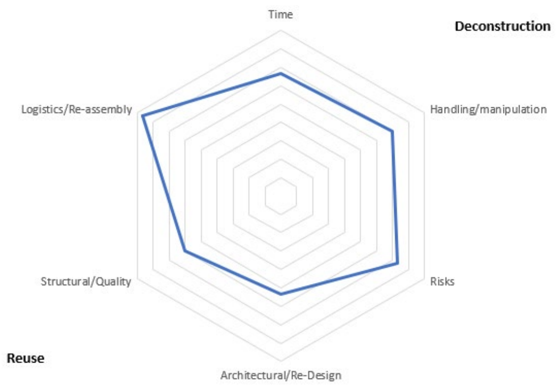
Design for deconstruction and reuse of timber buildings - testing an assessment tool in a workshop

Ylva Sandin, Karin Sandberg



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Borås

Foreword

InFutUReWood Innovative Design for the Future – Use and Reuse of Wood (Building) Components is a three-year project within ForestValue. The main aim of the project is to answer the question how we should build today to be able to reuse tomorrow. Work package 2 investigates how wooden frames can be designed to make them optimized for future deconstruction and reuse. One of the tasks is to develop a tool to assess the deconstruction and reuse potential of a building. This study is the basis for the development of an indicator system for circular improvement of timber buildings. The work was carried out closely together with the timber building industry and the tool was tested in a workshop with stakeholders. The work with an assessment tool that defines an optimal design and produces a rebuilding factor started in the end of 2019.

We would like to thank Anders Carlsson, Janina Östling, Karin Löfgren and Tommy Vince for your positive engagement in the preparations and implementation of the workshop – you made the workshop possible. Thank you also all workshop participants who contributed generously and inspired us to go on and take the ideas further.

Ylva Sandin and Karin Sandberg

May 31st, 2021

Pictures on front page: temporary market hall in Stockholm being deconstructed in May 2021 (left, photo by Andres Oswaldo Zabala Mejia), result from test of assessment tool presented as spin diagram (above right), Villa Anneberg from Derome (below right, photo by Derome).

Key words: Indicator system, Construction, Design for Deconstruction (DfD), Design for Adaptability, Rebuilding factor, Material efficiency, Structural Design, Sustainability.

ForestValue

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Summary

The InFutUReWood project addresses the topic of reuse and recycling of timber buildings and one of the work packages concerns design for deconstruction and reuse. Design processes that optimizes design to that respect are studied and a “rebuilding factor” to measure the potential for deconstruction and reuse is developed. A first draft of an assessment tool that defines an optimal design and produces a rebuilding factor has been developed. The draft was tested for an existing building and the produced material was examined and discussed during a workshop with stakeholders. Results show that stakeholders see a value in creating a tool and that some find a quantitative tool most interesting while others would prefer a qualitative tool. An assessment with a quantitative tool would produce a measure of the potential for a design to be deconstructed and reused, while a qualitative tool would be used to guide decision-making in the design process. For the draft version of the tool, assessment was complicated by the fact that indicators were open to interpretation. The further work on the tool will be based on the ISO 20887 *Sustainability in buildings and civil engineering works — Design for disassembly and adaptability — Principles, requirements and guidance.*

1. Introduction

1.1. A project to address reuse and recycling of timber buildings

The construction industry contributes significantly to Green House Gas emissions, raw material consumption and waste production and the need to a shift towards a circular economy is generally renowned. An important aspect of sustainability is to reuse resources that have already been extracted and used. This applies also to timber and wood-based products. The InFutUReWood project addresses the topic of reuse and recycling of timber buildings and is organised in work packages to reflect important themes:[1]

- Design of wooden frames for the future.
- Product design with recycled wood.
- Inventory, dismantling and quality of recycled wood.
- Strength grading recycled wood.
- Environmental and economic assessment of building structures intended for recycling.

The project gathers researchers, industry and public organizations and sets out to develop knowledge and solutions, spread knowledge and engage people within and outside the project. Twenty-two partners participate, from seven European countries.

In the work package “Design of wooden frames for the future”, we investigate how to design a wooden frame to make it optimized for future deconstruction and reuse. One of the tasks is to develop a measure of the potential to deconstruct and reuse, a “rebuilding factor”. The work also includes the development of new design concepts. The study reported on here is part of this InFutUReWood work package. In order to define a rebuilding factor, there was a need to develop an assessment tool.

1.2. Initiating the creation of an assessment tool

The aim of this study was to:

- Construct a draft version of a tool, intended for assessing timber building designs with respect to their potential for deconstruction and reuse.
- Test the draft version with stakeholders.
  The stakeholders in mind were manufacturers, architects and engineers designing timber frames. One specific question that we wanted to discuss with stakeholders, was if a quantitative or a qualitative tool would be most valuable. A quantitative tool could be an indicator system, where different parameters are assessed, graded, weighed and summed up. The result from using the tool would constitute the rebuilding factor that is sought within the project. Alternatively, the tool could be a checklist, aiming at guiding design decisions.
- Decide if and how to proceed with the tool.

Furthermore, the study aimed at engaging stakeholders and project members in knowledge development and experience exchange on the topic of design for deconstruction and reuse.

1.3. Assumptions and limitations

The work was based on the assumption that greater deconstruction potential means greater environmental efficiency.

The tool is related to modular, component deconstruction, were larger parts as wall elements, floor elements, roof trusses et cetera are being deconstructed and reused, as: “ [---] in the contemporary world, DfD emphasis must be attuned to modular, component deconstruction - i.e. of wall, floor and roof cassettes - as opposed to individual member deconstruction”. (Chisholm 2012).

The topic of the study is narrow:

- We focus on the load-bearing structures of buildings (rather than surface layers).
- We focus on how the design of a building can make it technically possible to dismantle and reuse the parts. We do not calculate costs and environmental impact of different scenarios. We will therefore not shed light here on whether, for example, it would be best to reuse certain parts of a building and recycle/energy recycle other parts. These important questions are addressed in other parts of the InfutUReWood project.
- We have a sharper focus on deconstruction and reuse than design for adaptability.

2. Methods

2.1. Literature study

A literature study, Cristescu et. al (2020), was carried out to identify important things to think of in design for deconstruction and reuse and to study already existing indicator systems The study included other building materials than wood. The work constituted a limited part of a broader survey, aiming to create a state-of-the-art review on design for deconstruction and reuse of timber structures). The part relevant for this study is accounted for in chapter 4 of that report.

2.2. Construction of assessment tool

Based on the literature study, a draft for an assessment tool was made, constructed as an indicator system. Indicators were chosen among the parameters and principles pointed out by the literature as important in design for deconstruction and reuse (DfDR) and design for adaptability (DfA). Indicators were listed, organized in themes, and a way to grade the indicators was suggested. The draft assessment tool (developed and described in Chapter 3.1) was tested in a workshop on two cases.

2.3. Workshop

Goal

A digital three hour long workshop was organized on the 3rd September 2020. The goal was that after the workshop we would know what the participants think of the analysis tool:

- If the suggested or a similar indicator system would be useful and desirable.

- If a quantitative tool (an indicator system) or a qualitative tool (a checklist) would be preferable.
- How the system could be improved.
- How we should test the system.

Participants were InFutUReWood project members in Sweden as well key persons invited by them, identified to ensure that stakeholders were represented. Specifically, we wanted to take in practitioners' views (architects and engineers). The number of participants was limited to 25 to allow for discussions in 4 groups.

The workshop had 22 participants. Nine were architects, three were structural engineers, five were researchers, four were manufacturers of timber structures and one was a municipal official. The workshop was held in Swedish.

Preparatory work

Prior to the workshop, the tool was tested for the concept building Villa Anneberg manufactured by Derome, together with Deromes research and development manager Anders Carlsson. The experiences were summarized to be presented in the workshop. Two more cases were prepared. The second case was the temporary market hall Östermalmshallen in Stockholm. One of its creators, architect Karin Löfgren, was interviewed and invited to present the history of the building and her thoughts on sustainability and reuse in the design process. The third case was a project by architect Tommy Vince, where deconstruction and reuse had been envisaged and Isotimber wall components were prescribed. This case was to be used in an exercise in the workshop, where participants could test the tool. Participants got information sent out prior to the workshop, containting information on the project that the tool was to be tested on, the background of the tool, the references used to construct it, other ongoing work on similar tools, terms and definitions and programme. Participants were divided into groups so that all types of stakeholder were to be represented in group discussions.

Programme

1. Welcome!
   Objective
   The InFutUReWood project, presented by Karin Sandberg
   Some concepts
   Inspiration lecture on the topic of temporary Market Hall Östermalmshallen,
   Stockholm, Sweden. Karin Löfgren, AIX
2. A tool to use in the design phase
   How the tool was created
   Presentation of the tool and how it can be used
   Example: test of tool for Villa Anneberg, Derome
3. Exercise: test the tool
   Scenario definition
   The building to test the tool for, presented by Tommy Vince
   Exercise in breakout rooms
4. Discussion
   Summary and conclusion

For a translated version of the workshop presentation, see Appendix 1.

Finishing work
After the workshop, notes were compiled and translated to English. The draft for a tool was slightly revised to account for some of the experiences made.

3. Results

3.1. A draft for an assessment tool

Constructing the tool
Generic principles for design for disassembly were sought with the aim of developing them into indicators in a tool. Such principles were found in several sources, as Crowther (2005), Guy and Ciarimboli (n.d.), and Hradil et. al. (2014). Examples of assessment models were found in Thormark (2001), Hradil et. al (2017), Durmisevic (2019) and Durmisevic (2019). An important document, the standard ISO 20887 was released in 2020, giving guidance on design for adaptability and design for disassembly but came too late to our knowledge to be accounted for in the work.

Guy and Ciarimboli (n.d.) presented a concise list of principles as the ten key principles of design for disassembly:

1. Document materials and methods for deconstruction
2. Select materials using the precautionary principle
3. Design connections that are accessible
4. Minimize or eliminate chemical connections
5. Use bolted, screwed and nailed connections
6. Separate mechanical, electrical and plumbing (MEP) systems
7. Design to the worker and labour of separation
8. Simplicity of structure and form
9. Interchangeability
10. Safe deconstruction

These could be considered indicators of appropriateness of design for deconstruction and reuse and be arranged in groups (Figure 1).

The ten key principles from Guy & Ciarimboli together with main indicators for deconstructability and reusability found in Thormark (2001) and Hradil at. al (2017) (Figure 2) were used as a departure for creating an indicator system.

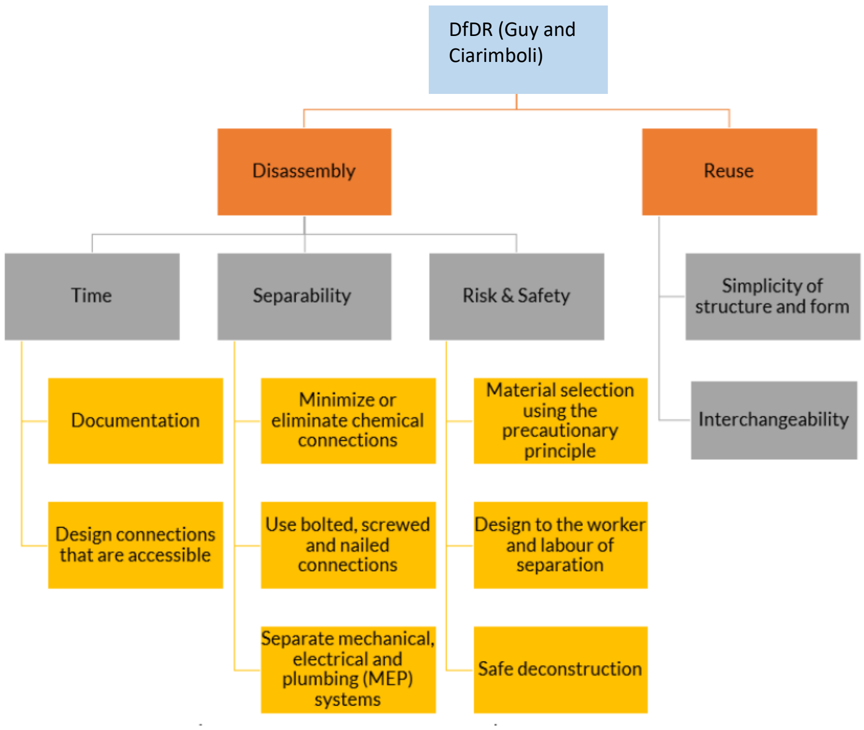

Figure 1 Ten main principles of design for disassembly from Guy and Ciarimbomli (n. d.) arranged in a hierarchy under main themes disassembly and reuse.

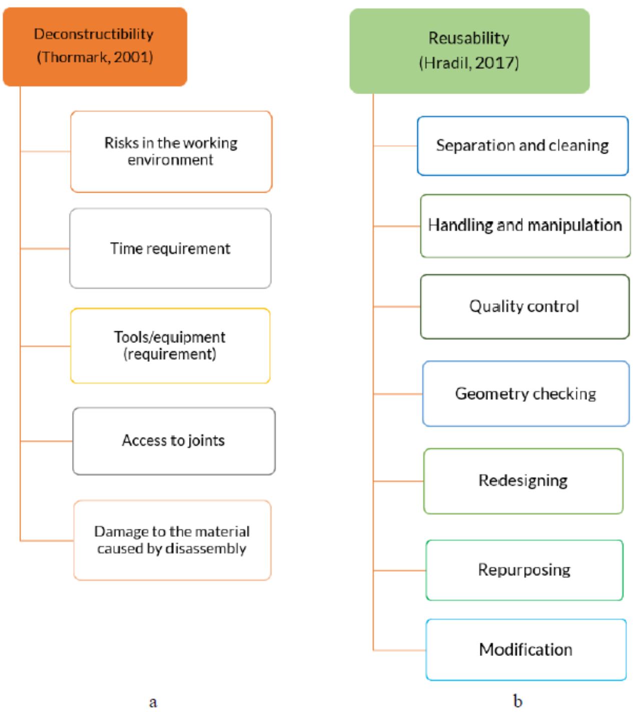

Figure 2 Main indicators of a) Deconstructability (Thormark 2001) and b) Reusability (Hradil et al. 2017. Picture from Cristescu et. al (2021).

Following the findings in the literature, it was decided that the assessment tool should be thematically divided into the categories “deconstruction” and “reuse”.
The indicator system was arranged in three levels (Figure 3):

- Level 0, containing the two main categories “Deconstruction” and “Reuse”.
- Level 1, with three sub-categories for each main category. (“Time”, “Handling/manipulation” and “Risks” for main category “Deconstruction” and “Architectural/Design”, “Structural/Quality” and “Logistics/Re-assembly” for main category “Reuse”).
- Level 2, with two to three indicators for each sub-category.

A grading system was suggested where scores could be given for each indicator. A possibility to multiply scores by weight factors was given, to account for the fact that some indicators might be more important than others. The weight factors were not further studied, but were given the value 1. Likewise, the possibility to use weighting factors on level 1 and level 0 was acknowledged.

The “rebuilding factor” might be defined as the sum of the two weighted scores for “Deconstruction” and “Reuse”. It could also be defined differently and its definition was left for future studies, as were all other questions on scoring as the focus here was on discussing a tool on a general level.

The draft of a tool was created in Excel (Figure 3) to facilitate calculations and the production of results as graphs.

	A	B	C	D	E	F	G	H	I
1	**Level 0**	**Score level 0**	**Weight level 0**	**Level 1**	**Score level 1**	**Weight level 1**	**Level 2**	**Score level 2**	**Weight level 2**
2	**Deconstruction**	3,5	1						
3				**Time**	3,33	1			
4							Accessibility*	2	1
5							Separability of subcomponents/materials	5	1
6							Sorting and cleaning	3	1
7				**Handling/manipulation**	3,5	1			
8							Tools/equipment	4	1
9							Low weights and small sizes	3	1
10									
11				**Risks**	3,67	1			
12							Susceptibility to damage (disassembled parts)	4	1
13							Human risks (workers heath/injuries	5	1
14							Risk to environment	2	1
15									
16	**Reuse**	3,33	1						
17				**Architectural/Re-Design**	2,67	1			
18							Documentation about design and maintenance	1	1
19							Adaptability (of building layout)	5	1
20							Standardization level (shapes, sizes, elements	2	1
21				**Structural/Quality**	3	1			
22							Ease of reassessment of structural properties (and damage)	3	1
23							Overdesign/structural reserve for flexible repurposing	4	1
24							Susceptibility to time effects (deterioration, excessive deformations	2	1
25				**Logistics/Re-assembly**	4,33	1			
26							Repetitiveness (number of similar elements	4	1
27							Similarity (variation of elements)	5	1
28							Transportation (location remoteness)	4	1

Figure 3 The first draft for an assessment tool, constituting an indicator system.

Results from the indicator system could be shown graphically as a spin diagram (Figure 4), for a more intuitive understanding of the strengths and flaws of the assessed building design.

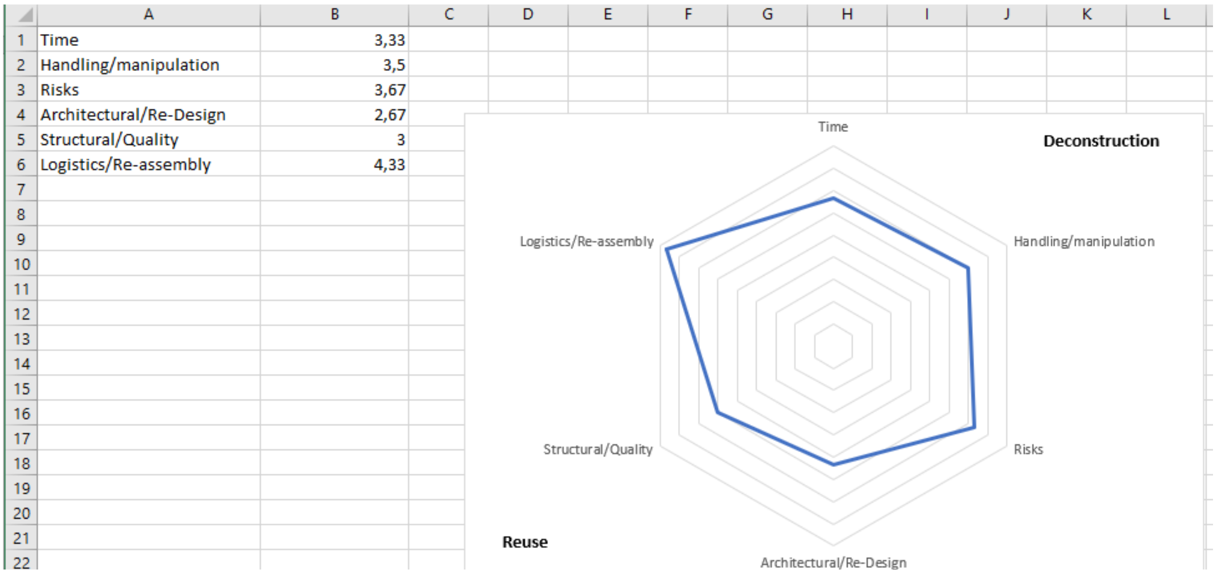

Figure 4 Results of an assessment could be visualized as a graph.

Suggesting how the tool could be used

An sketch for a process in which the future final tool could be used was drawn (Figure 5). Such a process should include defining a goal for the future reuse of the building. Future scenarios should be defined, for which the building design is to be adapted. Scenarios might be, for example: "The whole building will be deconstructed and the parts reused to form an identical building somewhere else" or "Valuable parts will be taken out from the building and reused in another building that might be different".

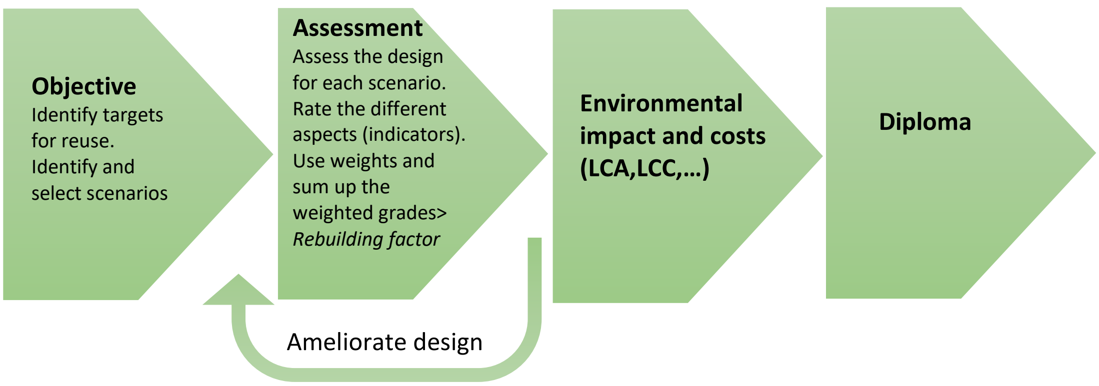

Figure 5 Using the tool: a suggested process.

Having defined the scenarios, the actual assessment could be carried out, based on a proposed design where drawings and descriptions of the building exist at some stage.

The result would be scores and a rebuilding factor showing how well adapted the design is for deconstruction and reuse. Reaching the highest possible score for all indicators would mean an optimized design. Alternatively, the tool could be used as a checklist, as a means to discuss and adapt design without grading. The process could be iterated by improving design and carrying out a new assessment. In addition to this, environmental impact and costs could be assessed and for the final results, a diploma or certificate could be issued.

3.2. Lessons learned from workshop preparations

The tool was tested on a case: the design of Villa Anneberg, a two storey, residential, light timber building produced by the manufacturer Derome (Figure 6). A future scenario was assumed were floor cassettes would be reused. The assessment was carried out by researcher and manufacturer and based on drawings and descriptions of the building. The test showed that indicators and scores would need to be better defined.[2] Nevertheless, the test lead to rewarding discussions on the potential of the design related to DfDR which in turn lead to ideas on how to change the design. An alternative connection floor-to-wall was outlined by Derome that would facilitate deconstruction of the floor cassettes.

Figure 6 Villa Anneberg, a concept house from Derome. An assessment of the potential to deconstruct and reuse the floor cassettes of this building was carried out in order to test the first draft for an assessment tool. Photo: Derome.

Recognizing the difficulties with insufficiently defined indicators, it was decided to keep them as they were in the workshop. The idea was to keep the draft of a tool open to discussion and to allow for ideas in different directions.

3.3. Temporary market hall: an object to study further

Karin Löfgren, architect at AiX, previously at Tengbom was invited to talk about her work with the temporary market hall at Östermalmstorg in Stockholm (Figure 7 and 8). The background was that the market hall Östermalmshallen, built in 1888, was to be thoroughly renovated in 2016 and it was decided that a temporary market hall should be constructed to make it possible for shopkeepers to continue their business during the renovation period. Tengbom architects got the commission from the client, the real estate office of Stockholm, to design the building and Karin was one of the architects responsible for the project.

Karin explained that even though the building was to be temporary there were no customer requirements that any consideration should be taken in the design to facilitate disassembly and reuse of the hall. The reason for this was a fear that this would make design and construction more expensive.

Two architectural ideas guided the design process. One was that visitors should feel that the building is temporary. The choice of materials should reflect that. Materials like, for example, particle boards and plywood were used. The other idea was that the temporary building should, like the original hall, transmit an experience of height and of daylight coming in from above.

Figure 7 Temporary market hall during construction. Photo: Karin Löfgren.

Karin pointed out that even if a client or employer does not require sustainability and reuse, this does not prevent architects from designing with these possibilities as a starting point. For this project, the architects at Tengbom considered future disassembly and reuse as a natural part of their interest in sustainability. The building frame was designed to be produced largely off-site. One reason was that fast assembly on site was important, as the streets around the square were narrow and possibilities to store building materials during construction were limitied. But it was also assumed that a modular design optimized for fast assembly and efficient transportation could be beneficial for the future disassembly process. Several of the connections in the building were designed to be possible to deconstruct. Roof beams and girders were connected with bolts. Walls were designed with panels produced off site. Plywood boards were fastened with screws. Plastic facade elements were inserted in slots. Glue was used to a limited extent in the building. Had the assignment included specific requirements to facilitate disassembly some connections using nails would probably have been made with screws.

When the market hall was ready and the customers had moved in, the discussion about the future use of the hall began. Tengbom took the initiative to carry out an internal workshop and presented a number of ideas. A long list of proposals and inquiries came in from around the country to the real estate office of Stockholm and at the time of the workshop (3rd September 2020) the hall was for sale.

The architect underlined that it would have been desirable to produce a manual for deconstruction and reuse, "a reversed IKEA manual". She underlined the importance of saving all relevant documentation and that a summary of aspects known to the design team could be stored for the purpose of facilitating reuse.

Finally, she raised some questions relevant to the disassembly:

- The hall contains a lot of mechanical and electrical services - what are the possibilities for second-hand use of these?
- The hall is facing dismantling, but we have little experience of such processes. Which is the practical way to do it? What is worth saving? Who decides what is worth saving?
- Could the process be studied in a practical research case?

Figure 8 Temporary market hall in use. Photo: Ylva Sandin.

3.4. Workshop suggested tool development in two directions

This chapter consists of compiled notes from workshops attendees that summarizes discussions held on usefulness and design of the tool as well as ways to proceed and develop it.

3.4.1. Usefulness

The tool was stated to be valuable for both manufacturers and architects. Opinions differed on how best to use it. (The question of how it should be used is closely linked to the question of how it should be designed which is discussed below). It could be used either for supporting dialogue or as a grading system. Several participants emphasized that a tool to guide and support dialogue tool would be beneficial. They emphasized saw a higher value in having a checklist for an ongoing design process, then having a tool to evaluate and improve a completed design. It was not considered plausible that a design would be re-made after an assessment. It would be more useful to have an "entry-level" tool when starting a project. The indicators we have proposed could be important as input parameters, forming a structure for discussion. The tool should not be a closed document, it should be an open tool for starting the discussion between architects, builders, etc.

Other participants saw a value in having a grading system that could, for example, be used by manufacturers to show that future dismantling has been considered as part of a sustainability work.

3.4.2. Tool design: directions

The discussions pointed in different directions as to how the tool should be designed. Two different main tracks came up in the discussions: "a wood-oriented checklist" or a grading system with predefined grades.

An opinion raised by several was that the tool should be developed more clearly towards *wood*. There was an expectation before the workshop that you would hear more about *wooden* constructions and reuse. The tool's indicators could, as it is now, be applied to all building materials. When it comes to wood, the system should highlight things specific for wood and include the most important aspects for wooden structures when it comes to reuse. A major issue for wood, for example, is moisture. Is the design risk-free in terms of moisture? The fact that moisture safety design has been assured should give a higher grade if grades are to be set. The system should include more such wood-specific parameters. It would also be useful to get more practical advice on how to reuse different components. You could get information on how to reuse wood-based components with regard to how they are surface treated, etc. What corrective measures are there for each type - how to repair, how to grind, how to correct cracks, etc.? It is important to know, for example, how to handle fire-impregnated wood.

A qualitative system could be more like a collection of fact sheets that describe what to consider when designing wooden structures with a view to future maintenance and finally reuse or recycling. It should be possible to make use of already published information on wooden structures, such as Träguiden.[3]

3.4.3. A quantitative tool with predefined grades

Some participants saw a value in further developing the tool with predefined grades for all indicators. If the grades are predefined, it all becomes more concrete. A quantified tool will not exclude a good dialogue; it can be used for qualitative purposes too. Someone felt that the tool right now is more aimed at manufacturers and production than at architects. Another point of view was that it was good for architects as well.

An existing tool producing a reversibility index for bamboo structures was mentioned and a benchmark study was suggested.

Questions to solve

Categories

The question was raised whether the tool must have different categories of questions depending on wood building system (CLT, stick frame,…) as issues might be unequally important for the various systems.

Aim and goal: what do we want to achieve with the indicator system?

The tool should steer towards easier deconstruction and reuse, but we need to specify the purpose of the reuse. Is it to:

- Avoid using new resources - resource scarcity?
- Achieve as low a CO2 equivalent as possible - CO2 saving?
- Keep costs down - financial frugality?

The purpose might include cascading and recycling (rather than prioritizing reuse of building elements in the same way as they were used before). You can, for example, make a hard facade board from a loose insulation. We need to be more clear about what we want to achieve with the indicator system.

The question of which future scenarios for reuse that should be considered was discussed. One participant said that scenarios where only *parts* of a building are recycled give too large losses and the aim should be to reuse *all* parts of a building. This point of view was argumented against by another participant: it is not obvious that the most sustainable thing is to reuse all parts for the same purpose as they are built. One could, for example, build five small houses of a large one without significant material or energy loss.

The question came up once more concerning what is special about *wood* construction. What should an indicator system steer towards when it comes to *wood* structures? What do we want to achieve in the development of wood buildings? Again, moisture safety came up as extremely important. If a building is erected in a moisture-proof way, this should give a higher rating in an indicator system that steers towards recyclable/reusable wood.

The question was raised whether the goal is that a building "*can* be disassembled" or "*should* be disassembled".

Continued use

It is better to continue to use a building than to dismantle it. How is design for adaptability considered in the indicator system?

Life span

The service life of parts and materials should be accounted for. How do materials change over time? How do we ensure properties over time? Sheet material, for example, should have lower grades than solid wood. If we want buildings elements to be reusable after 40 years, it is not a good idea to use material with a service life of 10 years.

Plausibility

At what cost should you plan for dismantling today? How much resources should we invest today to make a building demountable in the future?

Simplicity

It is incredibly important for the 280 Swedish municipalities that are small and do not have competence in house, that they have access to a simple system and get help in their assessment.

Information transfer

It is very important that information about the building remains within the building.

Qualitative or quantitative

The specific question of which is most valuable: a qualitative system (without grades) or a quantitative one, received different answers.

One opinion was that a quantitative system should be developed but that one needs to start with a qualitative one because it is too difficult to set grades. There will probably be government requirements that will mean that we will *have* to quantify.

A quantitative tool with grades and possibly a weighted "rebuilding factor" was seen as valuable in various ways. Partly because it can be used as a means of competition, to show that you meet requirements. Partly because in the grading, discussions are triggered and important choices are made.

Predefined grades were desired. This makes the questions / indicators more concrete and also starts good discussions. A quantitative system with grades can benefit a qualitative use.

When asked how to use and evaluate the results from a qualitative system, participants suggested that we look at work done within the roadmap for a climate-neutral construction sector in the city of Malmö, Sweden by 2030 (LFM30). Life cycle assessments (LCA) are done there that include the reuse potential (module D in the LCA analysis method). That work might give important insights.

Do we have the right questions / parameters?

According to some participants, readability is an important indicator. Still, in the exercise carried out in the workshop, it became difficult to assess how readable the system actually was. Participants argued that one should not exaggerate readablity by assuming that uneducated people will carry out the work when the building is to be dismantled. You always start from archived drawings etc. for conversions.

Economic factors and sustainability factors could be assessed separately.

3.4.4. How should we proceed to develop the tool?

Include property developers as stakeholders

It was suggested that we should seek feedback from those who are supposed to use used frames instead of new ones in the future. What would a property developer want to know about the material in a standing building in order to feel comfortable with using such material instead of using new ones? If we are to see buildings as “materials libraries”: what information do we want about materials in the library to be willing to use them? Such information should be gathered during the primary design process.

“Reuse documentation”

A “reuse documentation” should be created for each construction project. It would describe what to think about if you want to reuse parts of the building. All buildings are different and those who design normally know/develop a feeling for what would be easy to reuse for a particular object; what is natural for that particular building. The information is already available during planning. Reuse documentation could be an official requirement required for a building permit.

How should we test the tool?

1) Test against many different specific scenarios, type of building, different frame solutions.

The system should be tested on a large number of different buildings, which differ in scale etc. (eg detached buildings, apartment buildings, …) in order to be able to see which indicators should be included. Go from the specific to a wider image and then condense it down. A big job.

2) Test the system sharply

Case studies: look at houses that are being demolished now. See how the demolition material actually matches the grade the building would have received if the indicator system had been applied to it. However, it is difficult to evaluate buildings that were not planned for dismantling.

So far, we have looked at what you can do with an existing building. What is being demolished now is not built for dismantling and recycling. Things will change when you start building for disassembly from the beginning.

3.4.5. Revised tool

As a result from testing the tool in preparing the workshop and testing it with stakeholders in the workshop, it was clear that the tool needed a reformulation. To clean up the tool as a base for further work, a slight revision was made and descriptions and explanations for the first main category of the tool (Level 0 “Deconstruction”) were added. Weight factors were omitted. The revised part is shown Table 1.

Table 1 Revised indicators and explanations (below table).

Criteria	Indicator	Description	Score 0-2
TIME	Accessibility to components	Very low accessability	0
		Relatively good accessibility	1
		Good accessibility	2
	Separability	Joints cannot be disassembled without destroying the components	0
		Joints can be disassembled if special tools are manufactured or some minor damage from disassembly	1
		Joints can be disassembled with simple tools	2
	Cleaning	Considerable efforts needed to get components clean for reuse	0
		Some cleaning needed before reuse	1
		No cleaning needed before reuse	2
	Sorting / Standard dimensions	Components have measures that follow no standard	0
		Components have measures that are used in some places	1
		Measures follow a common, well known/often used standard	2
	Readability of the structure with regard to disassembly	Professional can not determine how system can be dismantled without significant preliminary investigation	0
		Professional can realize how the system can be dismantled	1
		Non-specialist can realize how the system can be dismantled	2
HANDLING	Tools and equipment for deconstruction	Special tools and equipment needed, severe costs involved	0
		Some special consideration needed	1
		Common and simple tools are enough	2
	Dimensions in relation to transporation	Exceeds normal transport limits and requires crane	0
		Keeps within normal limits for transport but requires crane	1
		Keeps within normal limits for transport and lifted without a crane	2
	Low weights and small sizes	Parts can not be carried / handled by humans.	0
		People can handle a single lift	1
		Can be carried / handled by humans	2
RISK	Sensitivity to damage	High sensitivity to damage: weather protection and/or special care necessary	0
			1
		Robust: no extra measures needed	2
	Personal safety	High risk for injuries (inhaling particles; falling, bad ergonomics, …)/or difficult or expensive/time consuming measures needed to handle risks	0
		Some risks, but can be handled with extra precautions	1
		No risks or can easily be handled with normal precautions	2
	Risk to the environment	There is a risk that toxic or harmful subjects are released in the deconstruction & reuse process	0
		Some risk	1
		No risk	2

Explanation and motives

Deconstruction

Purpose: measure how suited a design is for deconstruction. High score if well adapted to deconstruction

TIME

These aspects are assumed to influence time spent on deconstruction which will affect costs.

<u>Accessibility to components</u>

The indicator “accessibility to the components” should steer towards a design where building parts can be retrieved as easily as possible (and then reused). High score if for example: easy to reach and attach loops, easy to put a crane close to the building.
Separability
The indicator should steer towards designs that make it possible to disassemble joints with minimal damage to the parts and minimal time and energy consumption.
Cleaning
Reflects how demanding / difficult it is to clean the components from contamination/wear/sabotage (eg. graffiti) or surface treatments that might be expected.
Sorting / Standard dimensions
Components with modular or standard dimensions are advantageous. If the building's components can be used for several purposes, the chance increases that they will be used.
Readability of the structure with regard to disassembly
The indicator should steer towards designs where you can visually, on site, interpret how the system can be dismantled. High score if you can easily understand the load-bearing structure (what carries and what is carried) and see the location of nodes and what tools will be needed.

HANDLING/MANIPULATION
Tools and equipment for deconstruction
Design should be such that common and easily available tools are sufficient.
Dimensions in relation to transporation possibilities
This indicator must be investigated further. Should it steer design towards smaller elements that can be lifted by one person or towards larger element that can be lifted by a crane (which implies off site solutions).
Low weights and small sizes
This indicator must be investigated further as the same questions arise as for the previous one.
RISK MANAGEMENT
Sensitivity to damage (disassembled parts)
The indicator should steer towards components that are robust enough to withstand disassembly and transport.
Personal safety demolition workers
The indicator should steer towards building frames that can be dismantled and transported with minimal risk to workers. Risks may involve the risk of inhalation of particles from sawing or the risk of falling or other.
Risk to the environment
The indicator should steer towards a design where substances that are questionable or harmful to the environment are avoided.

3.5. Decision to proceed

It was decided within the InFutUReWood project that further development of the tool should be carried out, based on the interest from project participants and stakeholders.

4. Discussion

4.1. Reflections on results, methods and challenges

The aims of creating a draft version of a tool, test it with stakeholders, decide how to proceed and to engage people in knowledge development and experience exchange were reached and the methods used were efficient to that end. A tool was seen as valuable by stakeholders, to be used either as a basis for dialogue within a design process or for grading a completed design.

Nevertheless, the study showed that considerable work remains in order to reach a final verified tool and that methods could be improved.

Challenges identified included a need to clarify the choice of indicators and their definition and a need to provide support for discussions on a detailed level. These challenges suggest that it would be beneficial to base the tool on a commonly accepted and verified source, as the ISO 20887 standard.

Furthermore, for the draft version of the tool, assessment was complicated by the fact that indicators were open to interpretation.

The limited time (three hours) was not enough to get into detail on how to improve the system to that end.

As the tool was so far constructed, it was general to all materials rather than exclusive for timber buildings. Some of the workshop participants were motivated to learn more on the specific challenges associated with reuse of timber buildings and called for wood-specific advice. The limits of the study did not allow for an exploration of the value of a timber specific tool as opposed to a general tool.

Moreover, a systematic trial of other similar tools would have been useful. A comprehensive study (synthesis) on the specific subject of assessment tools, focusing on recent publications, was not feasible within the limits of this study and the literature survey that this work was based on was too broad and schematic for that purpose. Assessment tools were found on the internet, but their design was not found in published form and could not be critically reviewed.

4.2. Further studies

4.2.1. Two different tools to meet different needs

The workshop suggested that manufacturers saw a high value in an indicator system with predefined grades while architects seemed to find a guidance tool for the design phase favourable. The InFutUReWood project sets out to continue and develop both an indicator system and a design decision matrix.

4.2.2. Building an indicator system based on the ISO 20887

The standard ISO 20887 *Sustainability in buildings and civil engineering works — Design for disassembly and adaptability — Principles, requirements and guidance* makes it possible to formulate a tool based on extensive research and expertise. This will be a focus for the InFutUReWood project.

A compilation and test of already existing tools should be carried out, as it is not an end in itself to have a large number of tools. One motive for the InFutUReWood project to create its own tool is to ensure that results are relevant for the timber building industry. It has not though been examined whether already existing tools could be used.

4.2.3. Verify tools by following deconstruction processes in practice

Assessment tools should have grading systems that stimulates the development of building designs with members that are easily deconstructed and suited for reuse. To verify that the tool gives the right incentives, it should be examined if a design that gets a high score with an assessment tool behaves as expected in an actual deconstruction process.

4.2.4. Study of reuse in relation to building regulations

The question if reuse is plausible with regard to the pace of change in building regulations should be examined. Questions concern, for example, how elements such as floor cassettes are to be reused if acoustical demands are changed and how wall element can be reused if demands on energy efficiency are changed.

4.2.5. Follow the deconstruction of temporary market hall

It would be interesting to follow the deconstruction and reuse of the temporary market hall in Stockholm (Figure 9) and discuss how challenges and possibilities faced in the practical work accord with the intentions of the architects.

Figure 9 The temporary market hall during deconstruction in May 2021. The Swedish text on the sign says "Now we deconstruct the market hall and we give it a new life somewhere else." The sender of the message, Wallenstam, is the owner. Photo: Birgit Östman.

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ISO 20887:2020 *Sustainability in buildings and civil engineering works — Design for disassembly and adaptability — Principles, requirements and guidance*

Thormark, C. (2001). *Recycling potential and design for disassembly in buildings*. Lund Institute of Technology, Lund University, Lund, Sweden.

Träguiden: https://www.traguiden.se.

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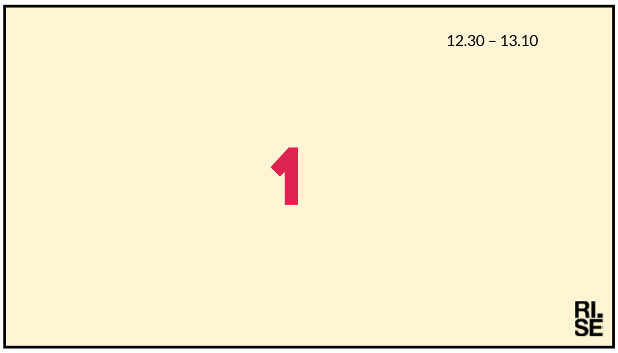
[1] InFutUReWood: https://www.infuturewood.info

[2] Questions arose on great many things. One example concerns if a large component is good or bad. One the one hand, if building designs with large elements should benefit from the grading, this would promote industrial off site processes. On the other hand, if designs with small elements would get benefits this would promote designs where components could be lifted and handled by people (without the use of a crane). It was out of the scope of this study to define indicators and scoring systems that can be verified to give designs with a minimal impact on the environment.

[3] Träguiden: https://www.traguiden.se (in Swedish).

Appendix 1



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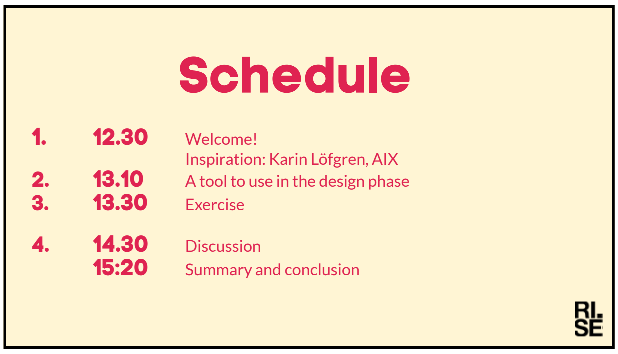

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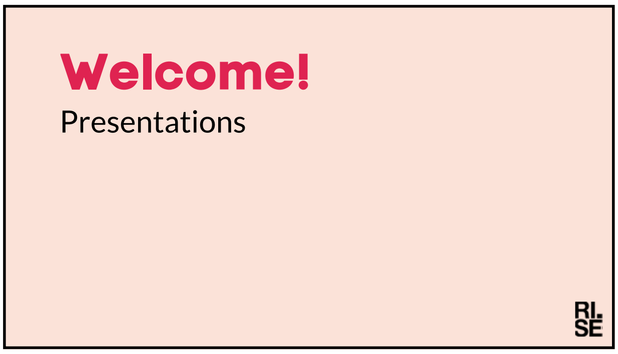

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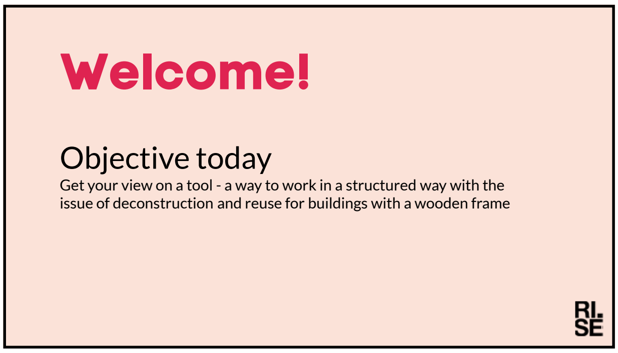

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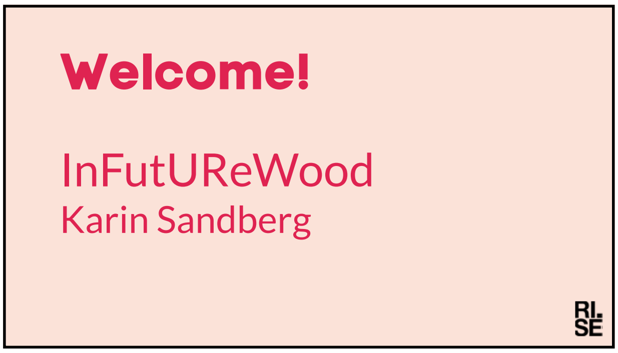


6

Welcome!

Some concepts

RI.
SE

7

Design for Deconstruction (DfD)

Design of the building so that the parts are easily dismantled and separated from each other for re-use or recycling.

Moffatt & Russel (2001)

RI.
SE

8

Reuse
...products or components are reused for the same purpose for which they were originally intended

EU 2008

RI.
SE

9

Recycling
... waste that has a useful purpose... replaces other material

EU 2008

RI.
SE

10

Design for Deconstruction
Design for Dissassembly
Design for Reassembly

RI.
SE

11

Kl. 12:40

Inspiration

Karin Löfgren, AIX arkitekter:
”Möjligheter med tillfälliga byggnader – hållbarhet och utveckling: Tillfälliga Saluhallen ett exempel på nudging... Och sen?”

RI.
SE

12

13:10-13.30

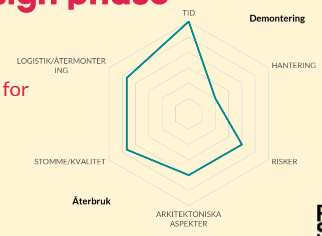
2

RI.
SE

13

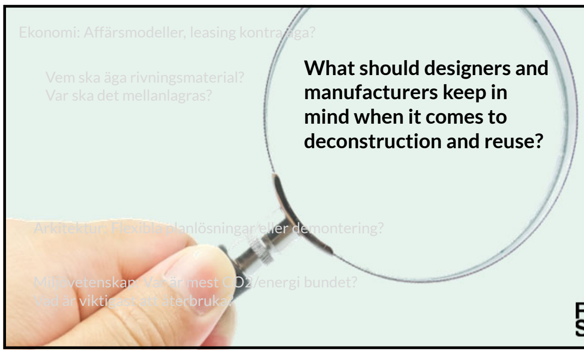
A tool to use in planning/design phase

– ”a checklist”
- a quantitative method for optimization



RI.
SE

14



Ekonomi: Affärsmodeller, leasing kontra äga?

Vem ska äga rivningsmaterial?
Var ska det mellanlagras?

What should designers and manufacturers keep in mind when it comes to deconstruction and reuse?

Arkitektur: Flexibla planlösningar eller demontering?

Miljövetenskap: Var är mest CO2/energi bundet?
Vad är viktigast att återbruka?

RI.
SE

15

How the tool was created

State of the art in research

- Crowther
- Hradil m. fl.
- Guy & Ciarimboli
- Thormark
- ---

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16

How the tool was created

State of the art in research

- Crowther
- Hradil m. fl.
- Guy & Ciarimboli
- Thormark
- ---

Important aspects that must be taken into account
”10 KEY PRINCIPLES OF DFD” etc.

Arranged thematically
Can be rated (?)

ARE NOT SPECIFIC, HOW SHOULD THEY BE USED?

RI.
SE

17

”10 KEY PRINCIPLES OF DFD”

1. Document materials and methods for deconstruction
2. Select materials using the precautionary principle
3. Design connections that are accessible
4. Minimize or eliminate chemical connections
5. Use bolted, screwed and nailed connections
6. Separate mechanical, electrical and plumbing (MEP) systems
7. Design to the worker and labour of separation
8. Simplicity of structure and form
9. Interchangeability
10. Safe deconstruction

Guy & Ciarimboli

RI.
SE

18

Relevant aspects for component reuse and building relocation

Minimise the number of different types of components
Use mechanical not chemical connections
Use an open building system not a closed one
Use modular design
Design to use common tools and equipment, avoid specialist plant
Separate the structure from the cladding for parallel disassembly
Provide access to all parts and connection points
Make components sized to suit the means of handling
Provide a means of handling and locating
Provide realistic tolerances for assembly and disassembly
Use a minimum number of connectors
Use a minimum number of different types of connectors
Design joints and components to withstand repeated use
Allow for parallel disassembly
Provide identification of component type
Use a standard structural grid for set outs
Use prefabrication and mass production
Use lightweight materials and components
Identify points of disassembly
Provide spare parts and on site storage for them and parts during disassembly
Retain all information of the building components and materials

Crowther, 2005

RI. SE

19

Tool = Checklist/ Indicator system

RI. SE

20

Deconstruction

TIME
- Accessibility to components
- Cleaning
- Sorting/Standard dimensions
- Readability of structure regarding deconstruction

HANDLING/MANIPULATION
- Tools and equipment for deconstruction
- Dimensions in relation to transporation possibilities
- Low weights and small sizes

RISKS
- Susceptibility to damage (disassembled parts)
- Human risks (workers health/injuries)
- Risk to environment

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21

Reuse

ARCHITECTURAL/DESIGN
- Documentation about design and maintenance – *reuse documentation*
- Adaptability (of building layout)
- Standardization level (shapes, sizes, elements

STRUCTURAL/QUALITY
- Ease of reassessment of structural properties (and damage)
- Overdesign/structural reserve for flexible repurposing
- Susceptibility to time effects (deterioration, excessive deformations)

LOGISTICS/RE-ASSEMBLY
- Repetitiveness (number of similar elements
- Similarity (variation of elements)
- Transportation (location remoteness

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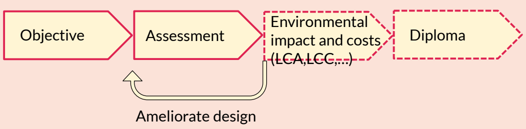
22



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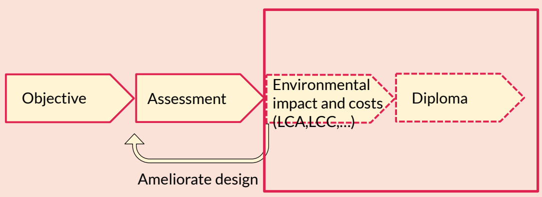
23

Might/should (?) be added.
Not in scope today



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24

1. Identify targets for reuse - formulate scenarios

2. Select scenario /-s

Objective → Assessment → Environmental impact and costs (LCA,LCC,...) → Diploma

Ameliorate design

RI. SE

25

1. Assess the design for each scenario. Rate the different aspects.

2. Use weights and sum up the weighted grades> Rebuilding factor

Objective → Assessment → Environmental impact and costs (LCA,LCC,...) → Diploma

Ameliorate design

RI. SE

26

Draft of tool, many questions:

Which indicators should be included?
Definition of indicators
Rating: predefined?
Rating relative what?
Rating scale?

Usage: who? when?

The benefit

RI. SE

27

Example

RI. SE

28

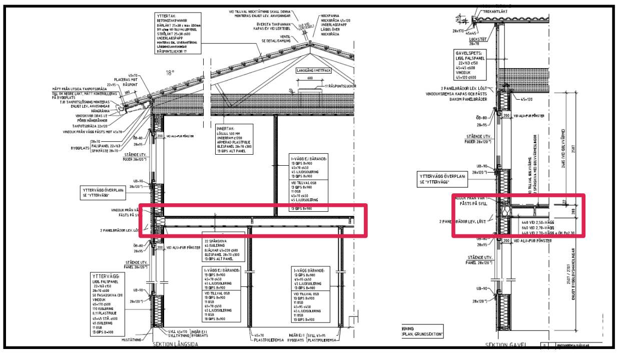
Scenario: You want to enable future **deconstruction** and **reuse** of the floor cassettes in Villa Anneberg.

What are the strengths and weaknesses of today's design?

Try using the indicator system to search for answers to the question.

29

30



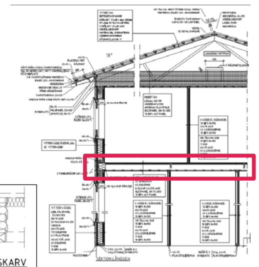
31

Deconstruction

TIME

- Accessibility to components [1]
- Separability [1]
- Cleaning [2?]
- Sorting/Standard dimensions [1? 2?]
- Readability of structure regarding deconstruction [1]

Joint with glue and skrews/nails



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	B	C	D	E	F	G	H	I
1	Betyg	Viktning	Nivå 1	Betyg	Viktnin	Nivå 2	Betyg	Viktning
2	1,417							
3			TID	1,25	1			
4						Tillgänglighet element	1	1
5						Separerbarhet	1	2
6						Rengöring	2	1
7			HANTERING	1	1			
8						Verktyg och utrustning	1	1
9						Låg vikt och små storlekar	1	1
10							0	0
11			RISKER	2	1			
12						Känslighet för skada vid demontering	1	1
13						Risk för personskada (rivningsarbetarnas hälsa)	2	1
14						Miljörisker	3	1
15								
16								
17	1,778							
18			ARKITEKTONISKA A:	1,333	1			
19						Dokumentation avseende utformning och underhåll	1	1
20						Anpassningsbarhet (planlösning?)	1	1
21						Standardisering/modulanpassning (former, storlekar, element)	2	1
22			STOMME/KVALITET	1,667	1			
23						Möjlighet att bedöma den lastbärande strukturens egenskaper	1	1
24						Överdimensionering/reservkapacitet för flexibel användning	2	1
25						Känslighet för tidseffekter (nedbrytning, stora deformationer)	2	1
26			LOGISTIK/ÅTERMON	2,333	1			
27						Repeterbarhet (antal liknande element)	2	1
28						Likhet (variation hos elementen)	3	1
29						Transport (avlägsen plats)	2	1

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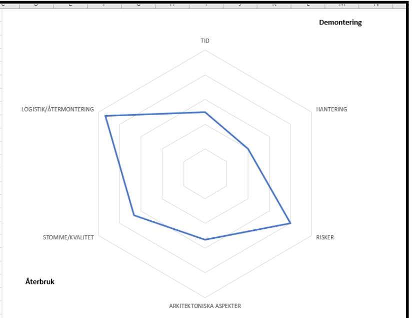
33

TID	1,25
HANTERING	1
RISKER	2
ARKITEKTONISKA ASPEKTER	1,333333333
STOMME/KVALITET	1,666666667
LOGISTIK/ÅTERMONTERING	2,333333333



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13:40-14.10

3

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35

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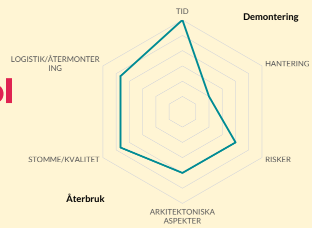
Exercice: Test the tool



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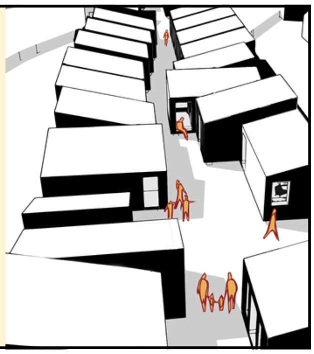
Scenario:

You want to enable future **deconstruction** and **reuse** of floors, walls and roof of the PEOPLE HIGH SCHOOL OF NOMADIC CYBORGS.

What are the strengths and weaknesses of the proposed design?

Try using the indicator system to search for answers to the question.



37

Scenario

The **entire building** will be dismantled, moved and reassembled in another location in 40 years.

What are the advantages and disadvantages of the design for **this scenario**?

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Instructions

1) USE THE SYSTEM AS A CHECKLIST - DISCUSS THE DIFFERENT PARAMETERS

2) RATE 1-3 (IF POSSIBLE)

1 = Failed
2 = Approved with potential for improvement
3 = Best possible solution

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The building

Tommy Vince

RI. SE

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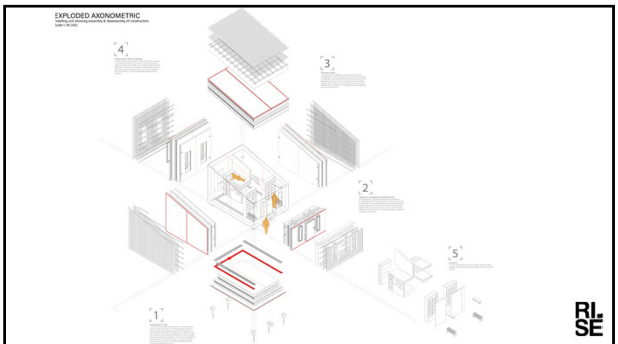

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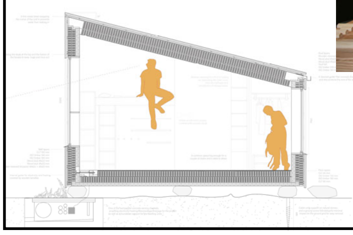
Element av: ---
Mått: ---
Hopfogningar: ---



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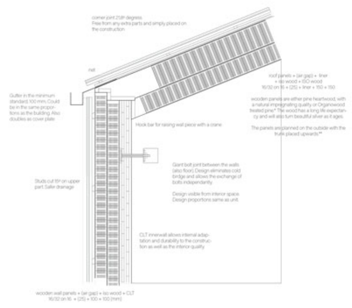

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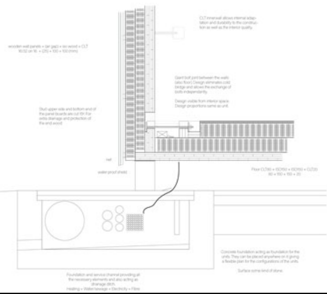

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Exercise

Breakout rooms

Secretaries represent InFutUReWood partners

1: Derome
2: Isotimber
3: Svenskt trä
4: Svenskt trä

45

Welcome back!

46

14.30-15.30

4

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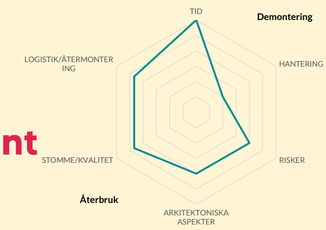
Discussion:

Usefulness
Usability
Development



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Usefulness & Usability

- In what way can the tool be useful / valuable to you?
- Who else can use it?
- How and in what situation can you use it?
- How would you like to develop the tool?

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Development

- Which is more valuable: a qualitative system (without grades) or a quantitative one?
- If quantitative: should the tool have predefined values?
- If qualitative: how to evaluate the result? How to use it?

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50

- Do we have the right parameters/indicators?
- How should we test the tool?

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SE

51

Summary and conclusion

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52

How do we proceed?

- Topic for the next ws?
- Suggested case study?

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Thank you!

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