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HOW TIMBER BUILDINGS CAN BE DESIGNED FOR DECONSTRUCTION AND REUSE IN ACCORDANCE WITH ISO 20887

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ABSTRACT: There is a need for a shift towards circular economy in the building and construction sector. Design for deconstruction and reuse (DfDR) and design for adaptability (DfA) have been suggested as means to facilitate reuse of buildings and diminish waste and material consumption. A standard, ISO 20887:2020, has appeared to support the implementation of DfDR/A. One objective of this study is to demonstrate timber building design examples that can be considered consistent with the standard and designs that should be avoided. Another objective is to examine if there are important aspects of DfDR/A for timber buildings that are insufficiently covered by ISO 20887:2020. The broader, long-term aim of the work is to remove thresholds to DfDR/A by providing support for designers and industry in applying the standard. The principles and strategies in ISO 20887:2020 are illustrated with practical examples from case studies, organised in a searchable database.

KEYWORDS: Disassembly, adaptability, circular economy, timber building, ISO 20887

1 INTRODUCTION

1.1 BACKGROUND

Greenhouse gas emission, raw material consumption and waste production from the building sector is huge [1]. If buildings (or their parts) were reused to a higher degree, material consumption and waste production could be minimised. For timber buildings, it is currently not viable and economic to extract timber for reuse [2]. The design philosophies *design for deconstruction and reuse* (DfDR) and *design for adaptability* (DfA) have been suggested to facilitate reuse of buildings, and a standard, ISO 20887:2020 (hereafter referred to as ISO 20887), has been published to support the implementation of these philosophies [3]. As this publication is recent, using it in timber building design is not yet standard practice. Also, the standard is comprehensive and general, and it needs to be interpreted. There is a need for showing timber building solutions that are in line with the standard and solutions that should be avoided.

1.2 AIM AND OBJECTIVES

The broader aim of the study is to support circular economy by removing thresholds to DfDR/A.
The objectives are:

- To show how the principles and strategies of ISO 20887 can be interpreted and fulfilled in practical timber building design.
- To examine if there are important aspects of DfDR/A for timber buildings that are insufficiently covered by ISO 20887.

2 METHOD

2.1 GENERAL METHODOLOGY

Case studies were carried out, where timber building designs were examined with respect to DfDR/A. The resulting advantages and disadvantages were then used to illustrate the ISO 20887 design principles. The study included three steps:

1. *Data collection in case studies*. Interviews were carried out to identify what manufacturers, builders and designers consider as advantages and disadvantages to DfDR/A in the design of timber buildings [4-6]. Drawings and documents were studied. Field studies were carried out. The result is a list of advantages and disadvantages, illustrated by pictures and design drawings.
2. *Interpretation of ISO and re-evaluation.* First, the structure of the standard was analysed. Thereafter, the advantages and disadvantages identified in step 1 were re-evaluated to identify

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which principle(s) in ISO 20887 they illustrate, if any. The result is a set of documented experiences from using the standard.

3. *Establishing a database of design examples*. Design examples were organized to illustrate the ISO design principles specifically for timber buildings.

2.2 COMMENT ON CASE STUDIES AND THEIR METHOD

Six practical deconstructions and eight simulated deconstructions of timber buildings in different European countries were analysed. All case studies represent modern timber buildings with different building systems (post and beam, volumetric or planar modules and either mass timber or light timber frame). The practical deconstruction and reconstruction cases (all in Sweden) include a hall (post and beam, mass timber), an office building (volumetric, light timber), a residential building (volumetric, mass timber), two pavilions (one with planar elements, mass timber and one with post and beam structure, mass timber). Four of them are illustrated in Figure 1, the fifth is shown in Figure 2.

Figure 1: *Four of the studied practical deconstructions. Photos: Masonite Beams (above left), Olof Mundt-Petersen and Oskar Linderoth (above right), IsoTimber (below left), Folkhem (below right).*

The simulated cases all regarded industrially produced systems and residential buildings in two stories: three light timber systems, one mass timber system in planar elements and one a combined post and beam/light timber system.

As the different designs were evaluated in interviews, the identified advantages and disadvantages are somewhat subjective and do not necessarily represent a comprehensive list of strengths and weaknesses in each case study. Especially in the simulated case studies, only information that was volunteered by third parties and interpreted based on informed assumptions could be included in the analysis, without the option to verify it in full scale deconstructions or in laboratory. Nonetheless, it is expected that each case study captures the most important aspects of DfDR/A. All interviews involved knowledgeable people. On average, there were 3-4 people per case study who participated with different competences and experiences in construction and deconstruction. One of the simulated deconstructions involved a person who had disassembled and reassembled a similar building and now lives in it.

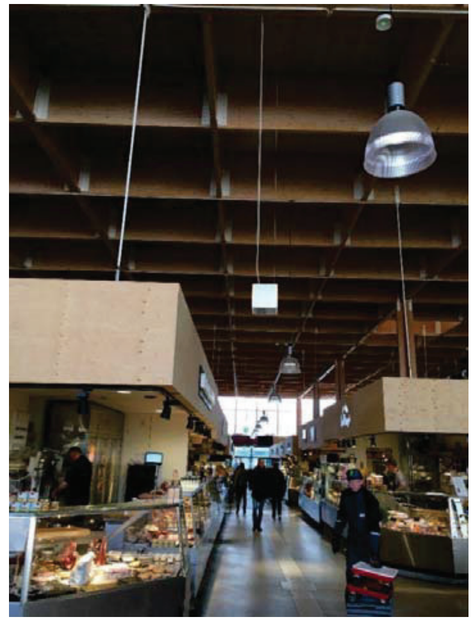

Figure 2: *A hall with post and beam structure, that first served as a temporary market hall and later became a sports hall. The photo shows the hall in its first use. Photo: Ylva Sandin*

2.1 LIMITATIONS

The study concerns *loadbearing structures* of timber buildings. The focus of the case studies was on DfDR, and although some of them gave considerations also to DfA, the gathered examples do not capture a comprehensive overview of DfA designs.

3 RESULTS AND DISCUSSION

3.1 DATA PRESENTED

In this section, one of the case studies, concerning the deconstruction and reconstruction of a hall, is first presented as an example of the case study method (section 3.2). Then, advantages and disadvantages to DfDR that were identified for that case are given (section 3.3). Thereafter, the ISO 20887 is presented, and examples are given of how data from the hall case can be re-evaluated with respect to the standard (section 3.4). It is then shown how the standard could be enhanced with a database of design examples (section 3.5). Finally, some reflections on the ISO 20887 following from the evaluation of all case studies are given (section 3.6).

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3.2 CASE STUDY EXAMPLE: TEMPORARY MARKET HALL

A temporary hall was erected at Östermalmstorg in Stockholm, Sweden, to enable the traders in the market hall “Östermalmshallen” to continue their businesses while the hall was renovated. The temporary hall was designed by Tengbom architects and was in use as market hall 2016-2020 (Figure 2). It has a post and beam structure of glulam and LVL (Laminated Veneer Lumber). The building was disassembled in spring 2021 (Figure 3) and reassembled in spring 2022 as a sports hall in Mölnlycke, Sweden (Figure 4). The entire frame was reused, as were all the façades. Much of the installations and other layers were also reused (see also [5] and [7].)

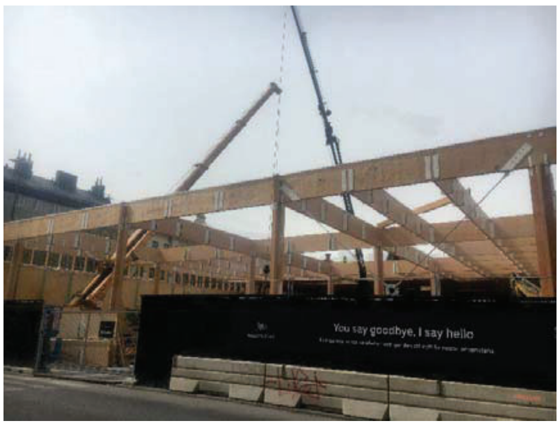

Figure 3: *The hall is disassembled, April 2021. Photo: Andres Zabala Mejia.*

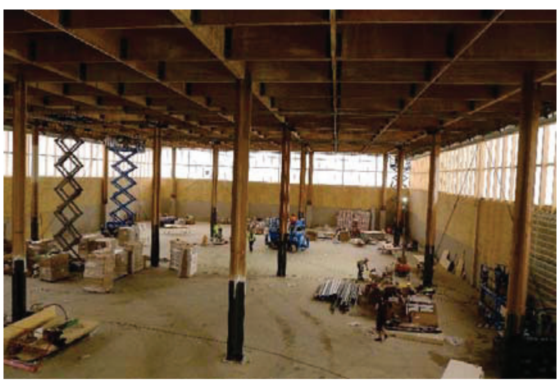

Figure 4: *The hall during reconstruction. Photo Ylva Sandin.*

For this case, data was collected on four occasions. First, one of the architects that had worked with the design was interviewed. Then, the deconstruction site was visited during disassembly and the project manager was interviewed. On a third occasion, the project manager was interviewed on video during reassembly and finally the reconstruction site was visited during reassembly and both the project manager and people from the construction firm were interviewed. The deconstruction and reconstruction sites were documented in photos.

3.3 IDENTIFIED ADVANTAGES AND DISADVANTAGES TO DFDR

When asked about advantages of the design, based on their experiences from deconstruction and reassembly, the project manager and construction firm mentioned the following.

3.3.1 Advantages

Adaptable to new use: The transformation from market hall to sports hall was successful. The post and beam system was flexible and adaptable to the new use. Posts could be moved without changing their dimensions. Roof beams affected by larger stresses, following the change of post position, were reinforced with steel fittings (Figure 5). Lengths of posts were adjusted with steel details. Steel details were considered as positive aesthetic expressions, showing that the hall is reused.

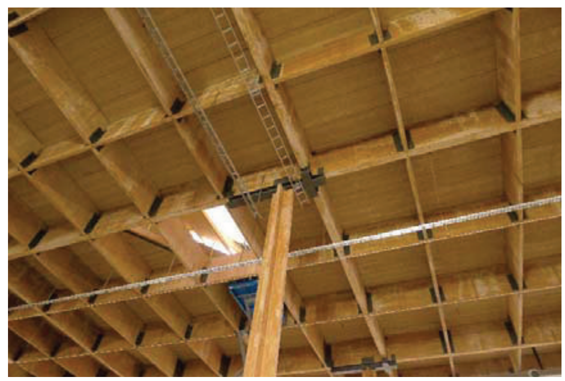

Figure 5: *A roof beam adapted with steel as bending moment changed when a post got a new position. Photo: Ylva Sandin.*

No waste: All parts of the loadbearing structure were reused – there was no waste (ignoring waste that did not concern the structure, particularly roof insulation.) Posts and beams were robust and durable. There were only minor marks on them from disassembly and transport, nothing major.

Prefabricated frame: The frame was prefabricated, and the disassembly process could be done as the assembly in reverse order. The roof was originally designed to be lifted into place quickly, in a narrow and busy urban environment.

Easily accessible and readable frame: The loadbearing and sound absorbing wood wool roof elements were attached one at a time and lifted. After this, the beams and posts were easily accessible, visible, and understandable. It was largely obvious how it would be dismantled.

Bolted connections: Beam-to-beam connections and beam-to-post connections were bolted, and the bolts were removable (Figure 6). There were no unforeseen connectors in the post and beam system.

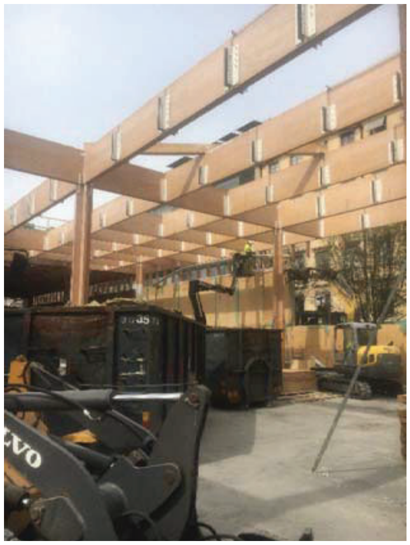

Figure 6: *Bolted connections could be undone. Photo Andres Zabala Mejia.*

Separable services: Mechanical and electrical services were independent of the frame and could be easily separated.
Documentation available: Original documentation and drawings were available, and the design was consistent with the drawings. Half of the original drawings could be reused; the new parts were just added.
Transportability: It was easy to transport the parts. An advantage of the LVL beams was that they provided smaller dimensions than glulam would have done.

3.3.2 Disadvantages

Extensive planning needed: It was time consuming and difficult to make plans for numbering, labelling and logistics. A logic way to number and label the parts of the structure (having for example more than one thousand roof elements) had to be found, considering how and in what order parts were to be dismantled, transported, and stored. This was pointed out as something that could have been thought of and documented already in the original drawings.
Invisible screw heads: The loadbearing wood wool roof elements were connected to roof beams with countersunk screws. The exact position of screws was not known but had been decided on site during original assembly and carpenters had made slightly different choices. At deconstruction, screw heads were therefore not easily visible and had to be searched for, which was time consuming.
Stabilising members optimised for original location: Some elements in the outer walls were included in the stabilization for wind load, but were not dimensioned for the new, higher wind load at the new location. They could easily have been oversized at low cost to take larger wind loads.
Walls dismantled with difficulties: Connections in the façade walls were hidden and difficult to dismantle. They had to be sawn apart.
Fire protective layer sensitive to moisture: The fire protection treatment for indoor use on the LVL beams was sensitive to moisture. It became sticky when wet and cracked when it dried.
Physical labelling: Once labelling of all the roof beams was done, it turned out to be hard to see the labels when beams were unloaded and stacked on the re-assembly site.
Weather protection of sensitive beams: It was difficult to plan how the LVL beams should be covered from rain during dismantling.
Adaptation for reuse with high aesthetic requirements: High ambitions for the aesthetics with the ambition that the reconstructed building should still be a beautiful, was a challenge. New steel reinforcements had to look good while at the same time signalling reuse. The property owner and architect did not want to change dimensions and they wanted to preserve the symmetry and other architectural qualities. All additions had to fit and could not be too much or too visible.

3.4 INTERPRETATION OF ISO 20887 AND RE-EVALUATION OF PROPERTIES

3.4.1 Presenting the ISO 20887

The standard presents three *principles for DfA* (Versatility, Convertibility and Expandability) and seven *principles for DfDR* (Ease of access to components and services, Independence, Avoidance of unnecessary treatments and finishes, Supporting re-use (circular economy) business models, Simplicity, Standardization and Safety of disassembly). Important advice is also given under the headings *General disassembly principles* and *Documentation and information*. The standard states that each of the principles should be examined on five *levels of analysis* (Systems, Elements, Components, Sub-components, and Materials). In this study, only one level per case is considered for analysis, based on relevance with respect to reuse scenarios. For example, the temporary market hall was analysed on the elements level as it was deconstructed into assemblies and components for reuse in a similar building. Apart from principles, the standard presents *strategies* and *guidance*.

3.4.2 Re-evaluation of advantages and disadvantages

The recorded advantages and disadvantages discovered in the interviews were compared to the principles and guidelines of ISO 20887. An interpretation was made of how each aspect corresponds to the ISO. This was done for all cases. Examples are shown here from the analysis of the temporary market hall.
Table 1 shows aspects of the design that can be interpreted as compliant with the standard, and Table 2 shows aspects that can be interpreted as inconsistent with the standard. Data from all cases was re-evaluated in a similar way.

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Table 1: *Advantages to DfDR and connection to ISO 20887. Examples from case study on temporary market hall.*

Advantage	Compliant with principle/guideline
Adaptable to new use	• Versatility, convertibility and expandability
No waste	• Supporting re-use (circular economy) business models: Reusability
Prefabricated frame	• Supporting re-use (circular economy) business models • Simplicity • Standardization
Easily accessible and readable frame	• Ease of access to components and services • Simplicity • Safety of disassembly
Bolted connections	• Independence: Reversible connections
Separable services	• Independence: General
Documentation available	• Documentation and information
Transportability	• General disassembly principles

Table 2: *Disadvantages to DfDR and connection to ISO 20887. Examples from case study on temporary market hall.*

Disadvantage	Inconsistent with principle/guideline
Extensive planning needed	• Documentation and information
Invisible screw heads	• Independence: Reversible connections • Ease of access to components and services • Safety of disassembly
Stabilising members optimised for original construction	• Convertibility and expandability
Walls dismantled with difficulties	• Independence: Reversible connections • Ease of access to components and services • Safety of disassembly
Physical labelling	• Documentation and information
Weather protection of sensitive beams	• Supporting re-use (circular economy) business models: Reusability • General disassembly principles
Adaptation for reuse with high aesthetic requirements	• Versatility and convertibility

The analysis of advantages and disadvantages and their comparison to principles and strategies in ISO 20887 is somewhat ambiguous - some properties could be associated with many principles and for others it was less obvious (but not impossible) to find any match in the standard. For example, solutions and problems around intermediate storage of recovered parts were usually interpreted to fit under *General disassembly principles*, though the ISO does not make explicit mention of storage requirements.

3.5 ILUSTRATING THE ISO 20887 PRINCIPLES AND STRATEGIES

Having re-evaluated the results according to the ISO 20887 design principles, a catalogue illustrating principles and strategies with practical examples from the studied cases was attempted using the general structure in Figure 7. This catalogue is a text document, aiming to fulfil the first objective of this study.

General disassembly principles
- Example 1
- Example 2
- ---

Ease of access to components and services
- Example 1 etc.

Independence
- Example 1 etc.

Avoidance of unnecessary treatments and finishes
- Example 1 etc.

Supporting re-use (circular economy) business models
- Example 1 etc.

Simplicity
- Example 1 etc.

Safety of disassembly
- Example 1 etc.

Standardization
- Example 1 etc.

Figure 7: *Principles and strategies in ISO 20887 can be illustrated with practical examples from the studied cases to form a catalogue, showing how the abstract principles can be treated in practice.*

Some of the designs in line with *General disassembly principles* found in case studies and stored in the catalogue are:

- *Example 1: Lifting points are marked out physically on the structure for future disassembly.*
  This can be done with paint or, in some cases, by leaving lifting loops in the structure during assembly, which will efficiently show where elements are supposed to be lifted, Figure 8.

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Figure 8: *Lifting loops in an element. Photo: Ylva Sandin.*

- *Example 3: Members are designed for easy transport*
  Members can be designed to have dimensions that are practical to handle. In the temporary market hall case, it was pointed out that choosing LVL instead of glulam for some members led to less heavy members, Figure 9.

Figure 9: *Laminated veneer lumber beams (right). Photo Andres Zabala Mejia.*

- *Example 2: Modules are designed for easy transport.*
  The structure can be modular, with dimensions optimised for transport and handling, Figure 10 and Figure 11.

Figure 10: *Modules designed for efficient transport: planar wall elements. Photo: Derome.*

Figure 11: *Modules designed for efficient transport: volumetric modules. Two modules can be transported with one vehicle. Photo: Masonite Beams.*

However, the amount of data in the catalogue became unpractical to handle as a text document. Many design examples were obtained from the case studies, showing both designs in compliance with the standard and designs that are inconsistent with the standard.
To store and arrange the large amount of data, the study uses a web application for data management (Notion). Data can thereby be sorted and filtered, for example by case or by ISO principle, Figure 12-Figure 14.

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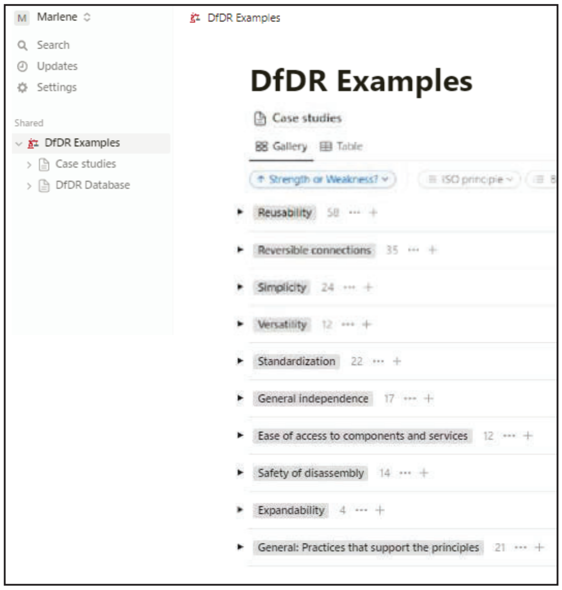

Figure 12: *Data is stored case by case and tagged to be sortable and filterable by ISO principle. A data management tool (Notion) is used.*

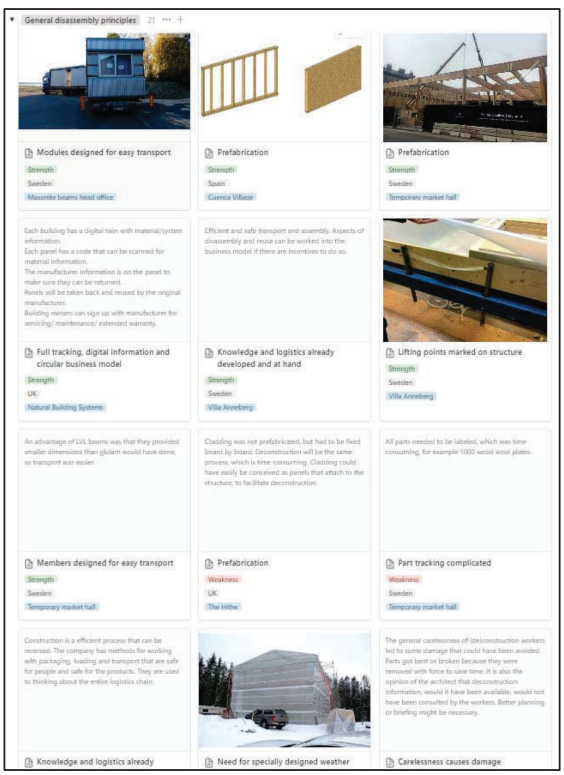

Figure 13: *Filtering data by choosing "General disassembly principles" will show case study data associated with this aspect. The picture shows a small sample of the data associated with this aspect.*

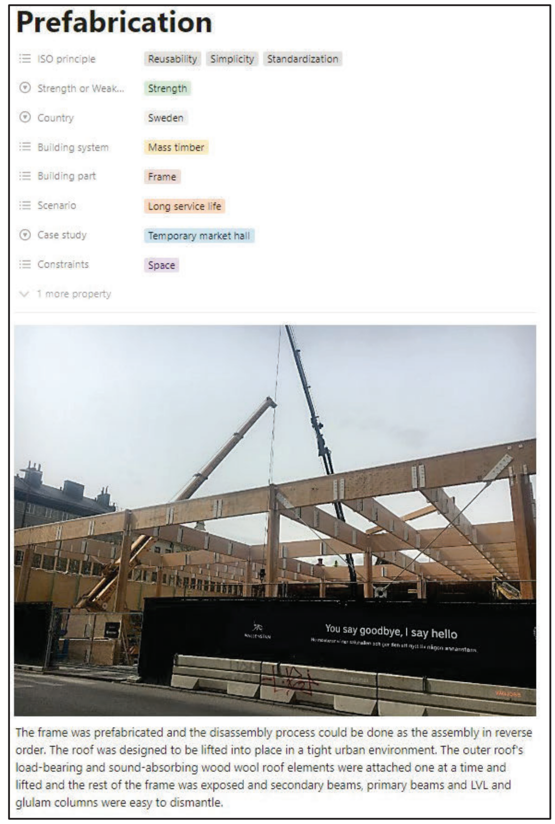

Figure 14: *Each design example is tagged under different headlines, e.g. country or building system, to allow users to filter for relevant context*

Storing the data this way makes it possible to get an overview of cases, see patterns and find inconsistencies. As an example of an inconsistency found, I-beams were judged reusable (compliant with the ISO) in two cases, and not reusable (inconsistent with the ISO) in another case. For one of the cases, the property owner pointed out that knowing the brand of the beams was an important basis for judgement and that having a personal knowledge of the product made it possible to rely on its reusability. This indicates that further investigations might be needed to find out if there are differences in quality of beams or differences in viewpoints between persons. It would be valuable to further study the effect of age on different timber materials.

The database is a prototype and a suggested methodology for collecting more data. Data from nine out of the fourteen case studies has been added to date (February 2023) and the work is ongoing.

More case studies should be carried out and data be added to the database, so that several examples of each type of timber structure is included.

The database is specific to timber construction. The intention is to show a multitude of examples, some describing practical experience, and show that contrasting views and evidence might exist. Contrasting views also

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suggest that lessons from the case studies might only apply to a certain building system, deconstruction scenario or regional context, and the database should allow to filter examples according to these criteria.

As researchers, property managers and manufacturers might seek different types of information and sort data in different ways, it is important at this stage to involve different stakeholders in a dialogue on the kind of data and sorting possibilities, as the work with collecting more data goes on.

3.6 REFLECTIONS ON THE ISO 20887

3.6.1 Examining if important aspects are insufficiently covered

Our second objective of the study was to examine if there are important aspects of DfDR/A for timber buildings that are insufficiently covered by ISO 20887. The result is ambiguous.

On the one hand, the standard *can in fact be said to cover the important aspects* identified in case studies. None of the stakeholders in any of the case studies set out to incorporate the ISO principles in their design, yet all design examples (advantages/disadvantages to DfDR) could be assigned to one or more of the ISO principles.

On the other hand, important aspects *are not explicitly treated*. The standard is generic and independent of structural material and cannot list design examples for every building type or civil engineering works. The specific and tangible aspects of DfD/A that emerge from case studies will not be found in the standard. It remains abstract and needs to be interpreted.

Some timber specific advantages/disadvantage not explicit in the ISO are given below.

Transportability. In several case studies, interviewed persons stressed as a significant advantage, that the structure (or rather its deconstructed parts) was well adapted for transport. As timber is a light material, this property might be characteristic to timber structures and should be recognised as a large benefit when choosing structural system for a building.

Designing for transportability is included in the standard, but the aspect is rather hidden. It is not a principle but mentioned among several practices that can support general disassembly principles: “When possible, materials and components, which can be easily, safely, and more cost-effectively replaced or removed and transported, should be used. […] Components that are sized to suit the intended means of handling should be used. Various possible handling options at all phases of assembly, disassembly, transport, reprocessing, and reassembly should be considered.” (ISO 20887, section 5.3.1.)

Reversible connections. One of the principles in the ISO is Independence and a sub-category of this is Reversible connections. While it is easy to intuitively understand that this is important, it is not very clear how the principle shall be interpreted in practical timber construction. The standard (section 5.3.3.2) states that “Reversible connections can be disconnected and/or disassembled for easy alterations and additions to structures.”. The interpretation of the principle was repeatedly discussed in case studies. The cases showed that bolted joints, screwed joints and nailed joints might all be considered reversible as bolts can be removed and the others can normally be sawn apart without causing damage to the connected members, although fasteners themselves will not be reusable. For timber structures, we suggest that “reversible connections” might be defined as connections that can be separated without damaging the connected members (at least not to a degree that generates waste or makes substantial refurbishment necessary). Thus, the choice of connector does not necessarily define the reversibility.

Handling moisture. It is crucial to protect a timber structure from moisture during disassembly, temporary storage, and reassembly. The ISO does not give explicit advice on weather protection and storage but whether timber parts are protected or not might strongly influence their reusability.

3.6.2 Some comments on the reinterpretation of the case study examples

The DfDR strategies are interconnected. Each design example found in case studies was assigned to 2.6 ISO principles on average. The reinterpretation of the case study examples gave insight in the relative importance of each design principle for the sample, Figure 15. *Reusability*, a sub-category to Supporting re-use (circular economy) business models, was by far the principle most design examples were assigned to, followed by *Reversible connections*, a sub-category to Independence.

Some principles were well matched in design examples, others were more problematic. Some examples are shown below.

Good match: *Reusability*

Case study examples that were assigned to this principle mostly covered one of four aspects:

- The condition of recovered parts, i.e. damage and remaining service life
- The generality of recovered parts and the resulting freedom in reuse options, e.g. the size and shape of recovered panels
- Barriers to reuse, e.g. timely and costly reconditioning, storage, adaptation
- Verification or available information for materials

All four aspects are mentioned in the ISO, although they could be more clearly separated and linked to examples.

Slight mismatch: *General Independence*

Under this principle, the standard mostly highlights the merits of independent layers, i.e. separating layers with different expected service lives. Although the case studies did not explicitly work with the concept of layers, design examples fit the principle well and mostly concerned:

- Independent installations

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- Separating the vapour control layer
- Independent façade

One difference between the description in the ISO and the case study observations was noted: While the ISO described the most important layers to be separable should be the most reusable ones, the case study examples showed problems were related the accessibility of the least reusable layer. This was because most cases targeted assembly reuse, and the least reusable layers often need to be accessed for replacement.

An aspect that is not explicit in the standard is the advantage of self-contained assemblies. It became clear that independence is as much about keeping similar parts together as it is about keeping different parts apart. Self-contained functional units are more easily separated and independently reusable, e.g., self-contained pods are more independent upon recovery than open panels that need to be finished with additional materials.

Stark mismatch: *Avoidance of unnecessary treatments and finishes*

The ISO states that treatments which would limit reuse should be avoided. Timber preservative and fire-retardant treatments generally do not limit its reuse options, but they should still be avoided where unnecessary to limit environmental impact (which is out of scope of this study). Finishes that hide the wood surface might limit visual inspection methods for verification, so these should be avoided as well. The ISO might need to clarify the motivations for avoiding different finishes and give specific examples relevant to different materials.

The principle was also interpreted more widely as avoidance of unnecessary components and finishes, so that recurring examples could be assigned:

- Avoidance of sensitive materials, e.g., the vapour control layer, though by no means unnecessary in all types of timber construction, can be eliminated in vapour-open systems, avoiding the use of damage-prone materials.
- Avoidance of wet construction methods, e.g., foundations can be minimised when designing lightweight structures.
- Avoidance of excess connectors, e.g., avoiding the need for unplanned connectors by providing temporary bracing during construction

Although most design examples could be matched to the ISO principles reasonably well, there is quite an amount of work left to do to adapt the standard to reflect the real world rather than the real world to illustrate the standard. Future guidelines to the standard could aim to include a wider range of strategies, so that common design considerations are made obvious to designers. It would be necessary to analyse a wide range of buildings and civil engineering works, in a similar way as in this study, to get a better understanding of the most important strategies, without it becoming too comprehensive.

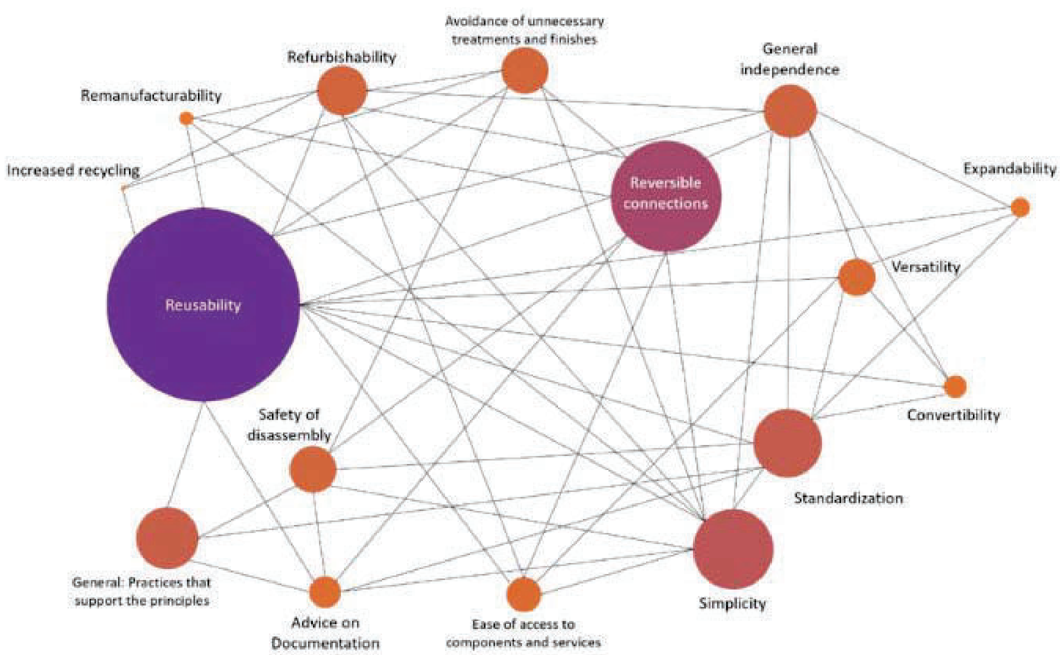

Figure 15: *ISO 20887 principles and their connection as given by data from nine case studies on timber structures of different sizes and types. The size and colour of the circles indicates how many examples were assigned to each principle and a connection was added between circles when at least one example illustrates both principles.*

4 CONCLUSIONS

The case study approach [4] resembles a top-down approach: An existing design is evaluated for its advantages and disadvantages to DfDR/A. This involved gathering the right expertise and discussing the design, its future deconstruction and reuse, recording advantages and disadvantages. This method was used in case studies simulating deconstruction and was found to be an easy, pragmatic, and inspiring process that provoked ideas for modified designs. The case study method results in specific design examples, but also reveals general DfDR/A barriers and solutions in the given context.

A bottom-up approach for developing new designs adapted to DfDR/A is described in ISO 20887. The standard follows a broad and holistic approach, including decision-making, design principles, documentation, and implementation of DfDR/A. It is, however, not easy to apply in practice.

When the DfD/A design examples gathered with the case study method were re-evaluated to fit under the ISO 20887 principles, it became clear that the standard reflects the overarching principles of DfD/A design well. Keeping the aim of the ISO, to give an overview of DfD/A principles for all buildings and civil engineering works, in mind, it is still not feasible to fully represent all these different structures with examples, and the standard will likely remain somewhat general and abstract.

Both approaches combined can provide valuable support for designers in creating and evaluating deconstructable designs. The result of this work is a non-exhaustive database of specific examples illustrating ISO 20887 design principles. A database that focuses on timber buildings, to narrow down the scope and become more accessible, can complement the ISO and provide the link between DfD/A principles and the real world. The database draws from reality rather than from abstract principles, and it does not only show the many good solutions that have been developed already but also mistakes from the past, to help avoid pitfalls even with best intentions. This study is only the beginning, providing design examples for the loadbearing structure of nine timber buildings. Further examples are needed, covering all chapters of the standard and more building types, layers, and levels. As the continued collection of case studies progresses, the experiences will form a base for guidelines showing how the ISO can be interpreted for timber buildings.

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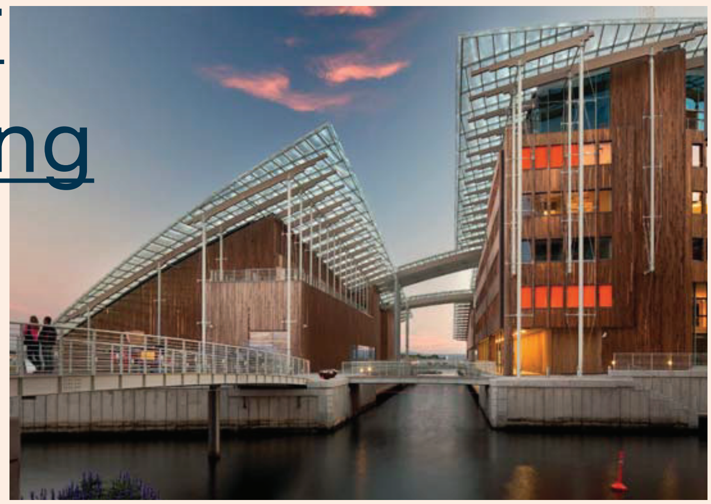

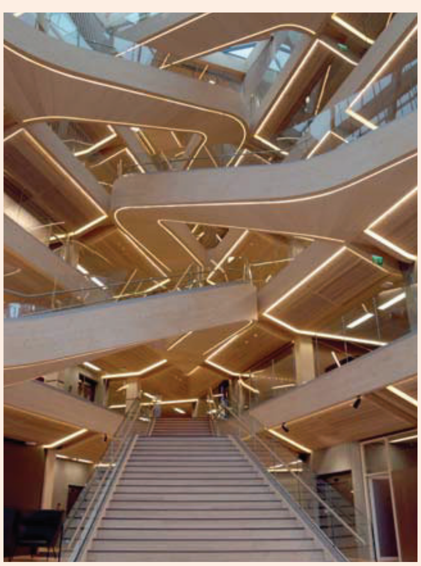

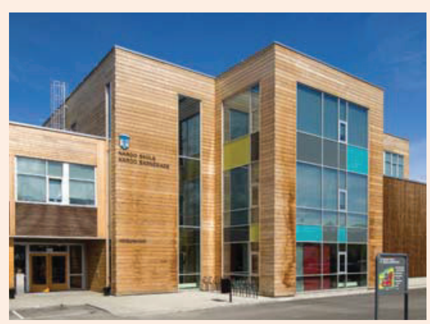

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Proceedings from the
13th World Conference on Timber Engineering (2023)

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All authors have submitted two-page extended abstracts, which were peer reviewed by the WCTE2023 International Scientific Committee. The full papers have not been further reviewed, but checked for conformity. Many of these papers represent ongoing research and it is expected that many of the papers will appear in a more comprehensive form in scientific journals in due course.

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