements that Palsgaard and Lilleheden must comply with. Such wood residues could be made into products such as trims, which could be utilised by Roust and Scandi Byg. Lilleheden's wood residues from the planning, gluing, and cutting processes contain glue, which may potentially be unsuitable for utilisation at the central facility.

Long Wood Fibres for Insulation

Fibre insulation could be made from the smaller wood residues, processed into fibres directly blown into walls and ceilings, ensuring that no residues are produced. This production could supply NVIRO with products, eliminating the need to purchase from northern Sweden as it currently does.

Smaller Cut Offs to Glue Laminated Timber

This could be a machine which could make finger jointed glue laminated timber from the pieces longer than 20 cm of construction wood residues.

Sawdust for Animal Bedding

The sawdust from the companies could be sold as animal bedding.

Export Wood Residues to Shop

The central resource facility could also transfer wood residues to the wood shop, which can make new products. These could be products such as bird boxes, which could both be bought externally by others and brought back to the production facilities at NOWI to ensure better conditions for biodiversity. Alternatively, it could be processed into furniture or flooring. The floor production is inspired by MOGU floors, which combine mycelium with wood residue to create biobased tiles (European Commision 2021).

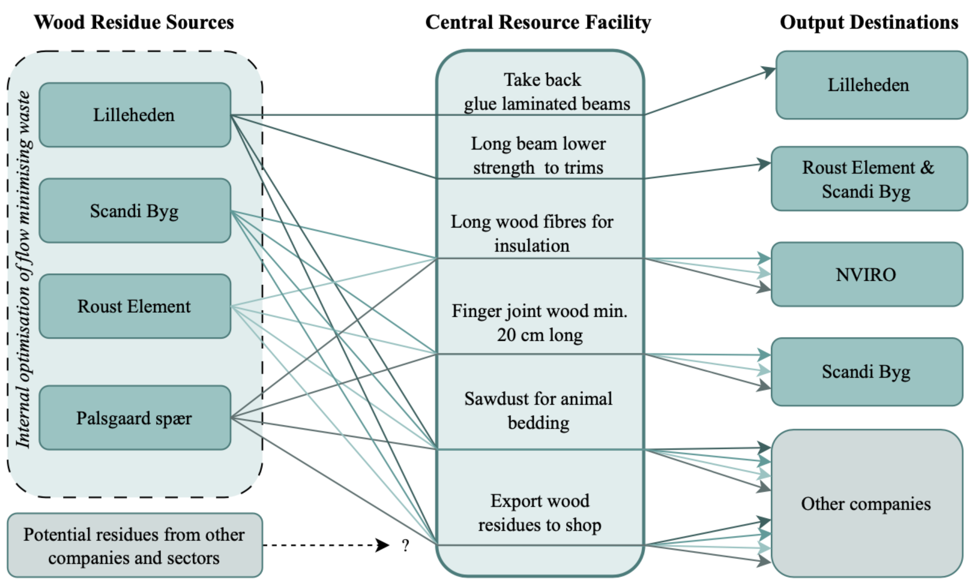

Figure 6.2: Overview of new wood residue flow in NOWI

Figure 6.2 illustrates how the central residue facility could provide a shared place for handling wood residues and the potential products that could be produced there, along with potential receivers. The dotted line around the companies illustrates how they could, as a first priority, make internal process and design optimisations within the companies to ensure minimal residue generation. The arrows moving from the central residue facility illustrate how the facility has six different production lines. The lines are determined by the type of residues received at the facility, and it is intended that they are prioritised to retain the highest CE value.

6.2 Assessing the Value Retention of Model

In the resource facility, different production lines correspond to varying levels of value retention. However, assessing retained value is context dependent. To assess value retention, the initiatives are mapped onto the Value Hill* framework developed by Achterberg *et al.* (2016), which visually represents CE strategies in a hierarchical value structure. The strategies are defined based on Potting *et al.* (2017). The different aspects of value retention are visualised in Figure 6.3.

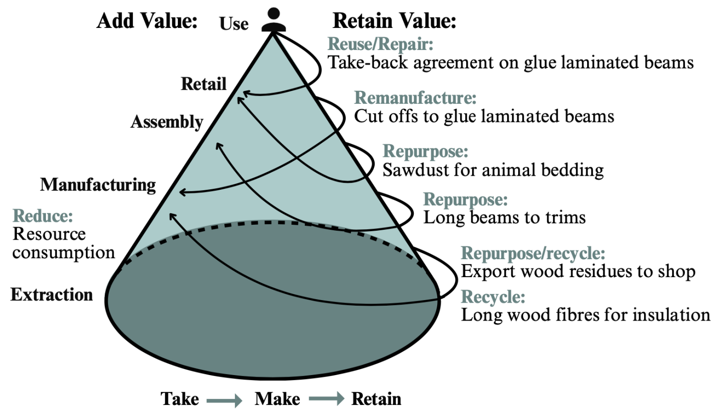

Figure 6.3: Positioning the model of IS on the Value Hill inspired by Achterberg *et al.* (2016)

Internal optimisation aimed at minimising residues retains the most value, as it occurs during manufacturing, reducing unnecessary material use and residue generation. The proposed take-back agreement for glue laminated timber similarly ensures high value retention through reuse with minor repairs, preserving the product's intended function. Using cut offs longer than 20 cm to produce finger jointed wood exemplifies remanufacturing, offering high value retention by transforming residues into structural elements, which hold greater value than smaller cut offs.

Repurposing long beams, discarded due to strength, into trims result in lower value than the abovementioned proposals. This is due to the cutting of beams into smaller trims. The proposal related to animal bedding will also retain value through the repurposing of sawdust, as the function changes without any needed treatment. The transfer of wood residues to the wood shop requires further clarification, as value retention depends on the specific products made. For example, creating bird boxes illustrates repurposing, involving minor processing while changing function. In contrast, producing floors inspired by MOGU tiles involves recycling, as residues are broken down and reformed. Producing long wood fibres for insulation also involves recycling, due to the required material processing.

6.3 Identified Challenges

Through the final session of the workshop, the participants were asked to write down challenges and concerns related to the IS model in NOWI. These included challenges related to economy, knowledge, sector norms, and collaboration.

Economy

The challenges related to economics covered concerns in relation to a shift in the heating source. Participants were unsure about the feasibility of investing in another heating source, such as solar panels.

Other economic challenges related to the transportation of the wood residues to the central resource facility were also raised. They were concerned about the environmental impacts of transporting residues and the logistical expenses. Besides transportation, they also addressed the economic expenditures related to processing residues at the central facility. It was identified that more knowledge was needed to ensure that it was feasible to process the residues, and that there was a market for them. A more general concern related to economics was the challenge of ensuring that the process started with 'the low hanging fruits' before making bigger investments.

Furthermore, there is a challenge related to deciding the price of residues when bought and processed at the central residue facility. This was articulated as a challenge, which must be addressed by the top management level in NOWI, to ensure that price setting will not influence the relational resources across the companies.

Knowledge

The challenges related to knowledge covered both the need for knowing what is allowed in terms of the strength sorting at Lilleheden, but also knowledge related to the legislation of utilising residues in new products. There were also addressed challenges related to the need for knowing the volumes of different residue fractions, and if these volumes were feasible to drive the central facility. Another challenge concerns the recurring aspects of GHGs, which are mentioned multiple times, as the potential environmental impacts from transport and processing may exceed the benefits. Furthermore, a challenge linked to the reuse of structural elements is that they must be re-certified and tested before being put into use again. This requires product specific knowledge. Lilleheden describes how its products could be chipped for identification in years to come. This however, also requires new knowledge in relation to how this can be implemented in practice.

Sector Norms

During the session, the participants also expressed challenges related to norms in the sector. This challenge is rather broad and covers aspects of the willingness to use reused products and recycled materials, but also the willingness to challenge existing practices. This relates to both material choices, but also design aspects, such as whether it is the materials or "the pen" that decides the design of a building. Addressing these challenges involves NOWI companies raising standards for both suppliers and customers. Another challenge related to changing norms, is the time aspect. The participants described the need for more time to ensure the most suitable material choices within a project. Therefore, the drawings needs to be finished in advance, so the companies have time to order correct length of wood.

The participants further highlighted the possibility of testing the reuse potential of structural elements stemming from, for example, the mink farms, which are being demolished in Denmark (Bygningsstyrelsen 2024). By collaborating with other sectors it could create the ability to have a higher productivity without being constrained by residues generation in NOWI.

Collaboration

The final challenge which was addressed was related to collaboration. They expressed a need to have a better collaboration both with their suppliers and customers, but also with fellow wood production companies in the sector. This could potentially mean that other structural beam or modular building suppliers could provide their residues to NOWI's resource facility. This could result in challenges related to competitive aspects.

6.4 Summary

The workshop resulted in a new co-created model of IS in NOWI. The new model contains the establishment of a central resource facility, where all wood residues from all NOWI companies can be transported to. Through the workshop six different production lines for wood residues were proposed.

- Lilleheden could have a take-back agreement on glue laminated beams. Beams that are selectively disassembled could be transported to the resource facility and be repaired and resold.
- Lilleheden has 24 m long beams with lower strength than C24, which could be transported to the resource facility and made into trims for Roust and Scandi Byg.
- Scandi Byg, Roust, and Palsgaard all produce wood residues that can be processed into long wood fibres for insulation, which NVIRO could utilise for its products.
- Scandi Byg, Roust, and Palsgaard produce 20 cm long wood residues, which could be transported to the resource facility, and through a finger joint process could be made into construction wood that can be utilised in Scandi Byg's modular building, but also other building companies.
- All companies produce sawdust which could be transported to the resource facility and sold as animal bedding.
- Any wood residues not utilised above could be transported from the resource facility to the wood shop, where it could be utilised into other products such as furniture, bird boxes, and floors.

Through the assessment of the model, it was found that the level of value retention varied in the proposals. The proposals ensuring that products were intact and served their original purpose ensured the highest value retention. This was, for example, the take-back agreement of glue laminated beams. Whereas the proposals processing materials through recycling, were retaining the least value. However, all proposals ensured the retention of more value, than the current practice. The workshop participants highlighted challenges of the model to be limited knowledge regarding both environmental, economic and legislative aspects. In addition to this the readiness of the sector in general and the sector norms, as NOWI cannot drive such change in CE practices alone. This further stressed the challenges linked to collaboration. Based upon these identified challenges and the proposed model, it is relevant to investigate the IC in NOWI, to assess if the workshop has contributed to the ICB, and how the willingness to continue with the IS development is.

Chapter 7

Institutional Capacity Insights

The following chapter presents the results from the assessments of the third sub-question:*How has the industrial symbiosis workshop contributed to the institutional capacity building in NOWI?* The methodology behind this analysis is described in Chapter 4.2.7. The chapter is structured according to the theory of ICB, thus drawing on aspects of both knowledge and relational resources, along with mobilisation capacity.

7.1 Knowledge Resources

The participants highlighted several aspects where they gained knowledge based on the workshop. Among these, five highlighted that they gained insights into residues from the other NOWI companies, and four highlighted how this knowledge led them to discover new opportunities for collaboration with residues in NOWI. This was further stressed by two participants, who described how they gained knowledge regarding how to help each other, while also saving money. In addition to these insights, two participants described how they gained insight into a potential collaboration through a changed mindset.

Based on the new knowledge, the participants were asked if they had gained new areas of focus. This revealed multiple aspects, where four emphasised the importance of creating symbiotic solutions, three highlighting the potential for reuse, and two focusing on turning residues into resources. In addition to these aspects, one highlighted the importance of carrying out internal optimisations with the aim of minimising wood residues.

The participants were further asked if they found aspects such as processes or structures challenging to work with regarding IS. Two participants described how their current heating supply utilises the wood residues, and that this challenged their interest in investing in IS. The investment and economic aspects are further mentioned as a challenge by two participants. Besides these challenges, aspects such as time, logistics, planning, and moving beyond current practices were each mentioned by a single participant. Furthermore, one respondent articulated a challenge related to the future facilitation, including the act of moving beyond ideas to actions. Figure 7.1 provides an overview of the responses related to the questions about the knowledge resources in NOWI.

Questions	Responses	Frequency	Respondence ID #1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
What are the two most important things you have learned about industrial symbiosis and waste through this workshop?	Residue insights from other NOWI companies	5											
	Opportunities for collaboration with residue	4											
	The potential to help each other while saving money	2											
	The need for more collaboration across	2											
	The potential for collaboration through a new mindset within NOWI	2											
	The approach to residue collaboration in NOWI	1											
	Balancing sustainability and economic considerations	1											
	Moving beyond existing business practices	1											
Is there anything new you have become aware of regarding your waste streams that you hadn't considered before?	Symbiotic solutions	4											
	Potential for reuse	3											
	Turn residue to new products	2											
	Internal optimisation for less residue	1											
	Reevaluate thoughts	1											
	No	1											
Are there internal processes or structures in your company that make it difficult to work with industrial symbiosis? If yes, which ones?	Current heating system utilises residue	2											
	Economic factors	2											
	Moving beyond current practice	1											
	Subsidiary companies	1											
	Logistics	1											
	Time	1											
	Prioritising over operation	1											
	Including residues in design and planning process	1											
	Facilitating the process	1											

Figure 7.1: Insights into participants responses to questions about knowledge resources

7.2 Relational Resources

The participants highlighted several aspects increasing the relational resources through the workshop. Five participants highlighted that they gained a better understanding of each other through the workshop. Following this, three participants stressed how they had gained new relationships, and further contacts were established to proceed with the work of IS in NOWI. The additional participants expressed that they found the relationships had improved significantly and contributed to shared empowerment.

In addition to this, the participants were asked which initiatives could strengthen the internal collaboration in NOWI. Five participants mentioned the establishment of a knowledge network group about IS, ensuring that the momentum from the workshop would continue to develop. Three participants described how they already intended to initiate a cross collaboration on surplus materials. In addition to this, specific internal steps for minimising residues were described. As the relational resources in IS are highly dependent on the trust among the actors (Wang *et al.* 2017), the participants were asked how they experienced the trust between the companies in relation to collaborating on residues and resources. Three participants described that they had very high levels of trust, while five described that they had high trust, and two described a moderate level of trust when collaborating on residue and resource issues. Figure 7.2 provides an overview of the responses related to the questions about the relational resources in NOWI.

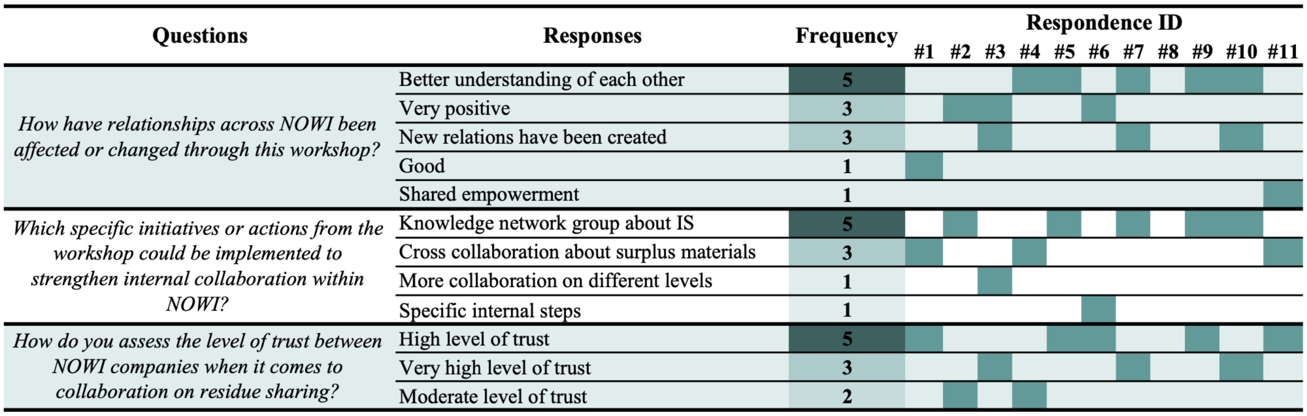

Figure 7.2: Insights into participants responses to questions about relational resources

7.3 Mobilisation Capacity

The participants highlighted several aspects that increased the mobilisation capacity in NOWI. Five participants described new internal collaborative residue initiatives. Three noted the ability to deliver products across companies, and three highlighted opportunities to extend existing collaboration One participant further highlighted the opportunities for external collaboration regarding residues.

Regarding external partners, participants were asked who might be relevant. Three participants mentioned other module and element manufacturers, and two described the potential for collaborating with other wood product manufacturers. Two emphasised unifying efforts across the construction sector to strengthen impact beyond NOWI. One participant further highlighted the opportunity for collaborating with universities and research institutions, and another participant argued that other suppliers and customers could be relevant to collaborate with. However, these are not specified. For the final evaluation, participants were asked about initiatives they would continue after the workshop. This provided multiple answers, including two participants who emphasised the ability to utilise wood at Roust discarded from Scandi Byg, Palsgaard, and Lilleheden, and two describing the prioritising initiatives at NOWI. Other initiatives included initiating a roadmap, external collaboration regarding residues, introducing external knowledge to solve problems, internal collaborative residue initiatives, internal optimisation, using glue laminated timber from Lilleheden at Scandi Byg, and utilising residues from Palsgaard at Roust. However, the participants described how they have varying roles in the continued work. Three described how their role involves coordinating, facilitating, and supporting efforts, while two described their role as contributing positively to collaboration about residues. One described the role of establishing the IS network, while others described the role as generating information about residues. One further described a role of calculating the effects of a potential IS in NOWI. These multiple specific initiatives are supported by the willingness among the companies to proceed with establishing an IS network. The participants were further asked how their willingness could increase. Four described how a collective IS strategy from NOWI would increase their willingness. In addition to this, two participants described that IS initiatives from the top management level would increase willingness. Furthermore, two described how visible actions and successes from all companies would increase their willingness. Figure 7.3 provides an overview of the responses related to the questions about the mobilisation capacity in NOWI.

Questions	Responses	Frequency	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
What new opportunities for working with industrial symbiosis and waste management have you identified?	Internal collaborative residue initiatives	5	■			■		■	■				■
	Deliver products across companies	3		■	■				■				
	Extended collaboration	3			■				■		■		
	External residue collaboration	1					■						
	Confirmation of existing ideas	1										■	
Are there companies outside of NOWI that could be relevant partners in an industrial symbiosis	Other module and element manufacturers	3		■	■		■						
	A unified sector is stronger	2	■						■				
	Other wood product manufacturers	2						■				■	
	Universities and research institutions	1									■		
	New suppliers and customers	1											■
Are there any specific initiatives or collaborations you would like to pursue further after this workshop? If yes, which ones?	Utilise wood at Roust discarded by Scandi Byg, Palsgaard, and Lilleheden	2			■						■		
	Prioritise initiative at NOWI	2										■	■
	Utilise residues from Palsgaard at Roust	1	■										
	Use gluelaminated timber from Lilleheden at Scandi Byg	1		■									
	Internal optimisation	1					■						
	Internal collaborative residue initiatives	1						■					
	Introduce external knowledge to solve problems	1							■				
	External collaboration regarding residues	1							■				
	Initiate a roadmap	1											■
What do you see as your area of responsibility/your role in establishing industrial symbiosis within NOWI?	Coordinate, facilitate, and support	3							■			■	■
	Contribute positively to collaboration on residues	2	■									■	
	Continue communication with production	1		■									
	Guide and advocate for new solutions	1			■								
	Generate information about residues	1					■						
	Establish IS network	1						■					
	Calculate effects	1							■				
	Work with standardisation	1									■		
How willing are you to continue working with industrial symbiosis in your company?	Willing	8	■	■	■			■	■		■	■	■
	Moderate level of willingness	2				■	■						
What could increase your willingness?	A collective IS strategy from NOWI	4	■		■		■				■		
	Visible actions and successes from all companies	2		■								■	
	Initiatives driven by top management	2			■		■						
	Responsibility allocation	1				■							
	Customer focus	1						■					
	Cannot be increased	1							■				
	Collaboration across companies	1											■

Figure 7.3: Insights into participants responses to questions about mobilisation capacity

7.4 Summary

Through the qualitative survey, it was found that the workshop and subsequent wood residue mapping positively contributed to increasing capacity building in NOWI. Firstly, the participants articulated how their knowledge resources increased, as they gained new insights into their own and others' resources. Secondly, the relational resources increased as they got to know each other better through the workshop, hereby gaining mutual understanding and higher levels of trust. Thirdly, the mobilisation capacity was increased, as the participants reflected on their own role in the future development, and their possibilities to proceed with the development. This positive development and the participants' willingness indicate that IS development in NOWI can be progressed.

Chapter 8

Discussion of Findings

This chapter discusses the research question by reflecting on the findings from the three analyses, each examined individually. Together, they inform the overarching question of how NOWI can increase the value retention of wood residues through IS.

The thesis was carried out in close collaboration with NOWI, offering a unique context. While IS often struggles with barriers such as limited trust, distance between actors, and uncertainty about mutual benefits (Park *et al.* 2018; Yedla and Park 2017; Ling Zhang *et al.* 2010; Schlüter *et al.* 2023b), many of these were mitigated within the NOWI group due to existing internal relationships and proximity. However, even though IS is often positioned as a partial solution for minimising environmental challenges, there are important limitations and challenges linked to the concept which must be addressed through systems perspective* to ensure the sustainability of initiatives. These biases and limitations linked to both the concept of IS, the methodological considerations of this thesis, and the specific context through this was carried out, will be discussed in the three sections, collectively providing the overall discussion of how NOWI can increase their value retention of wood residues through IS.

8.1 Insights from Mapping of Wood Residues

Based on the analysis addressing the first sub-question: *What are the types and hotspots of wood residues generated by NOWI companies over a year?*, it was found that NOWI companies generated a total of 4,466.5 tonnes of wood residues in 2024. Of these, 3,215 tonnes, corresponding to 72 %, were incinerated. The main hotspots for wood residue generation were identified as cutting processes, storage practices, material quality, and transportation.

The following section will provide a discussion of the results in relation to the challenges of residue generation, the national practice of wood residues in Denmark, and the mapping approach, as there are biases and limitations linked to the results.

8.1.1 Wood Residue Challenges

The analysis shows that companies view residue as inefficiency and are eager to minimise it. However, even though the companies want to minimise their residue generation, they can in some cases be constrained by, for example, legislative requirements such as Lilleheden's destructive tests to obtain the CE-marking. However, Samdal *et al.* (2023) have explored different possibilities for non-destructive tests for structural elements, such as ultrasonic testing, which is not general practice.

However, wood residues can also be generated based on external relations in the value chain. This is illustrated in the case of single-use pallets in Scandi Byg. Kørnøv *et al.* (2020b) found that pallets are a common problem for production companies. However, through a systems perspective, Kørnøv *et al.* (2020b) stress that taking back pallets from customers who are geographically far apart, may risk more environmental impacts than the impacts related to the production and discarding of single-use pallets.

Time and planning play a crucial role in the generation of residues, particularly because companies within NOWI often have limited time to procure materials before production must begin. The longer a project takes, the more costly it becomes (Flyvbjerg and Gardner 2023). While NOWI companies specialise in prefabricated building modules and products, which should in theory enable a high level of standardisation, these modules are often adapted to meet specific developer requirements and project designs. This project-specific tailoring reduces the potential for standardisation across projects. For example, companies like Scandi Byg follow standardised processes in production, but the actual materials used are customised to fit individual projects. Because they typically procure wood in standard dimensions rather than ordering it pre-cut to project-specific sizes, this mismatch between supply and design leads to residues. This is supported by (Flyvbjerg and Gardner 2023), who notes that standardisation helps reduce complexity and manage risk in project planning. Therefore, the challenge of residue generation is not only a matter of time constraints, but also reflects issues in coordination, collaboration, and shared responsibility between developers, designers, and producers. Through the discussions and workshop at BUILD (See Section 4.2.8), it was found that the procurement of building products along with the time planning, is a common challenge in residue generation in the sector. This illustrates that there is no single type of wood residue and thus no single solution for solving the problem as it is all a case of context and alternatives.

8.1.2 National Practice of Wood residue Management

As NOWI is one of the leading corporate groups focusing on wood in the Danish construction sector, it is interesting to compare the results with national practice. Butera *et al.* (2024) estimated the total wood residues in Denmark in 2021 to be of 195,000 tonnes. Subject to the uncertainties inherent in such a national calculation, NOWI contributes to nearly 2.3% of the total wood residue generation in Denmark. Aho *et al.* (2022) further describe how 82 % of the construction wood residues are utilised in particle- and chipboards. The remaining 18 % is used for heating (Aho *et al.* 2022). In contrast, the results from Chapter 5, illustrate that NOWI's practice of burning 72 % of its wood residues provides less CE value than the national average (Potting *et al.* 2017; Achterberg *et al.* 2016). On one hand, these findings illustrate the potential for improving the value retention of wood residues in NOWI. On the other hand, they illustrate the data gaps linked to the construction sectors mapping of wood residues (Butera *et al.* 2024). As several of the NOWI companies burn their wood residues without registering them, it can be assumed that they are not part of the national numbers. These data gaps align with the findings from Brownell *et al.* (2023), who also identify the challenges of data gaps when estimating wood flows in Denmark. There are also data gaps and potential biases, linked to the results of this thesis, which will be discussed below. The challenge with quantifying wood residues in the sector, may be due to a limited knowledge and focus on residues. Mbadugha *et al.* (2022) found that limited knowledge, combined with attitudes toward construction residues, contributes significantly to residue generation. The study further emphasises the need to increase awareness of residues within the construction sector. Ehrenfelt and Gertler (1997) support the need to increase awareness and a shift in cognitive domain, as the sector predominantly has focused on customer needs rather than preventing overconsumption and residue generation in their practices. Even though the findings from Ehrenfelt and Gertler (1997) are nearly 30 years old, the findings were reinforced during the workshop at BUILD (See Section 4.2.8), where it became evident that many companies still have limited insight into heir residues.

8.1.3 Mapping Approach

The varying levels of knowledge related to wood residues in NOWI affects data availability. Consequently, the residue mapping has been carried out differently for the companies depending on the data available (See Section 4.2.3). This results in different levels of granularity for the results and limits the robustness of the findings. The wood residues at Scandi Byg are specifically measured by Marius Pedersen, this results in minor limitations stemming from unmeasured residues being bought internally by employees, whereas Roust only has data on the wood which is bought and the residue data from their three saws. As Roust's wood residue quantity is significantly smaller than the other companies. This indicates that calculating wood residue quantities based on only the residue data from the saws is not sufficient for mapping residues in the whole production. Furthermore, this thesis does not account for the procured wood or productivity at the companies. For instance, Lilleheden has significantly higher residue generation than Roust, and this can both be a result of data quality, but also a result of productivity, if Lilleheden produces more than Roust. However, due to limited time and resources at the companies, it was not possible to identify these data gaps.

Another limitation for the analysis is the general challenge in quantifying the different residue types, such as the quantity of sawdust or C24 cut offs, or to quantify the different hotspots such as transportation, storage practices, and the design of products. This could only be mapped qualitatively through observations and field interviews. The study by Hasselsteen *et al.* (2024) identified the challenge with measuring residues at construction sites, which was only found done in 26% of their reviewed articles. These findings were further supported by the discussions at the BUILD workshop (See Section 4.2.8), where quantifying residues on construction sites were found to be a common challenge. Part of the challenge is also due to time, both in terms of the time it would take to measure all the different types of wood in a container. As the quantitative data that could be generated stems from 2024, and the observations were carried out in 2025, there is a potential bias in the timing of the different types of data. However, within the given project period, this was found sufficient, which is further strengthened by the fact that NOWIs products are standardised, resulting in the projects and processes being similar independent of years.

Drawing on the field interviews, it is important to note the risk of interview bias (Aarhus Universitet N.A.). This thesis risks being biased by general challenges with interview as a method, including a risk of bias in formulation of questions, misinterpretation of questions, but also a risk of interviewees withholding information in favour of the company (Aarhus Universitet N.A.). This can potentially limit and skew the findings of this analysis and downplay the significance of the residue hotspots. Field interviews were carried out with the head of production for each company. Therefore, the findings are limited in scope, as other professionals (e.g., carpenters) with different knowledge could yield different results.

All observations and interviews were made following the designed guide inspired by the Ishikawa diagram, with questions, ensuring the same questions were asked to all companies. However, there are inherent biases linked to this framework, as it aims to find the root cause of a problem. There can be multiple causes to a problem, and with a categorical framework like the Ishikawa diagram, there is a risk that potential correlations between the categorises are diminished (Paredes 2024). The guide provides a systematic approach to observing, which may result in the risk of overlooking other aspects. Following this, there is a risk that the researchers 'observe their own assumptions'. This is due to the observer, who observes from a selective position (Kitchin and Tate 2000). Thus, observation depends on the researcher's ability to interpret the observed phenomena (Kitchin and Tate 2000). However, the Ishikawa diagram is well-known in research as a means to identify root causes in residue generation (Kolaventi *et al.* 2020; Anggraini *et al.* 2022; Sagan and Mach 2025), and through discussions with Simon Wyke (See Section 4.2.5), it was justified to be sufficient for this thesis. Following this, the external validity is limited in relation to the results, however the internal validity is high, and the methodological approach can be argued to be robust.

8.2 Insights from Shared Vision of Symbiosis

Based on the analysis addressing the second sub-question: *How can a model of industrial symbiosis be designed in NOWI to retain value of wood residues and what are the main challenges?* a specific model of how IS was designed. The model was designed through a workshop where stakeholders from each company co-created a shared vision for how to handle wood residues in the future. The model contained a new central resource facility, which could handle all wood residues from NOWI as well as from other companies. The resource facility could also work as a test facility for new ways of using wood in close collaboration with universities. Six production lines at the facility were created: take-back agreement on selective disassembled glue laminated beams, long beams made into trims, long wood fibres made into insulation, smaller pieces made into finger jointed wood, sawdust to animal bedding, and a broader production line of export wood residues to a wood shop. The shop could make products to sell beyond the construction sector such as bird boxes or furniture. The wood shop could be managed as a social economic company. Through the discussions at the workshop, the participants identified several challenges linked to the designed model. These included economic challenges, the need for more and new knowledge, changing sector norms and collaborating across the production chain and internally in NOWI.

The section will provide a discussion of the methodological approach and underlying social constructivism of this analysis. Following this, the discussion will draw upon aspects of sustainability assessment, to critically assess the results of the workshop.

8.2.1 Model Construction and Approach

Drawing on aspects of social constructivism, the context through which people are part of, is influencing their perception of a given phenomenon (Egholm 2014; Roos and Victor 2018). With the workshop methodology, the researchers designed an arena for exploring IS in NOWI, where participants were placed with the specific aim of making them co-create a model (Mosely *et al.* 2021). This implies a risk that the workshop design might have influenced how participants conceptualised the model (Mosely *et al.* 2021). To strengthen the workshop design, the researchers consulted three times with experienced workshop facilitators at Aalborg University. It is argued that these meetings contributed to a higher internal validity of the methodological approach. However, the results have limited external validity due to their strong contextual dependency. Park *et al.* (2018) also found the composition of a group to be important when facilitating an arena for IS development. Group thinking also poses a potential bias in the workshop approach, because participants were grouped by company, which may have influenced their creativity and limited their willingness to challenge majority standpoints (Montuori 2011). However, this design choice was deemed sufficient due to time constraints.

8.2.2 Critical Systems Perspective on Value Retention

While the co-created model enhances value retention, this does not guarantee sustainability. IS has often been criticised for being limited to recycling solutions, with limited value retention and failing to consider the implications of solutions in a broader systems perspective (Mirata 2005). During the workshop, the companies highlighted initial resource efficiency as important, though this was not reflected in the model, as participants focused on symbiotic solutions. Following this, while the initiatives may retain value, this does not guarantee the sustainability of the initiatives. Therefore, the different aspects of the model must be critically assessed in a systems perspective beyond NOWI (Ruini *et al.* 2025). Drawing on findings from Schlüter *et al.* (2023a), producing new products is not considered sustainable unless they fulfil a need. Otherwise, IS solutions in NOWI risk legitimising current residue-generating practices (L. Kørnøv, personal communication 2025; Greer *et al.* 2021). Furthermore, it risks resulting in sub-optimisation, rebound effects, and a false perception of sustainability (Schlüter *et al.* 2023a). Life Cycle Assessment* (LCA) is a well-established method for evaluating environmental impacts of a production system throughout its life cycle (Kanafani *et al.* 2021). However, in the early phases of IS development, limited data, particularly on residues, as identified in Chapter 5, makes it difficult to accurately quantify the environmental impacts of IS solutions (Ruini *et al.* 2025).

To address the limited data availability in the early stages of IS development, Kørnøv *et al.* (2020a) developed a qualitative assessment framework to evaluate the sustainability of symbiotic initiatives. This includes questions such as assessing additional processing, the implications of changing utilisation, and design modifications (Kørnøv *et al.* 2020a). Another approach is the conceptual framework developed by Schlüter *et al.* (2023a). This framework emphasises the need to qualitatively assess causal relationships between subunits within the broader system, and how changes in one area influence adaptations in others. It further illustrates how early assessment of sustainability is guided by qualitative approaches such as the rule of thumb[1], and the framework from Kørnøv *et al.* (2020a). In the later stages, screening LCAs and full LCAs can be appropriate for quantitative assessment.

Energy Use and Value Retention

Implementing IS initiatives would require changes to the energy systems of Roust, Lilleheden, and Palsgaard. However, workshop discussions revealed that the current practice of using wood residues for heating creates a lock-in, limiting incentives to reduce wood residue generation or to implement IS initiatives (Ellen MacArthur Foundation 2023). This lock-in is driven by economic self-interest, as the current practice avoids both residue disposal costs and heating expenses. To address this lock-in, the IS model was developed under the prerequisite that no residue burning would occur. This aligns with a CE perspective, where burning eliminates the material value of residues. However, burning wood is not inherently unsustainable, as its impact depends on the available alternative heating sources (European Environment Agency 2022; Schlüter *et al.* 2023a). Maier (2022) argue that wood incineration

[1] The rule of thumb in this context refers to the general aim of CE to keep products and materials as close to their original purpose and function (Ellen MacArthur Foundation 2013b; Schlüter *et al.* 2023a).

can be more sustainable when it replaces non-renewable heating sources, such as coal, which emit high levels of GHGs. Additionally, the energy system is continuously evolving with an increasing share of renewable energy (Danmarks Statistik 2024). Such developments affect sustainability assessments, as results are likely to change over time with the evolving context (L. Kørnøv, personal communication 2025). This illustrates the complexity of assessing sustainability of IS initiatives in NOWI and highlights the need for an iterative, reflective approach where the model's sustainability is continually reassessed (Schlüter *et al.* 2023a).

Market Conditions for Value Retention

Although IS initiatives theoretically offer value retention and can be assessed for environmental sustainability, they may face practical implementation challenges due to market conditions. Taqi *et al.* (2022) found that market uncertainty poses a challenge to the successful implementation of IS. This is linked to companies' reluctance to depend on and share resources and knowledge with others, especially when these are potential market competitors (Taqi *et al.* 2022). Hossain *et al.* (2024) also argue that immature markets present a barrier to implementing IS initiatives. This relates both to the limited consumers (European Environment Agency 2022) and to institutional constraints, such as legislation and standards, which can create lock-ins (Taqi *et al.* 2022; Hossain *et al.* 2024). VCØB (N.A.) stress that the legislative requirements often challenge the implementation of CE solutions, such as the take-bake initiative where Lilleheden's glue laminated beams can be reused. When products are reused, they are not subject to waste regulations but must still meet the same requirements as new products (VCØB N.A.). This is challenged by the need to comply with the CE-marking, which cannot be obtained when products re-enter markets in Europe (VCØB N.A.). In this case a voluntary European Technical Assessment can be obtained, to document the sufficient technical information regarding quality to enter the European market(VCØB N.A.). Bhasin *et al.* (2020) further emphasise that IS markets are also constrained by internal factors, such as limited sawdust availability, which depends on companies' overall productivity. European Environment Agency (2022) found that markets for secondary wood use in European countries are challenged, due to limited market size, weak policy drivers, and strong competition between energy recovery and other CE strategies. Therefore, to assess the sustainability impacts of IS initiatives, value retention strategies must be integrated with systemic insights into energy use and market dynamics, supported by iterative, reflective evaluation. Without such integrated, adaptive approaches, IS risks reinforcing existing unsustainable practices rather than transforming them.

8.3 Insights from Institutional Capacity Evaluation

Based on the analysis addressing the third sub-question: *How has the industrial symbiosis workshop contributed to the institutional capacity building in NOWI?*, it was evident that the workshop contributed positively to the ICB in NOWI. Through the qualitative survey, the participants highlighted how they gained knowledge both in relation to their own company, and about the other companies. The workshop further increased the relational resources in NOWI as the participants stressed how they got to know each other better, and strengthened the trust across the companies. This was further strengthened by the workshop through the creation of a shared vision built using LEGO® bricks. By visualising the shared vision, the participants further articulated how this increased their willingness to reach this vision, and highlighted specific steps, along with the role each participant could play in achieving it. Consequently, the mobilisation capacity, the relational resources, and the knowledge resources were increased through the workshop.

The following section will provide a discussion of the methodological approach, including the theoretical framework, followed by a discussion of the role of the facilitators in this IS development.

8.3.1 Methodological Approach and Theoretical Framework

A qualitative survey was chosen as the methodological approach, as it enables the collection of in-depth data, similar to interviews, while allowing respondents time to reflect before answering (Braun *et al.* 2020). This approach was also selected because it produced textual data, which facilitated both collection and subsequent coding for analysis (Braun *et al.* 2020). However, the survey presents several limitations. First, the survey was completed immediately after the workshop, which may have led participants to respond more briefly or differently than they would have at a later time. Second, the lack of anonymity may have influenced the honesty of responses (Choi and Pak 2005). However, this choice was made to assess whether some companies were more willing than others to continue IS development in NOWI. Additionally, the survey questions may contain biases stemming from their formulation (Choi and Pak 2005). The questions were designed with inspiration from the theory of ICB. The methodological approach is inspired by the study of (Wang *et al.* 2017). As a result, aspects not covered by the theory were omitted, and thus resulting in a potential bias in the survey design. ICB is a broad conceptual theory, making it suitable for structuring analyses of how IS can emerge (L. Mortensen, personal communication 2025). However, its broad nature introduces biases and limitations, as it can be difficult to apply in practice (L. Mortensen, personal communication 2025). In addition to this, it needs interpretation when applying the broad theory to a real-life setting. Drawing on the aspects of social constructivism, there is thus a risk of limiting transparency when formulating questions based on the theory, as researchers risk understanding and interpreting the theory differently (Egholm 2014). Nevertheless, as the questions were developed based on ICB literature it is argued that there is high internal validity, robustness, and transparency. However, the questions were specifically formulated to the case of NOWI, so the external validity is limited.

Beyond its broad conceptual nature, the theory provides overarching themes and arenas necessary for IS development but does not specify what these arenas should entail. (L. Mortensen, personal communication 2025). For example, there is a need for knowledge resources, but it does not specifically state who needs to know what and when. de Abreu and Ceglia (2018) found that, even though there is willingness and interest in IS, there must be some kind of top-down management driving the process further. This is supported by the findings from Hossain *et al.* (2024), who identify that limited support from the top management is a critical barrier for the development of IS. While top management support is important, support and willingness at all organisational levels are important. Therefore, it is not enough to have a top management that wants to utilise wood residues in symbiotic solutions, if production employees do not sort the wood residues (L. Mortensen, personal communication 2025). However, the theory does not provide information as to how this process should unfold. Consequently, the theory does not account for the important aspects of facilitation and implementation of initiatives.

The theory presents knowledge resources, relational resources, and mobilisation capacity as equally important components. However, Boons and Spekkink (2012) argue that the mobilisation capacity is a more critical aspect, as it includes the perception of relevant options in the IS development, including if a solution is feasible. Furthermore, Wang *et al.* (2017) found that sufficient knowledge and relational resources are not enough to establish IS, if the mobilisation capacity is limited. Part of the mobilisation capacity also includes having a shared vision, with strategic initiatives such as a roadmap providing momentum for further development (Schlüter *et al.* 2023b). However, Yu *et al.* (2014) argue relational resources are of more importance for effective IS, than the mobilisation capacity linked to a roadmap or specific resources.

The theoretical framework of ICB is found to have some limitations when applied to the case of NOWI. Based upon this, it can be discussed if further theoretical development is needed. The theory does not specify how much capacity is required to establish IS. This is particularly relevant when considering mobilisation capacity and related economic factors. Economic aspects were found highly relevant in practice, as participants in the workshop highlighted it as a determining factor for the implementation of initiatives. This is supported by Hossain *et al.* (2024), who identify the challenge of high cost to both processing, transportation, and storage limiting the feasibility of IS. The importance of economic incentives is also emphasised in the findings from Ehrenfelt and Gertler (1997), but this is not addressed in the theory.

In order to ensure willingness across all levels and assess the feasibility of initiatives and ensure strategic actions, the facilitation role becomes highly important in IS development. The following section will thus discuss the role of a facilitator in relation to NOWI.

8.3.2 Facilitation Role for Institutional Capacity Building

This thesis served as a catalyst for initiating IS development in NOWI. Consequently, the thesis work facilitated the initial steps, including several meetings, supplementary learning materials for each company, and the facilitation of a workshop. However, an important limitation of IS, is that it does not occur without facilitation (Södergren and Palm 2021). Therefore, there is a fundamental need for finding new ways of facilitating the IS development in NOWI. It can be discussed whether the external facilitation role of the master's students offers a unique position, potentially perceived as more neutral compared to facilitation by a company representative. Södergren and Palm (2021) and Taqi *et al.* (2022) suggest a third party, preferably local government or industry associations, to facilitate and support IS development. Following this, Schlüter *et al.* (2022) uncover that it cannot be anyone, as they must possess specific attributes to ensure a successful facilitation. Schlüter *et al.* (2022) provide an overview of an extensive skill set needed to facilitate IS. In general the facilitator must take a proactive approach, in both creating specific arenas that bring the right people together and motivate them to an extent where they are empowered to take ownership and responsibility (Schlüter *et al.* 2022, 2023b). The facilitator must simultaneously create and share knowledge to ensure an iterative learning process (Schlüter *et al.* 2022). Adaptability is also essential, as the role requires the intuition to read a room, understand when and how to engage individuals, and tailor communication accordingly (Schlüter *et al.* 2022; Mosely *et al.* 2021). Based upon this, it can be discussed if one person is capable of taking on the role of facilitator in NOWI or if the role could be shared among several people.

Employees from each company possess important specific knowledge related to the companies' resources and processes making it highly relevant to have these included in a network. An IS network could ensure momentum on the IS development. This stresses the need to ensure that all relevant employees are part of the network, and that the network is facilitated by several people capable of developing it into a platform that delivers mutual benefits for all involved.

8.4 Recommendations for NOWI

Based on the findings of this thesis, eight recommendations have been formulated to support the development of IS in NOWI.

1. Identification of Facilitators and Their Roles

Facilitation has been identified as a critical factor in the initial development of IS in NOWI. Based on findings from the third sub-question, it is recommended that NOWI appoint a facilitation team to lead future IS initiatives. This team should include individuals with complementary competencies and in-depth knowledge of the participating companies. A shared facilitation approach would broaden the range of expertise available, reduce individual workload, and enhance continuity. The facilitators are expected to coordinate key activities such as organising meetings, developing agendas, hosting workshops, and ensuring relevant stakeholders are engaged throughout the process.

2. Establish IS Network

During the workshop, participants expressed clear interest in continuing collaboration on IS development. To sustain this momentum, it is recommended that NOWI establish an IS network comprising key stakeholders from each company, particularly those who attended the workshop. The network should meet regularly and be supported by appointed facilitators to maintain structure and continuity. This platform would enable knowledge sharing, identification of new opportunities, and coordinated implementation of IS initiatives.

3. Improve Data Quality and Residue Mapping

To strengthen the mapping of wood residues, it is recommended that NOWI addresses existing data gaps. Currently, the companies have limited knowledge of their residue generation, which limits the accuracy of the mapping and identification of symbiosis opportunities. A more robust dataset would improve the prioritisation of relevant hotspots for further assessment. To achieve this, each company's head of production should take responsibility for data collection, guided by a standardised residue mapping procedure developed collectively. This process should be initiated through a meeting facilitated by the network coordinators.

4. Assess the Problem at the Core

While IS offers opportunities for retaining value, it is essential to evaluate its broader sustainability implications. IS is not inherently sustainable, and simply redirecting residues does not address its root causes. Uncritical implementation may address only the symptoms of resource inefficiency and lead to a false perception of sustainability. Therefore, it is recommended that NOWI critically examines the origins of residue generation and prioritise residue prevention over alternatives such as recycling. In the case of Lilleheden, it could utilise the wood, which has previously been discarded based on strength tests in the centre of its products, as there are lower strength requirements in the centre compared to the ends of a glue laminated beam.

5. Development of IS Model
While this thesis introduces a preliminary IS model, it is recommended that NOWI treats it as a dynamic framework, which is subject to further development. The model should evolve in response to ongoing insights gained through future workshops and meetings. This iterative approach will ensure that the model remains relevant, adaptable, and continues to support cross-company collaboration.

6. Identify the Regulatory Landscape linked to the Model
When new IS initiatives emerge, the regulatory landscape must be identified to ensure that it is implementable in practice in compliance with existing legislation.

7. Sustainability Assessment of IS Initiatives
Before implementing IS initiatives, it is essential to evaluate them from a systems sustainability perspective. These evaluations should acknowledge that assessment outcomes may evolve over time due to changing contexts. Continuous reassessment is necessary to ensure that initiatives do not result in unintended negative consequences and to maintain the legitimacy of IS efforts in NOWI.

8. Develop IS Roadmap
It is recommended that NOWI develops a strategic IS roadmap, prioritising short- and long-term initiatives. The roadmap should include clearly defined targets for wood residue reduction and assign responsibility for each action point. This roadmap could also be incorporated into a future sustainability strategy.

8.5 Recommendations for Future Academic Research

This thesis identifies several directions for future academic research. One promising avenue is exploring how the LEGO® Serious Play® methodology can enhance IS development, particularly within the construction sector. Findings from the third sub-question indicate that a high level of willingness and the identification of IS opportunities alone are insufficient for successful implementation. It is therefore recommended that the theory of ICB expand beyond the existing categories to include aspects of implementation and facilitation. Part of the implementation could also develop aspects of economic factors and how willingness to participate in IS may vary across organisational levels.

Figure 8.1 outlines how the thesis provide 11 recommendations, eight for NOWI, and three for future research and theory development. Three colours represent the sub-questions. The dotted-line boxes illustrate the raw results from the analysis, insights from the discussion, and the corresponding recommendations. Arrows indicate the logical progression from results to findings to recommendations.

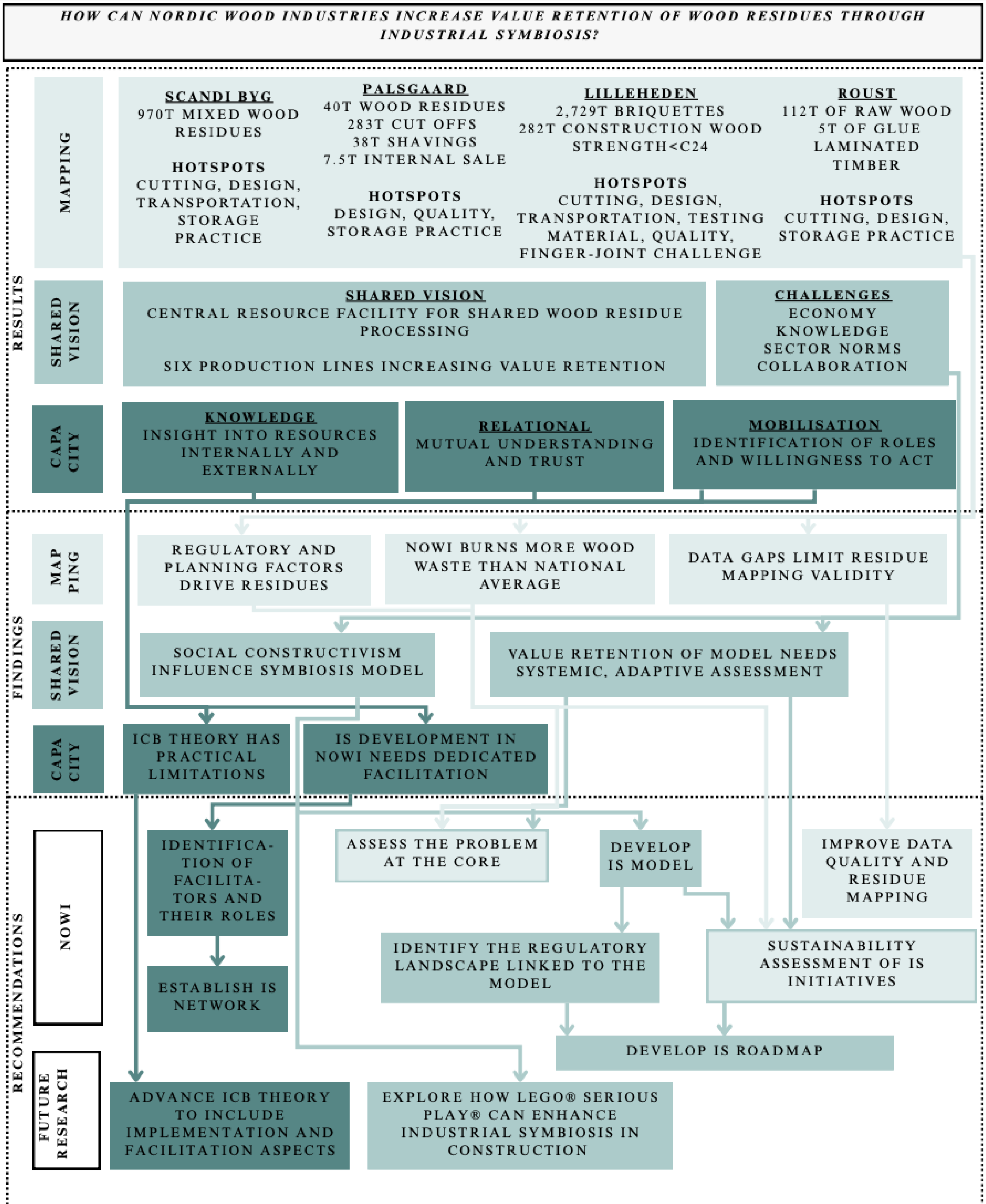

Figure 8.1: Recommendations based on the findings from this thesis

Chapter 9

Conclusion

This thesis applies a single embedded case study, to explore how NOWI can increase value retention of wood residues through IS. To address the research question of this thesis: *How can Nordic Wood Industries increase value retention of wood residues through industrial symbiosis?*, three analyses were conducted, including a mapping of wood residues, a workshop aimed at creating a shared vision for IS, and a qualitative survey evaluating the IC in NOWI related to IS. These analyses collectively contribute to the assessment of the overall research question.

Through a mixed-method approach the wood residues in NOWI were mapped. It was found that NOWI generated 4,466.5 tonnes of wood residues in 2024, with 3,215 tonnes burned for energy recovery. However, the varying levels of knowledge about residues within the companies, limit the robustness of the mapping, and the reliance on self-reported data may introduce biases. However, based on the observations and interviews, the architectural design, cutting inefficiencies, and storage practices were found to be hotspots of residue generation. Residues mainly consist of Swedish spruce construction wood in various sizes, shavings, and sawdust.

A workshop, inspired by the LEGO® Serious Play® methodology, was designed to explore alternative ways to increase residue value retention. Participants co-created a LEGO® model illustrating a shared vision for handling NOWI's wood residues. The model contained a central resource facility which could collect the residues to generate six production lines utilising wood residue in new products. The production lines provide varying levels of value retention, including strategies such as reuse, remanufacture, repurpose, and recycle. The model was designed under the assumption that residues should not be burned to ensure value retention. However, this does not ensure sustainability. It is therefore concluded that the IS initiatives should be critically assessed for their sustainability impact before implemented. This is important for ensuring that IS initiatives do not simply legitimise current residue generating practices or create sub-optimisation in a broader system. Additionally, the initiatives developed through this thesis should be seen as part of an idea-generation process rather than a final model. Through the workshop, participants highlighted several challenges regarding IS development, including limited knowledge of legislation and sustainability, reluctance within sector norms to explore new building practices, economic feasibility, and the need for customers and suppliers to change the current practice.

Through a qualitative survey, it was found that the workshop contributed positively to the ICB in NOWI. The workshop improved knowledge of residues, increasing the mobilisation capacity by identifying specific initial steps, and strengthened relational trust and the willingness to support one another. Findings thus indicate sufficient IC and willingness to continue IS development within NOWI. However, it remains uncertain whether this will translate into actual implementation without addressing aspects of facilitation or economic incentives.

Based on the findings of this thesis, the following recommendations have been formulated to increase the value retention of wood residues through IS in NOWI:

- **Identification of Facilitators and Their Roles:** Assigning specific individuals within NOWI to facilitate future IS meetings and maintaining momentum.
- **Establish IS Network:** Formally create a network within NOWI with regular meetings, communication, innovation, and change-agents to integrate the work into each company.
- **Improve Data Quality and Residue Mapping:** Enhancing the consistency, transparency, and robustness of data.
- **Assess the Problem at the Core:** Critically assess the production practices and understand the limitations and potential pitfalls of the IS concept.
- **Develop IS Model:** Treat the current model as iterative and subject to ongoing development.
- **Identify regulatory landscape:** When new IS initiatives emerge, the regulatory landscape must be identified to ensure they are implementable.
- **Sustainability assessment of IS initiatives:** Evaluate IS initiatives in a system perspective to avoid potential sub-optimisation.
- **Develop IS Roadmap:** Prioritise IS initiatives over time, with specific responsibilities and targets.

The exploratory nature of this thesis has shed light on the possibilities for developing IS in NOWI through co-creation. However, this approach is not without limitations. The absence of detailed environmental assessments means that the practical feasibility of the proposed solutions remains uncertain. Addressing these issues in future research could enhance the robustness and applicability of IS solutions in similar contexts. The qualitative and exploratory nature supports the internal validity, with the possibility of applying the mixed-method approach in similar cases and different sectors. However, the case-specific findings limit the external validity.

The LEGO® Serious Play® inspired workshop was found to encourage creative engagement, but future studies should assess whether such co-creation leads to concrete IS actions. It is further recommended to expand the ICB theory to address its limitations in implementation and facilitation of IS, incorporating economic factors and willingness to act across organisational levels.

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Appendix A

Conversions of Residues

Lilleheden: Quantities sold to DTE

In 2024 Lilleheden sold 855 m^3 to DTE. Based on discussions with Lilleheden, the density was set to 330 kg/m^3, which corresponds to 282 tonnes of wood residue.

$$\text{Mass of raw wood} = 855\,\text{m}^3 \times 330\,\frac{\text{kg}}{\text{m}^3} = 282{,}150\,\text{kg} = 282.15\,\text{tonnes}$$

Lilleheden: Energy from Purchased Wood Chips

Lilleheden has an agreement with Hirtshals Fjernvarme to supply 14,073 MWh of heat annually. To meet this demand, Lilleheden purchased 313.2 tonnes of wood chips. Based on discussions with Lilleheden, the energy content of the wood chips was set at 9.3 Gj per tonne, corresponding to approximately 809 MWh.

$$\text{Energy content per tonne} = \frac{9.3\,\text{GJ}}{3.6\,\frac{\text{GJ}}{\text{MWh}}} = 2.58\,\frac{\text{MWh}}{\text{tonne}}$$

$$\text{Energy from wood chips} = 313.2\,\text{tonnes} \times 2.58\,\frac{\text{MWh}}{\text{tonne}} = 807.1\,\text{MWh}$$

Lilleheden: Residues to Hirtshals Fjernvarme The energy supplied from purchased wood chips to comply with the agreement is 807 MWh. The remaining energy supplied from Lilleheden's wood residues is 13,264 MWh.

$$\text{From MWh to GJ} = 13,264\,\text{MWh} \times 3.6\,\frac{\text{GJ}}{\text{MWh}} = 47,750.4\,\text{GJ}$$

Through further discussion with Lilleheden, the energy content of these wood residues was determined to be 17.5 GJ per tonne, which corresponds to about 2,729 tonnes.

$$\frac{47,750.4\,\text{GJ}}{17.5\,\frac{\text{GJ}}{\text{tonne}}} \approx 2,729\,\text{tonnes}$$

Therefore, the total wood residues generated by Lilleheden in 2024 was 3011 tonnes.

$$\text{Total wood residue generated by Lilleheden} = 282 \text{ tonnes} + 2,729 \text{ tonnes} = 3,011 \text{ tonnes}$$

Roust: Wood Residue Calculations

Roust estimated a residue ratio of 4% for raw wood and 1% for glue laminated timber. To calculate an estimated quantities of wood residues, this is compared to the purchased wood. In 2024 they purchased 6,500 m^3 of raw wood and 1,200 m^3 of glue laminated timber.

Through discussions with Roust, the density was set to 430 kg/m^3, this corresponds to 112 tonnes of raw wood, and 5 tonnes of glue laminated timber.

$$\text{Mass of raw wood} = 6,500\,\text{m}^3 \times 430\,\frac{\text{kg}}{\text{m}^3} = 2,795,000\,\text{kg} = 2,795\,\text{tonnes}$$

$$\text{Residue from raw wood} = 2,795\,\text{tonnes} \times 0.04 = 111.8\,\text{tonnes}$$

$$\text{Mass of glue laminated timber} = 1,200\,\text{m}^3 \times 430\,\frac{\text{kg}}{\text{m}^3} = 516,000\,\text{kg} = 516\,\text{tonnes}$$

$$\text{Residue from glue laminated timber} = 516\,\text{tonnes} \times 0.01 = 5.16\,\text{tonnes}$$

Consequently, the total wood residues generated in Roust in 2024 was 117 tonnes.

$$\text{Total wood residues generated by Roust} = 111.8 + 5.16 = 116.96 \approx 117\,\text{tonnes}$$