World Conference on
Timber Engineering
Oslo 2023

REUSE OF WOOD – LEARNING ABOUT THE BENEFITS AND CHALLENGES OF HIGH- AND LOW-TECH DIAGNOSTIC METHODS THROUGH ACTION RESEARCH IN NORWAY

Wendy Wuyts[1], Artur Tomczak[2], Kristine Nore[3], Lizhen Huang[4], Thomas Haavi[5]

ABSTRACT: Digital technologies for the diagnosis of underused timber construction and the reclamation and reuse of wood in timber construction have not been widely deployed. One of the reasons is the need for diagnosis processes with large amounts of data. This paper is a product of the learning process in the Norwegian project SirkTRE, and specifically, the sub-project SirkLåve (Circular Barns), which aims to address the problem of underused and vacant barns and other agricultural buildings in Norway. Moreover, this multiple-case project aims at understanding the feasibility, costs, and benefits of circularity strategies, such as deconstruction and reuse of wood in new projects or renovations. The learning processes draw upon explorative desktop-based research, interviews with key informants, and our own experiments and experiences with various cases of barns. The scope of this paper is the reuse of wood from barns that is deemed ineligible for renovation. This paper describes low- and high-tech methods for surveying redundant buildings to applying extracted components in new designs. This multiple-case study reflects on the preconditions of the context in which these best practices may succeed, as well as on the benefits and the challenges.

KEYWORDS: Digital technologies, Empty barns, Engineering for the circular built environment; Innovation and learning processes; Rural circularity practice

1 INTRODUCTION

Globally, millions of tonnes of wood waste is generated in different phases of the value chain and incinerated after being applied only in one building. The EU-27 produced 60 million tons of wood waste in 2014 (1). There are several categories of wood waste treatment across countries, the most common being energy recovery (incineration) and recycling (panel board industry) (1). European policymakers are adopting circular economy policies and digitalisation strategies that are changing the way we produce and consume timber as well as handle wood waste. The European forests are under stress, and circularity and the cascading use of wood will significantly contribute to reducing the pressure on forests. The cascading use of wood refers to reuse over multiple use cycles, that is, using wood materials more than once, first for the originally intended purpose and then reusing for other purposes, finally recycling it into other wood products before its energy is recovered. Wood cascading delays emitting carbon into the atmosphere by several decades and allows natural resources to be used for a long time in different products instead of mining virgin forests. In countries like Norway, Switzerland, and Belgium, constellations of different actors (e.g. architects, deconstruction companies, local governments, and building owners) are investigating and implementing the reuse of timber in new constructions and renovations. A trend that can foster circularity transitions is digital technologies, such as laser scanning, blockchain, material passports, and artificial intelligence (2,3).

However, digital technologies have not been widely deployed for sustainability goals due to legislative and economic reasons, and investment lock-ins (3, 4). The renewal of new European and national laws and digital transformation strategies are opening new opportunities for circularity (5).

This paper is a product of the learning process in the Norwegian project SirkTRE (6), and specifically, the sub-project SirkLåve (Circular Barns), and aims to address the problem of underused and vacant barns and other agricultural buildings in Norway. This multiple-case project aims at understanding the feasibility, costs and benefits of circularity strategies such as deconstruction and reuse of wood in new projects or renovations. In 2022,

[1] Wendy Wuyts, Omtre AS, Norway, wendy@omtre.no
[2] Artur Tomczak, NTNU Norwegian University of Science and Technology, Norway, artur.b.tomczak@ntnu.no
[3] Kristine Nore, Omtre AS, Norway; kristine.nore@omtre.no
[4] Lizhen Huang, NTNU Norwegian University of Science and Technology, Norway; lizhen.huang@ntnu.no
[5] Thomas Haavi, NTNU Norwegian University of Science and Technology, Norway, thomas.haavi@ntnu.no

https://doi.org/10.52202/069179-0539

around 10 barns were selected within the SirkTRE project. The scope of this manuscript is the reuse of wood from barns deemed ineligible for renovation. Reuse of elements and components is one of the circularity strategies in the built environment, which can create value in different ways: "1) coherent financial structure and viability of the case company, 2) employment and value creation for partners in the value chain network, 3) customer value, 4) environmental impact reductions" (7). However, the reuse of timber is not widely deployed. One reason is that the environmental benefits of reusing timber are not adequately measured under the current carbon metrics (8). Notwithstanding, a low deployment of reuse has not always been the case in the Norwegian AEC sector. Before the Second World War, Norwegian society used to reuse building elements, but after the introduction of new materials and widespread education, accompanied by a new consumption culture, it adopted a linear and throw-away model (9), hence, missing opportunities in creating environmental, financial and social value.

One of the principles behind the SirkTre consortium is supporting the Norwegian industry to become a pioneer in wood reuse while leveraging new digital technologies not available in pre-war times. Back in 2021, the first questions we asked were *what are the best practices of reusing wood,* and *what are the lessons that pilot projects and the growing ecosystems of actors in European countries can provide us* for the Norwegian wood industry to leapfrog to a pioneering position in timber engineering for the circular built environment.

Different scholars investigated the barriers (10, 11, 35), as well as the factors that could enable the reuse of building components (12). Lack of data, as well as the fragmented coordination and exchange of information between key actors in an urban or regional ecosystem or a seamless data pipeline management, where circular systemic solutions could operate, is often pinpointed as one of the big obstacles in digital transformations for circularity (e.g. 14, 15, 16). Digital technologies can help address this perceived barrier of information asymmetry (16). Nordby (9) investigated the barriers and opportunities for reuse in Norway, pointing out technical and organisational, legal restrictions, and information needs. Nordby advocates for an information system that allows the transfer of the right information and data to the right stakeholders at the right moment (9). In literature and practice, there is evidence of an emergence in research, development, and implementation of digital technologies, and in particular information and communication technologies (ICT) enabling circular economy in the architecture, engineering, construction, and demolition sector (17,18). Bellini and Bang (18) did interviews in Norway on data management and also highlighted the lack of data availability and interoperability, lack of competencies, and unwillingness to share data as barriers.

Another concern that we encountered in the first phases of SirkLåve is the lack of a (perceived) fair distribution of costs, benefits, and risks in all the organisations involved in the phase of deconstruction, logistics, relocating, and environmental and economic valuation and reselling. One of the distributional aspects is related to data sharing and trust. Research on the success of Industrial symbiosis projects in the United Kingdom, (19) demonstrated that "the economic benefits should fulfil the desired economic expectation of any actor, and a fair benefit-sharing mechanism is essential to motivate the collaborative behaviours". Different stakeholders can benefit from these inventories, but this requires information facilitation and stakeholder collaboration. There are different stakeholders (users and suppliers of materials and information) who have their different information, personal, collaboration needs and requirements, but also *want* distributional justice and a *perceived* fair distribution of risks, costs and added value/benefits. Hence, we followed the process from the stage of reuse surveys to the actual reuse and map out which actors were involved and why.

2 ACTION RESEARCH

This multiple-case study is action research in engineering and management in the construction sector, addressing practical problems, and creating and extending existing theoretical frameworks (13). This paper should be regarded as an intermediate report of a still ongoing action research within SirkTRE tackling practical problems related to information requirements for reclamation and reuse of wood elements in construction.

2.1 Authors' roles and perspectives

SirkLåve is an applied research project in which learning and innovation are iterative processes. We wish to understand the challenges, costs, and benefits of new digital technologies with the objective of increasing the wider uptake of reclaimed wood. The authors involved in circWOOD and SirkTRE projects (6) had roles ranging from project managers or work package leaders to researchers and solution designers. We had access to internal documents and participated in meetings to discuss, for example, data collection. In 2022, the first author assumed the role of critical researcher, and in early 2023, joined the start-up leading this sub-project in SirkTRE. Thus, this manuscript reflects and describes the learning processes and decisions from a practitioners' perspective. The remainder of this paper includes reflections about mistakes and failures that hindered the authors in calculating the precise impacts at each stage in the life cycle of the different wood elements, as even failures and mistakes can provide valuable insights for the future phases of SirkTRE and SirkLåve, planned for 2023-2024). Consequently, the *learning by doing* was an organic but messy process, which constitutes the foreground in our discussion.

2.2 Desktop-based research and consulting key informants

The first phase involved desktop-based research during 2022. We sought insights on wood reuse workflows and their dataflows on Google Scholar and Scopus. We reached out to our European networks of circular economy and construction to learn about processes in different life cycle phases and digital solutions which (can) support these practices. We held conversations with key informants and attended international networking events on digital technologies for the built environment and wood reuse. We had talks with key informants and partners in the SirkTRE consortium and read their reports and blogs. We drew from previous research and reflected on circularity in the (timber) construction sector in Norway, Japan, and Belgium. In this sense, we did not do a systematic but rather a critical literature review, relying on academic and industrial circles (20). The risk of this approach is cherry picking potentially missing relevant solutions. On the other hand, as we consider this as an interactive learning process in which we keep our options open, we acknowledge the risk of this approach. The exploratory desktop-based research led to the adoption of an existing framework which helped us to frame and structure the different solutions and information needs we encountered in reclaiming wood from barns to integrate them in new applications.

Fig. 1. Reference building, a traditional Norwegian barn, dismantled in spring 2021. Source: Omtre AS.

2.3 'Follow the Thing'

For transparency, we were not present in every stage in every barn case in SirkLåve. The first author was not often on-site and embraced the role of critical investigator in this case study. On the other hand, as we were also interested in tracing and tracking wood elements, the first author applied the 'Follow the Thing' approach to comprehend the relations between the wood elements and the stakeholders and how digital solutions did or did not help. The 'Follow the Thing' approach is inspired by the work of Appudarai, and developed by Cooke and his colleagues as some sort of 'geographical detective work' (21). In this approach, you start with a product and investigate which people were involved in the creation of this product. Thus, we followed both the material and the data. In some cases, we started with the wood elements in a storage place and asked where it came from and where it might end up. In other barn cases, we started with the barn itself and traced what happened afterwards with the wood elements, which data was created and collected, and used afterwards. This detective-style process became our *modus operandi*.

3 THE FIVE "D"s FRAMEWORK

This conference paper focuses on digital technologies that can assist in the identification of material stock hibernating in vacant constructions that will not serve society anymore (otherwise, it would be more circular to sustain the structure and repurpose them, see (22)) to the relocation of these materials for a new purpose. The structure of this paper follows the 5"D"s-framework by Catherine De Wolf: Data, Detection, Disassembly, Distribution, and Design (23).

3.1 Data (for sourcing)

Data stands for the collection of macro-level data to track which material stocks are or will be available soon which helps planners to prioritise which stocks to reclaim (24). Stock tracking can be done with geographical information systems (GIS) and estimation models of vacancy (see e.g. 25, 26). However, this macro-level data -or estimations- is often not detailed enough for reclaimed wood scouting professionals. Other data that should be collected is which organisations own how much wood waste and in which fractions they are sorted and stacked, for example.

3.2 Detection

Detection refers to the collection of micro-level data and the creation of material, building passports, or building information models. Scholars have investigated designs of digital tools or proposed design criteria for tools to enable reuse of building materials and components. For instance, Durmisevic et al. (48) designed reversible Building Information Model (BIM) to estimate reuse potential, however not with enough data on which function these building components could be reused. Other scholars investigated digital technologies surrounding material banks and platforms where materials get stored and exchanged for value, foregrounding BIM objects as a key intermediary product (27-29). All these technologies need data inputs, and therefore wood reuse surveys or diagnostic tools are required. Starting from available material stocks which can be reclaimed, we can distinguish between different material sources for reuse, which implies several stakeholders. The first group of key actors are the owners of the materials that can sell or donate their timber. In the case of timber in buildings, urban miners, specialised demolition companies, or deconstruction companies, can harvest the materials, often after a reuse survey. In the current state-of-art, these reuse surveys are often done by visual inspection, but sometimes digital scans are also used as a basis for BIM models. Some researchers suggest transcribing such information into Material Passports, which is a tool for value tracking (3).

3.3 Disassembly

Disassembly is a type of non-destructive deconstruction where the objective is to harvest components or materials which are needed for later design. Unlike demolition, where the final product is pure waste, disassembly aims at

https://doi.org/10.52202/069179-0539

waste reduction and mining as many useful elements as possible. In addition, other information that is needed concerns how to disassemble and evaluate safety and feasibility. These reuse surveys can reduce health and safety risk for the deconstruction staff in later phases. OPALIS (30) calls to consider the health and safety risks to be included in the reuse surveys, such as the presence of hazardous substances or if dismantling and subsequent operations would present a safety risk.

3.4 Distribution

Distribution encompasses the logistics: transport and storage. As materials are often not reused directly after mining, the workflow requires a physical circular hub, material banks, and other spaces where the material is collected and pre-treated. They are often at the periphery of cities unless the public authorities provide a space (e.g. Material bank in Trondheim, Norway, RotorDc in Brussels). There, the reclaimed material is often separated according to quality, and which functions they can serve as well as pre-treated. The pre-treatment is a time-intense process, because each reclaimed material is different. For example, in reclaimed wood, nails and hazards have to be removed, while metals (e.g. steel) could be melted. Some of these materials must be treated locally. For example, concrete that has to be recycled locally, not only for environmental reasons, but technical feasibility too (31), while reclaimed wood can be sold to manufacturing companies who integrate them into building components (32).

3.5 Design

Following the above, these building components can return to the supply chain and be sold to those who build new or renovate existing buildings. However, consecutive design requires knowledge, processes, and competencies that are scarce in the current market. Standardisation can help reduce the need for all these "knowledge search costs". A potential enabler is the parametric design approach, where multiple alternatives can be compared in a short time, but it requires proper preparation of the input information, both geometrical and alphanumeric, as well as computational engineering competencies.

4 DIGITAL SOLUTIONS USE CASES

We read the SirkLåve experiments through distributional justice goggles. It is pivotal to ask who benefits, who pays, and who will be accounted for the risk. Some benefits can be perceived as valuable for society, but not for certain stakeholders. For example, interviews on platforms for industrial symbiosis in Norway indicated that managers see sustainability often as a profit-losing business, with benefits for society, but not for the company itself (15). Implicitly, each task requires *specialised* labour with the associated costs for the business itself. In the next section, we focus on costs, benefits, and risks for the *specialised* labour force, using the chosen method, and drawing from live experiences and participatory and marginal observations in SirkLåve.

By winter 2022, we traced wood elements from 6 barns. Table 1 provides an overview of the barns and who got involved in which phases.

Table 1: Experiments and learning experiences on 1. data stage, 2. detection, 3. disassembly, 4. distribution, 5. design, with experimentations done by ◆: NTNU students; ▲: NTNU staff; ●: Omtre AS, ⬢ other SirkTRE demolition and reuse survey organisations, ★: architects and structural engineers, ֍: destructive testing facilities

Barn cases	1	2	3	4	5
C1. Kviteseid, Telemark (Fig. 2)	●	▲◆֍	⬢		
C2. Nes 1, Ådal	●	▲◆֍	⬢		
C3. Nes 2, Ådal	●	▲◆֍	⬢		
C4. Brøttum barn (Fig. 1), with part reused in Slettelokka	●	●	●	●	★◆
C5. Nedre Sem barn, Asker	●⬢	●⬢	⬢	⬢	★⬢
C6. Hønefoss	●	●			

4.1 Data

This stage of collecting data on where and how much reclaimable wood was available, was skipped in the first phase of SirkLåve. Firstly, because the problem of obsolete barns is known, and secondly because the empty barns offered free by their owners were located far, implying a high demolition and waste management costs making it necessary to look into alternatives. The only information that was required for deciding to take this project was the distance costs between the location of the barn and the involved actors of the next D-stages. Noteworthy, barns are widely spread over the countryside which implies longer travel time and transport costs for labour, equipment, and tools; hence, reclaiming the wood might not be economically viable.

4.2 Detection

Different reuse survey methods or diagnostic tools were explored in the Sirklåve project in 2022. Table 2 lists the diagnostic tools and the data analysed by the different stakeholders. In case (6), we observed an expert (with material and building knowledge and surveyance experience), who judged by visual inspection and verified with a crowbar that there was not enough suitable wood for reuse, although no laser scanning was performed. The C6 project ended there; it got demolished in the traditional way. In cooperation with students, partners who are certified to grade materials did destructive testing on elements of cases C2-3. The timber elements were graded as C30 and above (47).

In cases C1-3, a LEICA scanner was used for on-site diagnosis. The scanning took a full day. The 2 students involved in transferring the scans to BIM-objects needed 2-3 weeks, partly because they struggled with material identification and the lack of data of the interior (Fig 2). Please refer to (33) for the technical details. The process was slow, implying high specialised labour costs (i.e. BIM). This issue with scanners has been reported in previous research (4).

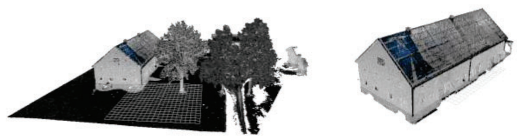


Fig. 2. Before and after processing the scan by the two NTNU students. Source (33).

In all these six cases, different basic tools and methods were used to make a data inventory. The reclaimers took mostly photographs and short notes, and made lists of photographs, inserted in templates or cost-benefit reports and invoices. In research projects, the focus is mostly on high-technologies, like scan-to-BIM, and often coupled with automation detection or artificial intelligence (i.e. deep learning methods), which requires large training datasets. We tried different methods, including the use of LEICA scanners, but there was no data availability downstream in the value chain.

Table 2: Overview of diagnostic methods

Data collection method	Technology	Data stored	Barn cases
Destructive quality test	Press test	Reports	C2-3
Non-destructive	X-ray	Compressed images	None.
Scan (of barn onsite)	Laser scanning	Point cloud , processed into BIM object	C1-3
Scan of elements (in sorting centre)	Photogram metry	Mesh, texture	C4
Modelling / estimating	GIS	Graph data, tabular data	None
Visiting the site and measuring with analogue tools	based on hindsight experiences	Photographs (JPEG, PNG); Excel	All
Archive work		PDFs, plans, etc.	C1-C3

4.3 Disassembly

The footprint of one barn (C4; Fig. 1) was ca. 600 m2 and 12–15 m height. There were 158 timber framing elements that ended up in the material bank of Omtre AS, where they were measured and assessed. Then, 66 were selected and further integrated in the new construction, substituting 144 elements from the design of Slettelokka project in Oslo (34). This was made possible by cutting out some elements and assigning them to multiple locations in the model. An important step was labelling (i.e. tagging, adding unique identifiers) for later tracking and tracing wood elements. In most cases, the tagging was performed in the storage places. Numbers, added manually, corresponded with the excel lists that include the inventory, and data about dimensions of these wood elements, next to the descriptions of the faults, such as potholes and carvings. This included those elements that we know are of lower quality (8%) (visual test). Different people measured in two different days (one day in August, and a second day in November 2022) 158 elements with a total volume of 18,4 cubic metres (8,2 cubic metres and 10,2 cubic metres in November). We took photographs of all the elements, including special features, like pockets and carvings. Some scans were captured with a handheld scanner and the Leica scanner, but the process was slow and inefficient.

4.4 Distribution

The distribution and relocation of the wood emits CO2, depending on the means of transport, which is again dependent on the existing logistic infrastructures and systems. There are questions on how much CO2 would be emitted in the deconstruction, manufacture, and transport, especially from the wood products used in the new construction. Most barns are in the periphery of cities like Oslo and Trondheim where they will be integrated, and long travel distances are unavoidable. We needed to critically examine if the CO2 that is avoided and/or captured compensates enough the CO2 emitted in the process.

In case of barn 1, we estimated that the travel distance of one wood element from source (empty barn) to the new construction was 270 km. This is still low compared with the travel distances that virgin wood often travels in the global timber markets. However, we are not certain, as we did not have advanced tags with geolocation data.

Barn C5 was an ideal project from an economic and environmental cost-benefit perspective; the barn and the new project both were and will be located in the same municipality, reducing transport costs in a significant way. Barn C6 was close to the storage space. However, the quality of the reclaimable wood was not deemed as high value.

Additionally, the materials are stored somewhere and for a period. Storage space and time have a cost, which was covered by the SirkTRE project's funding. In the case of these barns, it took at least a year before some building elements were reintegrated. More research is needed on governance and business models to reduce the cost of the storage requirements enabling reuse.

4.5 Design

A fraction of the reclaimed wood from C4 would be integrated in the Sletteloka construction project in Oslo in spring 2023 (34). The designers will use the spreadsheet

https://doi.org/10.52202/069179-0539

list, made after Disassembly and the few images to select the elements for the integration in the Slettelokka design. This led to reflections if scan-to-BIM are needed, and if useful information for design can be used in a more controlled environment, with fast scanners that can label, process, and separate wood elements.

5 DISCUSSION

5.1 Information requirements

In all the D-stages, there are different data requirements, for the different possible users of this information (see e.g. 35). These follow the information requirements in any construction project (see 36); however, there are some new roles and stages that need an expansion in these lists. Sustainability consultants and researchers need data inventories that help them calculate environmental life cycle costs in their Life Cycle Assessment (LCA), and specialised demolition companies need lists with geographic coordinates to harvest reusable components before demolition, etc. We observed indeed the need and emergence of new actors with their own information requirements, as echoed in Table 2. The actors involved in collecting the data and making decisions in the experimentation stages, were the urban miners and specialised demolition companies (●; ⬢) , environmental impact researchers and consultants for the economic and environmental validation (◆; ▲), and designers (★). They have their own information requirements and this D-framework helps mapping the information flows and requirements, which in turn helps collecting data on environmental and economic risks and benefits and assess if this circular economy practice is really sustainable. Figure 3 outlines the workflow for 2022.

Noteworthy, the data collection for diagnosis and data flows are partly subsidised by education institutes (employing students) and research and innovation funds. Not many high-tech digital solutions were used, and this was a (specialised) labour-intensive action research project. On the other hand, this organic and messy learning process and experimentation has led to insights about requirements and specifications for digital solutions (e.g. scanner specifications), which will inform the purchase of equipment in the next phase of SirkTRE. One of the specifications is a result of learning about unintended negative impacts. While learning about all these different tools, we became aware of the growing evidence on the environmental costs of data spaces, programming languages, data formats and their consumption of resources (e.g. 37 about the energy consumption of more than 20 software programming languages).

5.2 Limit in tracking and tracing the wood elements in the case study

We applied the ‘Follow-the-Thing’ approach to investigate who used which digital solutions during all these phases. However, we did not apply advanced tags to enable tracking and tracing of different wood elements reclaimed from all these six barns, which presented a severe limitation for understanding and collecting data about environmental and economic impacts. Additionally, it was a challenge for the first author to have an overview of the different material and data flows for the different barns: identifying who did what, what did not happen, and the logics behind the different decisions in the material and data flows. In the next phase of SirkTRE, we will investigate different tagging tools to improve traceability and tracking, from QR-codes, bar codes to even wood print solutions (i.e. the constellations of knots can serve as unique identifiers). This would also include deeper studies on data formats, interoperability protocols, and data pipeline management. Currently, our reflections on what happened in 2022 are informing the design of a more standardised workflow for the barns-to-construction projects to be implemented in the following years.

5.3 Tensions with social impact

Barns are part of the cultural heritage of rural landscapes in Norway. There is an observation in the literature (e.g. 38) that cultural heritage and rural circularity practices such as renovation and reuse are interlinked. However, there might also be tensions. In SirkLåve, the barns were offered by the barn owners until now. As long as empty constructions are offered, the circular business model should work, while reducing costs. In Japan, the problem of empty houses is in some cases transformed in opportunities for new purposes creating positive social impacts (39). However, there can also be negative impacts. Altering the rural landscapes in this way might create tensions with sustainability goals of heritage and identity (40). Besides the legal owners, there are neighbours who are culturally the inheritors of these rural landscapes, where barns are considered as inherent landscape scenery, and might feel distressed by changes in the landscape and features that make them feel at home (41). In some places, the constructions will be restored to preserve the identity, but mostly deconstruction, or worse demolition, takes place. By deconstructing the barn, there is the risk that we erode the Norwegian rural identity of that landscape. On the other hand, in interviews with urban miners active in rural southern Norway, we heard about the supporting communication and branding practice for preserving the story of the reclaimed materials. Thus, they can sell the materials if it comes from a building with a historical value. The idea is to collect these stories in the Detection stage (or relabel these steps as part of the Documentation stage). This would contribute to tracing the source of these materials too. However, it was out of the scope to document complaints of neighbours and look into renovation and rural revitalisation strategies. This is one of the potential social value creations—or destructions which can occur in a project such as SirkLåve. Social value creation (or destruction) through circular economy is still under-researched (42).

5.4 Reflecting on the Ds-framework and diverse value creation

The Ds-framework helped us to structure fragmented actions and knowledge creation in different life cycle phases but is focused on data collection and processing for the technical aspects surrounding reuse, namely enabling logistics, design and calculations.

The Detection stage can encompass different diagnoses or detections. One important stage, especially for a material such as wood, is the quality testing and grading. Destructive testing was done by certified stakeholders for elements of barns C2-3. The elements were graded as C30 or above (see 48). However, not all elements can be destructively tested, if we want to reuse them. Then there is also the critique on the current 'virgin wood' grading system. Thus. there is a new standard being developed for reclaimed material. That standardisation work is part of SirkTre consortium (in another work package). The current grading system does hinder a wider uptake because of the uncertainty about ownership of the risks that cannot be covered by the current grading system. The legal research on accountability is outside the scope of this paper, but we mention the legal research to stress out that there is a need for a D-stage of (legal) documentation.

Documentation is the negotiation process where risks are documented through experts or digital technologies. One of the reasons behind documentation and data storage is risk reduction for stakeholders in the construction projects itself, especially in the case of larger projects using reclaimed matters in structures and load-bearing functions. Documentation should include data and information (which implies qualitative data) about social and other values for the different stakeholders, including neighbours and even full landscapes.

Dissemination is the ongoing process that attracts the required suppliers, users of information, and materials. This includes materials for public authorities that want to monitor circularity and the diverse value creations but also materials for training. Universities and other educational institutions are essential for training and educating the required workforce, as well as for monitoring the life cycle costs and advising other key actors about the potential for value creation of the various circularity strategies such as reuse.

5.5 Preconditions for scalability

Early 2023, the reclaiming of wood from abandoned barns is still a small-scale endeavour within the SirkTRE project. One reason is that barns are small-scale sources of materials and require time and effort. Another bottlenecks is the diagnostic tool in reuse surveys. Both high- and low-tech reuse survey methods are time consuming, not only for collecting but also the processing of the complex data (4). Additionally, high-tech methods require large investment and operation costs because of equipment like laser scanning (4). On the other hand, this is a rapidly changing market and we have become more knowledgeable about new diagnostic tools (e.g. 43) which addresses these problems. However, we have noted two concerns.

First, those reuse methods are often tested and applied in high-density areas like cities, while barns are located in remote settings, deep in land and far away from cost effective infrastructure such as river and maritime ways. Therefore, space matters. In the past 1-2 years of the SirkTre experimentations, we have applied a critical lens to the contexts or territories in which these pilot cases and constellations emerge, as different studies already demonstrated how spatial aspects are important for sustainability transitions (44), including for circularity (39). We have to note that actors behind these innovations are situated in economic regions in the periphery with high to moderate levels of cooperation and innovation (e.g. Gjøvik, Asker), but also in less cooperative and innovative regions (e.g. Hønefoss) (45). A more territorial approach on the economic geography of innovations can bring better insights on where urban mining businesses, using diagnostic methods, can thrive.

Second, in other projects in Belgian, Swiss, and Dutch constellations, such as the BAMB project (3), the reuse survey included visits to the building to make a diagnosis of how many and which elements can be reclaimed. This would include tagging and giving all reclaimable elements an unique identifier on-site. However, the tagging of every wood element is only possible after deconstruction. In our experiments, the tagging (and start of tracing) happened in the first temporary storage space, which is often a more controlled and more comfortable environment than a 'chaotic' deconstruction site. In the Nordic timber construction sector, off-site prefab manufacturing is encouraged, and off-site diagnosing, integrated in other off-site processes such as sorting, might be safer and more efficient than on-site diagnosis.

5.6. The risk of linearity at industrial scale

One of the remaining important questions in the iterative learning process is how to scale up to an industrial scale. This activity at industrial scale should compete with the forestry sector and linear waste management practices in a country like Norway. Early 2023, we evaluated the fractions of barns as a possible input for an industrial processing plant. However, the fractions arrive in small volumes, are heterogeneous and not secure, while industrial processing prefers the opposite. This can lead to the risk that reclaimed wood from barns might not be selected for a reuse economy at the industrial scale in the next phase of the consortium. The reuse economy, like the recycling economy, can fall into the profit-oriented logic trap of capitalism. There is considerable critical literature on reuse centres, e.g. in the clothing sector, highlighting how such centres do not address the roots of high consumption, and might even lead to more guilt-free consumption and waste creation of often low-quality items (e.g. 46). Ironically, while the barns in five of these six cases contain enough amounts of high-quality wood, our observations and reflections suggest that the barns might not be considered in a portfolio of industrialised processes. Even more ironically, if this decision of

 https://doi.org/10.52202/069179-0539

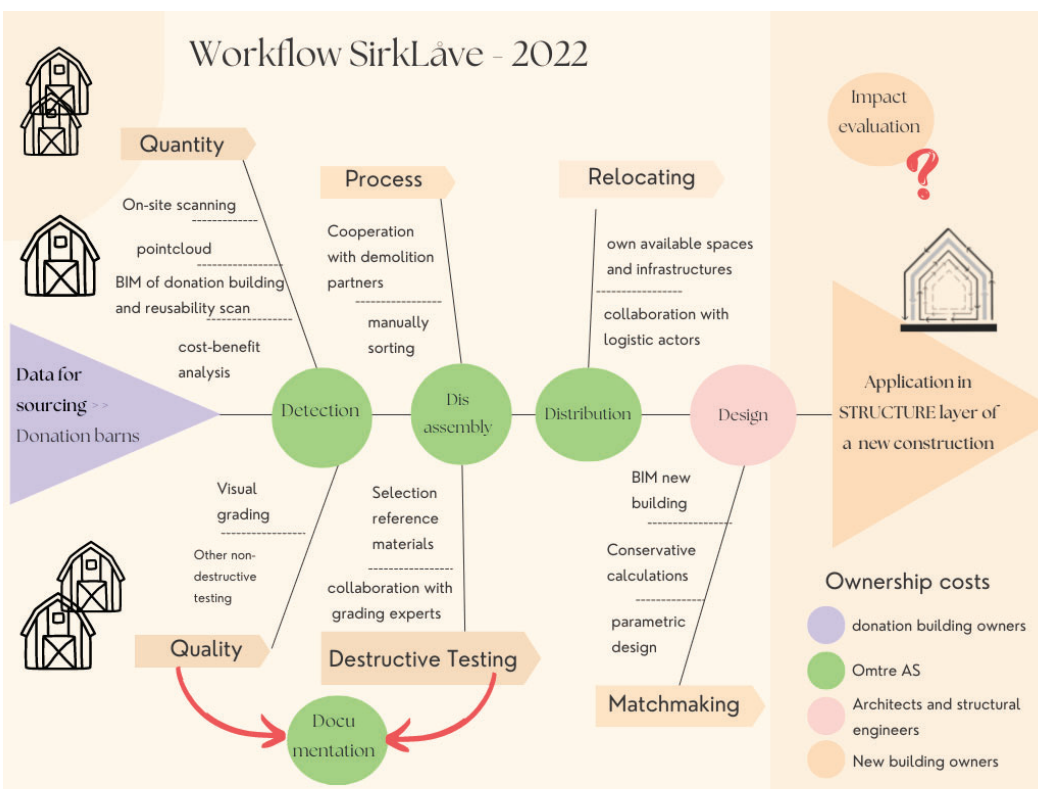
exclusion would happen, this would render the need for high-cost digital solutions obsolete, instead allowing human creativity and cooperative work, or pushing more circular activities such as repurposing the building and extending the service and lifetime of this construction, or even better, addressing the reasons why such buildings become obsolete in the first place.

6 CONCLUSION

In early 2023, the SirkTRE consortium is still in the first stage of the process of innovation, learning, and unlearning about what circularity means for the wood and timber construction sector, citizens, and public authorities. A fair distribution of costs, benefits, and risks is important, but as long the costs are higher than that in these other industries, and the benefits and other diverse value creations by such activities (e.g. safety, environmental health/toxicity, community cohesion, climate change mitigation and adaptation) do not get monetised or rewarded and valued by policy makers and other decision makers, the problems that circular economy intends to solve will only increase.

Different stakeholders require different data and information, which leads to additional costs. However, in a project like SirkLåve, these data flows are partly subsidised by education institutes (by employing students) and research and innovation funds. Not much high-tech was used, like fast wood scanners, and this was a (specialised) labour intensive action research project. Our final observation is that this model is not competitive on its own. These insights can help formulating the research design for future studies diving into where to draw the line between the cost of collecting and storing the data and information and the benefits of the actors, for different regulatory and economic scenarios. This can be part of a larger systems engineering framework, where this can be integrated in especial technical (e.g. requirement analysis) and agreement processes (e.g. which stakeholder takes responsibility and accountability for which risk and cost). Although the technology readiness level for the proposed methods is high, the market readiness and integration level of these circular systemic solutions in the timber Architecture, engineering, construction and demolition sector is low. Future research should focus more on the actual costs and the identification of sustainable business models and project governance for the required data and information management enabling reuse of materials in new constructions, as well as evaluating the phases in which data is collected and processed and where (e.g. onsite versus offsite) and when to integrate which digital solution.

Fig. 3. Workflow SirkLåve 2022



ACKNOWLEDGEMENTS

This conference paper is funded by the projects SirkTRE (project nr 328731) and circWOOD (project nr 328698), funded by the Norwegian Research Council. Secondly, we want to thank the other Omtre AS employees, other SirkTRE partners and NTNU students who contributed in the SirkLåve sub-project.

REFERENCES

[1] Bioreg 2015. 'Absorbing the Potential of Wood Waste in EU Regions and Industrial Bio-based Ecosystems — BioReg' Accessed at https://www.bioreg.eu/assets/delivrables/BIOREG%20D1.1%20EU%20Wood%20Waste%20Statistics%20Report.pdf

[2] Çetin, Sultan, Catherine De Wolf, and Nancy Bocken. 2021. "Circular Digital Built Environment: An Emerging Framework." *Sustainability: Science Practice and Policy* 13 (11): 6348.

[3] Luscuere, 2016, Materials Passports: Optimising value recovery from materials, Waste and Resource Management Volume 170 Issue WR1

[4] Uotila, U., Saari, A., & Junnonen, J. M. (2021). Investigating the barriers to laser scanning implementation in building refurbishment. Journal of Information Technology in Construction, 26, 249–262. https://doi.org/10.36680/j.itcon.2021.014

[5] Staab, P., Pietrón, D. and Hofmann, F., 2022. Sustainable Digital Market Design: A Data-Based Approach to the Circular Economy.

[6] SIRKTRE. 2022. SirkTRE website. Last accessed 31 January 2023. Home | SirkTre

[7] Nußholz, J.L., Rasmussen, F.N., Whalen, K. and Plepys, A., 2020. Material reuse in buildings: Implications of a circular business model for sustainable value creation. Journal of Cleaner Production, 245, p.118546.

[8] Parigi, D., Kanafani, K. and Rasmussen, F.N., 2022. Why current carbon metrics for buildings fail to show the benefits of timber reuse. In Structures and Architecture A Viable Urban Perspective? (pp. 559-566). CRC Press.

[9] Nordby, Anne Sigrid. 2009. "Salvageability of Building Materials: Reasons, Criteria and Consequences Regarding Architectural Design That Facilitate Reuse and Recycling." Norges teknisk-naturvitenskapelige universitet, Fakultet for arkitektur og billedkunst, Institutt for byggekunst, historie og teknologi. https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/231092.

[10] Rakhshan, K., Morel, J.C., Alaka, H. and Charef, R., 2020. Components reuse in the building sector–A systematic review. *Waste Management & Research*, *38*(4), pp.347-370.

[11] Charef, R., Morel, J.C. and Rakhshan, K., 2021. Barriers to implementing the circular economy in the construction industry: A critical review. *Sustainability*, *13*(23), p.12989.

[12] Charef, R. and Lu, W., 2021. Factor dynamics to facilitate circular economy adoption in construction. *Journal of cleaner production*, *319*, p.128639.

[13] Salman Azhar; Irtishad Ahmad; and Maung K. Sein, 2009, Action Research as a Proactive Research Method for Construction Engineering and Management, Journal of Construction Engineering and Management
Vol. 136, Issue 1 (January 2010)

[14] Çetin, S., Gruis, V., Rukanova, B., Tan, Y.H. and De Wolf, C., 2022. A Conceptual Framework for a Digital Circular Built Environment: The Data Pipeline, Passport Generator and Passport Pool. In *2nd International Conference on Circular Systems for the Built Environment, ICSBE 2 (Hybrid/Online): Advanced Technological and Social solutions for Transitions* (pp. 97-106). Technische Universiteit Eindhoven.

[15] Krom, P., Piscicelli, L. and Frenken, K., 2022. Digital Platforms for Industrial Symbiosis. *Journal of Innovation Economics & Management*, pp.I124-XXVI.

[16] Knoth, K., Fufa, S.M. and Seilskjær, E., 2022. Barriers, success factors, and perspectives for the reuse of construction products in Norway. *Journal of Cleaner Production*, *337*, p.130494.

[17] Yu, Y., Yazan, D.M., Bhochhibhoya, S. and Volker, L., 2021. Towards Circular Economy through Industrial Symbiosis in the Dutch construction industry: A case of recycled concrete aggregates. *Journal of cleaner production*, *293*, p.126083.

[18] Bellini, A. and Bang, S., 2022, December. Barriers for data management as an enabler of circular economy: an exploratory study of the Norwegian AEC-industry. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1122, No. 1, p. 012047). IOP Publishing

[19] Mirata, M., 2004. Experiences from early stages of a national industrial symbiosis programme in the UK: determinants and coordination challenges. *Journal of Cleaner production*, *12*(8-10), pp.967-983.

[20] Snyder, H., 2019. Literature review as a research methodology: An overview and guidelines. *Journal of business research*, *104*, pp.333-339.

[21] Cook, I. and Harrison, M., 2007. Follow the Thing: "West Indian Hot Pepper Sauce". Space and Culture, 10(1), pp.40-63.

[22] Wuyts, W., Miatto, A., Sedlitzky, R. and Tanikawa, H., 2019. Extending or ending the life of residential buildings in Japan: A social circular economy approach to the problem of short-lived constructions. Journal of Cleaner Production, 231, pp.660-670.

[23] De Wolf C. 2022. Inaugural talk of assistant professorship. Ceci ce n'est pas un pipe. ETH Zurich, Switzerland. 22 March 2022.

[24] Levoso, A.S., Gasol, C.M., Martínez-Blanco, J., Durany, X.G., Lehmann, M. and Gaya, R.F., 2020. Methodological framework for the implementation of

https://doi.org/10.52202/069179-0539

circular economy in urban systems. *Journal of Cleaner Production*, *248*, p.119227.

[25] Wuyts, W., Sedlitzky, R., Morita, M. and Tanikawa, H., 2020. Understanding and managing vacant houses in support of a material stock-type society—The case of Kitakyushu, Japan. *Sustainability*, *12*(13), p.5363.

[26] Wuyts W.; Miatto A.; Khumvongsa K.; Guo J.; Aalto, P: Huang L. 2022. "How can Material Stock Studies Assist the Implementation of the Circular Economy in Cities?" Environmental Science & Technology

[27] Jayasinghe, L.B. and Waldmann, D., 2020. Development of a BIM-based web tool as a material and component bank for a sustainable construction industry. *Sustainability*, *12*(5), p.1766.

[28] Cai, G. and Waldmann, D., 2019. A material and component bank to facilitate material recycling and component reuse for a sustainable construction: Concept and preliminary study. *Clean Technologies and Environmental Policy*, *21*, pp.2015-2032.

[29] Xing, K., Kim, K.P. and Ness, D., 2020. Cloud-BIM enabled cyber-physical data and service platforms for building component reuse. *Sustainability*, *12*(24), p.10329.

[30] OPALIS 2022. FCRBE Reuse toolkit - the reclamation audit. Last accessed 02 February 2023. https://opalis.eu/sites/default/files/2022-02/FCRBE-Reclamation_Audit-v12.pdf

[31] Van den Berghe, K.B. and Verhagen, T.J., 2021. Making it concrete: Analysing the role of concrete plants' locations for circular city policy goals. *Frontiers in Built Environment*, p.136.

[32] Virtanen, M., K. Manskinen, V. Uusitalo, J. Syvänne, and K. Cura. 2019. "Regional Material Flow Tools to Promote Circular Economy." *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2019.06.326.

[33] Rekdal, J.C. and Billing, J.B.N., 2022. *Scan to BIM av eksisterende bygg* (Bachelor's thesis, NTNU).

[34] Łuczkowski, M., Tomczak, A., Izumi, B. 2023, Proposal Of Interactive Workflow For Circular Timber Structure Design (forthcoming)

[35] Tomczak et al. (2023). Challenges and experiences with the reuse of products in building design. 14th European Conference on Product & Process Modelling. At: Trondheim, Norway

[36] Tomczak, A., v Berlo, L., Krijnen, T., Borrmann, A. and Bolpagni, M., 2022, November. A review of methods to specify information requirements in digital construction projects. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1101, No. 9, p. 092024). IOP Publishing.

[37] Pereira, R., Couto, M., Ribeiro, F., Rua, R., Cunha, J., Fernandes, J.P. and Saraiva, J., 2017, October. Energy efficiency across programming languages: how do energy, time, and memory relate?. In *Proceedings of the 10th ACM SIGPLAN International Conference on Software Language Engineering* (pp. 256-267).

[38] Wuyts, W. and Majidi, A.N., 2022, December. Towards solutions and infrastructure for circular neighbourhoods in rural areas. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1122, No. 1, p. 012023). IOP Publishing.

[39] Wuyts, W. and Marjanović, M., 2022. The Development of Spatial Circularity Discourse in Japan: Ecomodernist, Territorialised, or Both? The Story of Onomichi's Wastescapes. *Circular Economy and Sustainability*, pp.1-27.

[40] Preston, S.D. and Gelman, S.A., 2020. This land is my land: Psychological ownership increases willingness to protect the natural world more than legal ownership. Journal of environmental psychology, 70, p.101443.

[41] Kaltenborn, B.P. and Bjerke, T., 2002. Associations between landscape preferences and place attachment: a study in Røros, Southern Norway. Landscape Research, 27(4), pp.381-396.

[42] Quintelier, K.J., van Bommel, K., van Erkelens, A.M. and Wempe, J., 2023. People at the heart of circularity: A mixed methods study about trade-offs, synergies, and strategies related to circular and social organizing. *Journal of Cleaner Production*, *387*, p.135780.

[43] Raghu, D., Markopoulou, A., Marengo, M., Neri, I., Chronis, A. and De Wolf, C., 2022. Enabling Component Reuse From Existing Buildings Using Machine Learning-Using Google Street View to Enhance Building Databases. In *Proceedings of the 27th International Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA 2022)* (Vol. 2, pp. 577-586). Association for Computer Aided Architectural Design Research in Asia (CAADRIA).

[44] Coenen, L., Benneworth, P. and Truffer, B., 2012. Toward a spatial perspective on sustainability transitions. *Research policy*, *41*(6), pp.968-979.

[45] Giuseppe Calignano, Trond Nilsen, Anne Jørgensen Nordli & Atle Hauge (2022): Beyond 'periphery': a detailed and nuanced taxonomy of the Norwegian regions, Geografiska Annaler: Series B, Human Geography, DOI: 10.1080/04353684.2022.2141654

[46] Berry, B., 2022. Glut: Affective Labor and the Burden of Abundance in Secondhand Economies. *Anthropology of Work Review*, *43*(1), pp.26-37.

[47] Fauske, J.K., Rokke, Å. and Sveen, T.H., 2022. *Ombruk av eldre trevirke* (Bachelor's thesis, NTNU).

[48] Durmisevic, E., Guerriero, A., Boje, C., Domange, B. and Bosch, G., 2021, October. Development of a conceptual digital deconstruction platform with integrated Reversible BIM to aid decision making and facilitate a circular economy. In *Proceedings of the the Joint Conference CIB W78-LDAC, Luxembourg* (pp. 11-15).