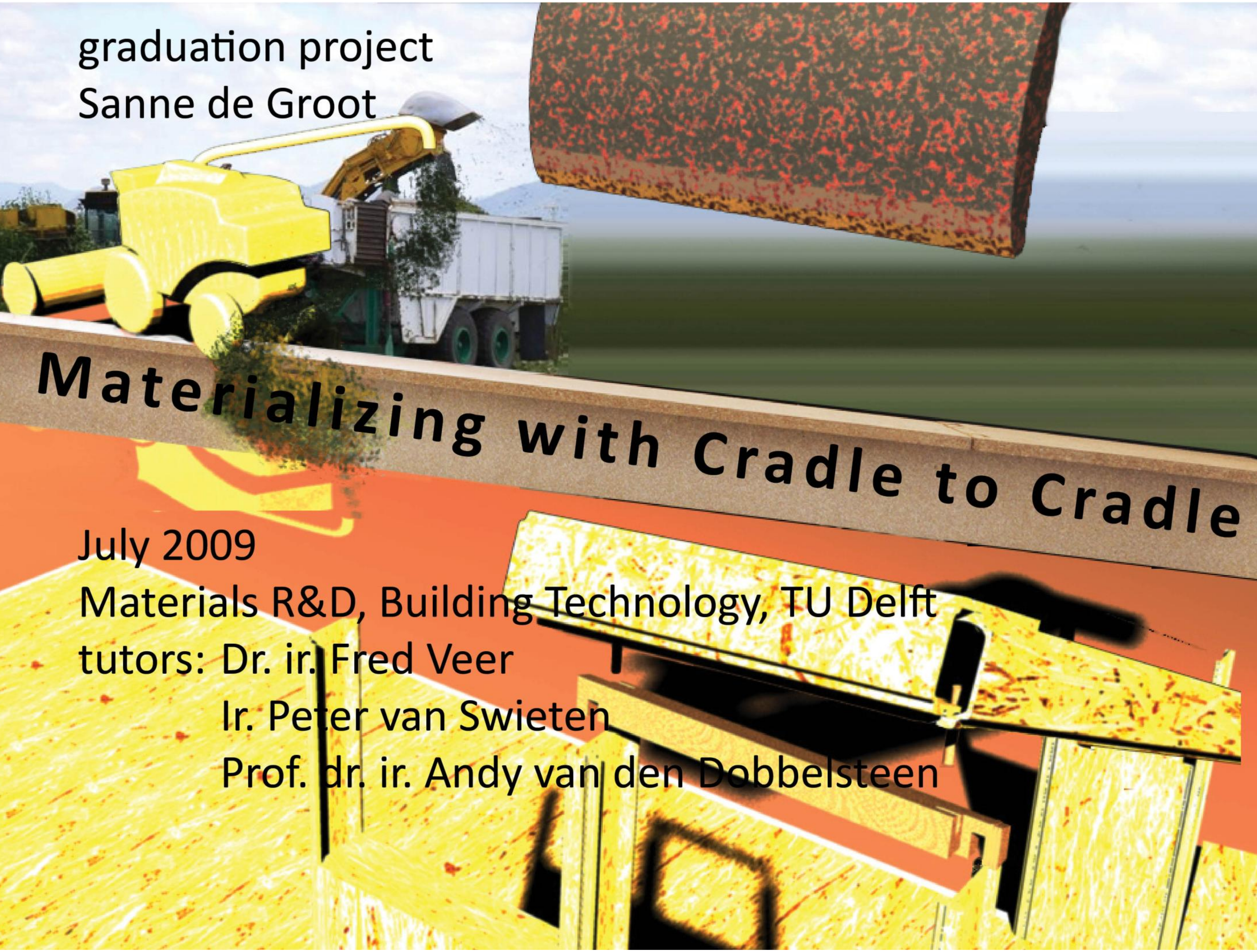


graduation project
Sanne de Groot

Materializing with Cradle to Cradle

July 2009

Materials R&D, Building Technology, TU Delft
tutors: Dr. ir. Fred Veer
Ir. Peter van Swieten
Prof. dr. ir. Andy van den Dobbelsteen

preface

This is a graduation project for Materials Research and Design at the TU Delft with an appendix on Technology in Sustainable Development. The Materials Research and Design lab is part of the department of Building Technology at the faculty of Architecture.

Possible subjects I came with in the beginning of the graduation project included a sustainable resort for Easy Sport and this Cradle to Cradle assignment.

I would like to thank my main tutor dr. ir. Fred Veer for not getting lost from the main subject. Also ir. Peter van Swieten for his critical attitude. And not the least prof. dr. ir. Andy van den Dobbelsteen for the push in methodology. Delicate of the exam committee Susanne Pietsch helped me show the relevance of my design. Following the symposia Cradle to Cradle in de Polder and a piece of SASBE with Michael Braungart helped me with some definitions and tools to structure things. Finally my parents, other students and interested people were there for feedback.

Companies that are involved are the NIBE in Bussum that made the conceptual design. So thank you for trusting the elaboration of this design to me and maybe use it for the final design. There has not been any contact between me and the client for the design, the Meerlanden. Their request for a Cradle to Cradle building has been a major input in this project what I am thankful for. And BCA-Boards is a company that distributes straw boards that cooperated with supplying the material for the straw FJI-beam prototype.

abstract

For a truly sustainable society the Cradle to Cradle guidelines are a useful guide. Different technical and bio materials are integrated in design options. System designs are compared with a Life Cycle Assessment. To test innovative constructions some prototypes have been made and are tested for strength and deformation. Outcome is an extruded kenaf core tube. This fast and harsh growing crop can be manufactured in a constructive material and composted at the end of the use.

Content

1 introduction

This report is part of the graduation lab Materials Research and Design. The aim of this lab is to apply an innovative material on the biggest scale possible. Designing a prototype with this material is the main challenge. Also building a prototype and testing this on its properties is part of participation of this lab. The ZAPPI research program at the TU Delft is testing innovative building materials like glass, cardboard and Grancrete. This making and testing of prototypes in this project is not intended to certify a product for the market but is more the validating and improving of innovative concepts.

The design used for this graduation project was made by the NIBE. It is a Pavilion for the waste processing company the Meerlanden (see figure 1.1). Earthship (Reynolds 2000) elements are applied in the design with regard to the Dutch climate. Materials are available within several kilometres like the waste flows handled by Meerlanden.

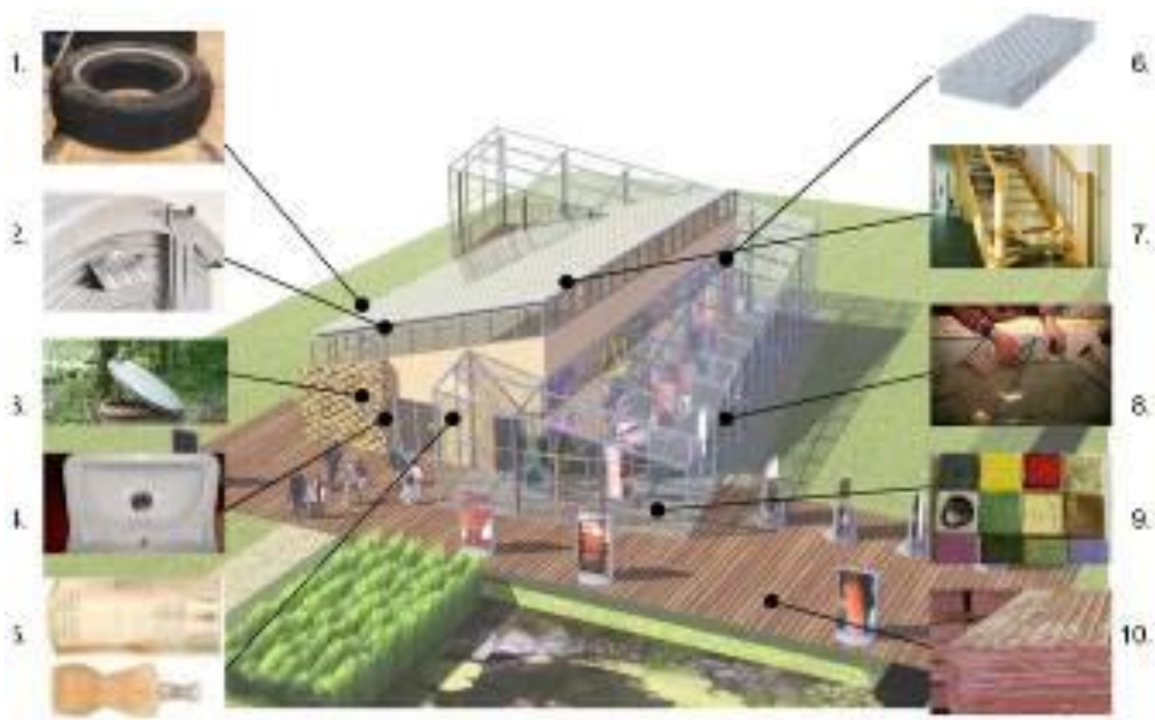


Figure 1.1, illustration pavilion the Meerlanden from NIBE

A request from client the Meerlanden was to integrate the Cradle to Cradle philosophy in the design for the pavilion. This would fit to their ambition to transform from waste processer into a material supplier. A pavilion that could be made from waste streams would be the perfect scenario.

The first step of Cradle to Cradle is to make a truly closed material cycle. Building with a closed cycle will be needed to stop depleting resources. Biodegradable or reusable buildings are also an advantage in the future to make demolishing abundant. The second step is to minimize environmental impacts with a LCA calculation. These two steps are a little contra-dictionary: a drive to enlarge the footprint against a drive to reduce it.

Figure 1.2, human and elephant footprint, source: Flick, user Matt.

The question with most environmental streams is if they really would result in a sustainable society. Also Cradle to Cradle still isn't perfect yet. If a product is 99 percent Cradle to Cradle there are still unsustainable effects . It is only less bad! In the future only a society with no waste will be sustainable. If that future without waste is really possible than it makes sense to start going there although it will not be perfect yet. This report investigates how far one could go with Cradle to Cradle.

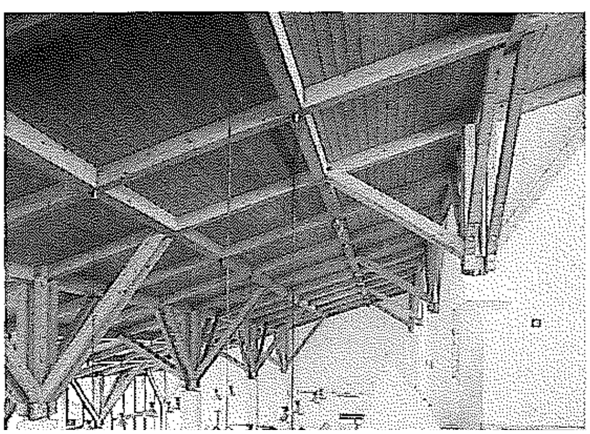


Figure 1.3, wood construction in Holzbau Atlas

2 theory Cradle to Cradle

2.1 philosophy

Cradle to Cradle strives to a material cycle with no waste. The qualitative, eco effective approach gives a new look on our way of life. The difference with other “sustainable” philosophies is the drive to be totally good instead of less bad. Contra dictionary to Life Cycle Analysis design that is minimizing environmental pressure, Cradle to Cradle design strives for zero environmental pressure. Also harmful effects on human health must be abolished. For example formaldehyde emissions and radiation can be reduced with choice of materials.

Problems are material down cycling and energy use. Energy use can be theoretically solved with the enormous power available from the sun. If we continue down cycling materials they will become scarce. So we must avoid mixing them to useless substances that can only be incinerated and thrown away. Energy is not available unlimited yet. So energy use must come from sustainable sources as much as possible.

2.2 measuring and labeling

The qualitative approach of Cradle to Cradle is not unique. Industrial Ecology would be a term with a similar meaning. Other qualitative labels range from social to health and environmental aspects. C2C is a corporate trademark of MBDC. This means that C2C certification will always be in collaboration with them or a partner organization

Figure 2.1, Cradle to Cradle logo

Because Cradle to Cradle certification© is based on qualitative criteria, judging is difficult. Especially with unknown materials and involved parties. Also a weighting factor of different criteria is not determined. A product can only be labelled convincingly if it meets all the criteria that are required for that label.

Cradle to Cradle products can be labelled of basic, silver, gold or platinum (Braungart 2002):
Basic requires:

- assessment of environmental effects.

Silver means all basic measures and:

- production takes environmental effects into account.

Gold means all silver measures and:

- material cycle is totally closed for recycling or composting.

Platinum means all gold measures and:

- all social and environmental problems are solved.

With different methods popping up to design in a C2C way, the next paragraph will attempt to give an overview over the different scales.

2.3 building design

Realized buildings with Cradle to Cradle mainly focus on the building use. This is logical with a short payback time and large savings. The methodology for water and energy design is developed in Park 20|20 in Hoofddorp. Here, a 7 step approach was introduced.

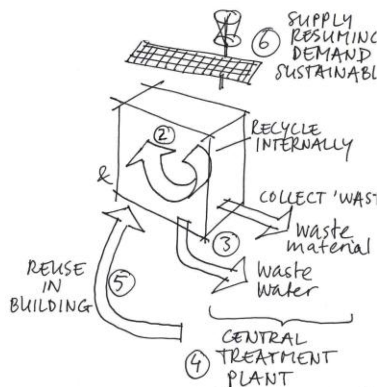


Figure 2.2, The 7 steps for water, energy and materials:
1. demand reduction
2. direct recycling
3. transport to central facility
4. treatment in central facility
5. transport to buildings
6. sustainable output
7. sustainable input
(Dobbelsteen and Grinten 2008)

But material flows on the longer term are also essential to preserve them for future generations. Materials used in existing Cradle to Cradle buildings have no toxic ingredients. Also materials with a bad environmental impact are banned (like PVC, cadmium, lead and chlorine). Except the photovoltaic solar collectors. The Cradle to Cradle Protocol says that in the next step as much as possible materials from a green, positive list can be used. Of course this selective approach makes the design economically competitive. But for a true revolution there will have to be a design with ONLY green materials.

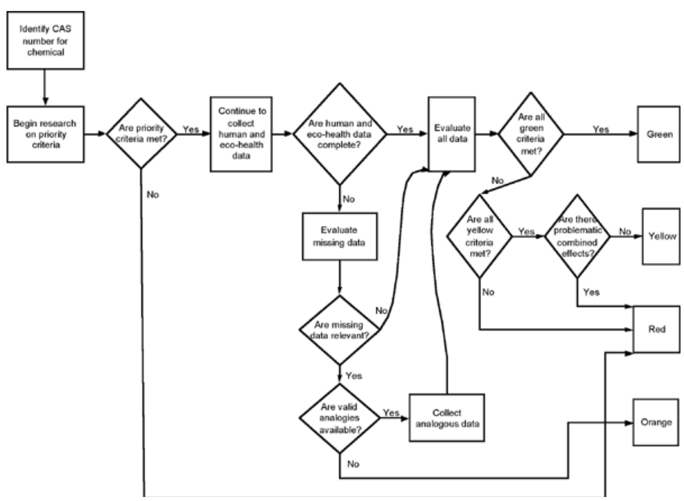


Figure 2.3, preliminary assessment MBDC's Material Assessment Protocol (McDonough 2003)

The final step is to make the building improve its surroundings like cleaning water, air and soil. Also urban tools are developed with the Almere Principles (Oost 2008).

2.4 materials

Different biological and technical materials can be Cradle to Cradle. They must be able to separate to recycle them. That is why hybrid materials are not discussed here.

Figure 2.4, different wood beams

2.4.1 wood

Wood is known as building material for a long time. This means there is much experience with details and applications. But the properties and size are not always competing with modern materials. So the characteristics of the material have to be taken into account in the design. Especially shrink caused by moisture and temperature variations can determine the joints. The shrink is not equal in the fiber direction and perpendicular to it which can cause tolerance problems.

Natural materials like wood need little energy input in comparison to steel or concrete. They can also be part of a closed material cycle. The figure below shows the small cycle of component reuse and larger cycle for renewables. This is not complete yet because there are also waste flows from harvesting, processing, construction and building use.

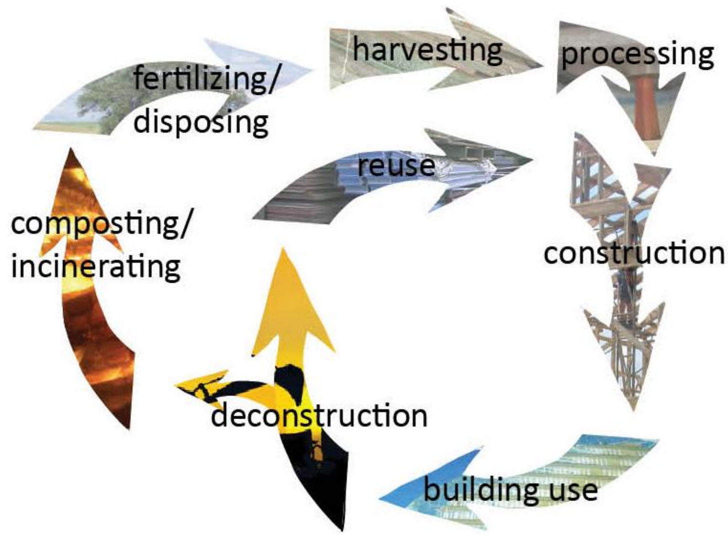


Figure 2.5, scheme of possible life cycles of wood

2.4.1.1 solid wood

Soft and hard wood can be harvested by cutting trees. The natural origin limits the dimensions. Long and high wood beams will warp, twist and split. Especially using the heartwood in the middle will cause splitting when the wood is being dried.

Figure 2.5, wood parts from a trunk, source: Houtwijzer Naaldhout

2.4.1.2 wood fiber board

Leftovers from the solid wood can be chopped into fibres and compressed into board.

During the wet manufacturing procedure there are no extra glues needed. The lignin from the wood itself can bind the fibres together to soft board.

After use the board can be used in the same process to make new board. This can be regarded as downcycling because the fibre size reduces. But is not a problem from a C2C viewpoint because it is part of a cycle that can be composted or incinerated.

Figure 2.6, wood fiber board in a closed cycle, source: www.ecologischbouwen.be

2.4.2 cork

This material is known as whine-stopper in bottles. Harvesting is from the Cork Oak tree. Over 50% of the worldwide production is in Portugal. Other products from cork are floor tiles, expanded insulation, bricks, musical instruments, baseballs and rockets for its fire safe properties.

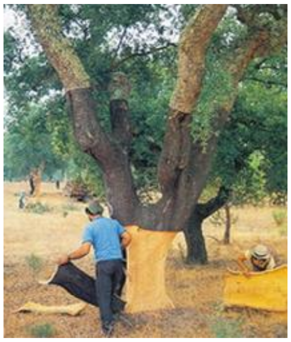


Figure 2.7, harvesting of cork from cork oak, source: www.vinckier-nv.be

A tiny fraction is being reused after deconstruction. If reuse is taken into account in the design this could be increased. Down cycling is also possible with chipping and binding it together to plates again.

2.4.2.1 expanded cork

Expanded cork boards are used for insulation where a compression strength is needed like on flat roofs.

Production exists of chipping the cork in pieces and expanding them together with steam. During this process the cork releases suberin that binds the board together.

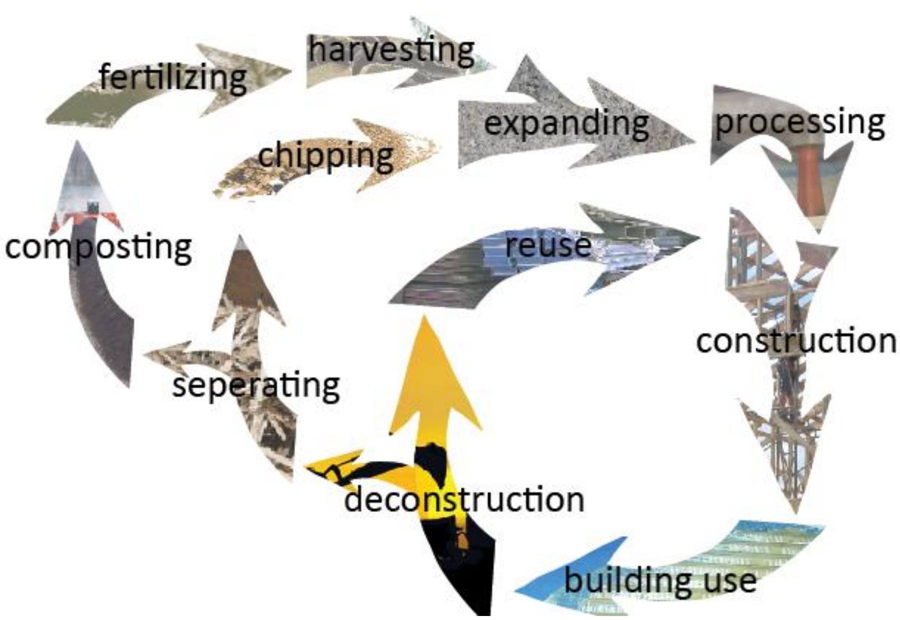


Figure 2.8, scheme of possible life cycles of cork

2.4.3 straw

Straw is left over from the production of wheat. It can be used as a building material in the form of bales or compressed board.

2.4.3.1 straw bales

There have been built a lot of ecological homes with straw in the last decades. Bales are mostly used as outside walls. They act as enclosing and insulation. Structural use is also possible.

Figure 2.9, application of straw bales in the *Santa Clarita Transit Maintenance Facility designed by HOK , source: .inhabitat.com/2007/10/25/hoks-leed-gold-certified-straw-bale-building*

2.4.3.2 straw board

Boards can be used for covering wood frames. BCA-Board is a brand for wheat straw board. It is produced in Indonesia for lower material costs. This of course means an ecological impact from transportation. Despite this transport issue, a study from the NIBE shows that BCA-Board is one of the most eco friendly boards in the Netherlands (Haas 2008).

Figure 2.10, production of straw board, source: stramit-int.com

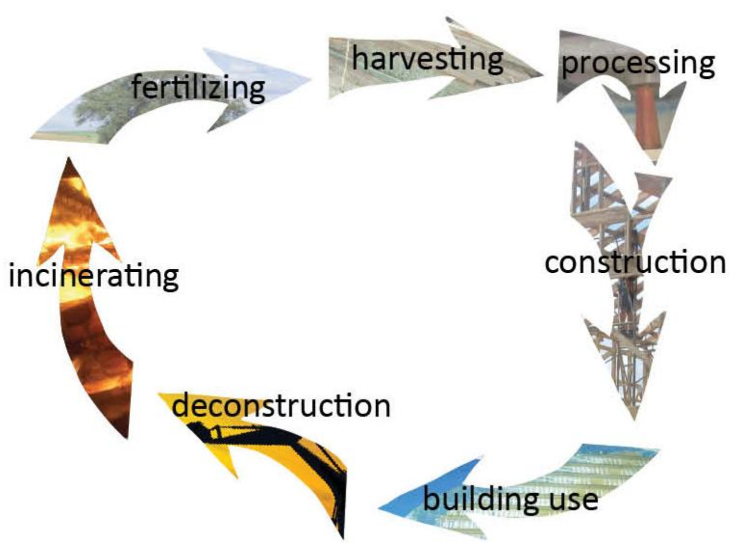


Figure 2.11, scheme of possible life cycle of straw board

2.4.4 reed

Reed can be harvested from water sides. Reed is still being used for roof covering. Modern buildings have a wood underlayment to reduce risk of fire and increase the air tightness.

Figure 2.12, thatching reed, source: www.riet.com

Figure 2.13, Modern building with reed roof, source: www.riet.com

With a minimum roof angle of 45 degrees the roof will stay good for 25 year but in most cases 35 year.

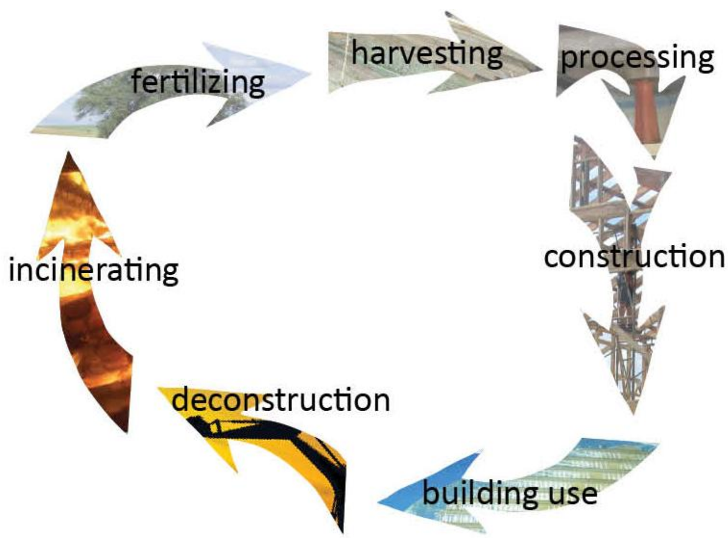


Figure 2.14, scheme of possible life cycle of reed

2.4.5 natural glue

People are using natural glue for thousands of years. Ingredients are derived from animals, milk or plants. Properties of glue are depending on the quality of the ingredients. Chemical tests of moisture and ash are tested on the laboratory. Other chemical on natural glue are seldom made. The reason is that they do not give any trustworthy ideas as to its practical value and are too time consuming (Alexander 1923).

The invention of synthetic glues in the 20^{th} century often replaced natural glues for its water resistance. Disadvantages of the containing formaldehyde are health effects as a carcinogen and that it is not part of a closed cycle.

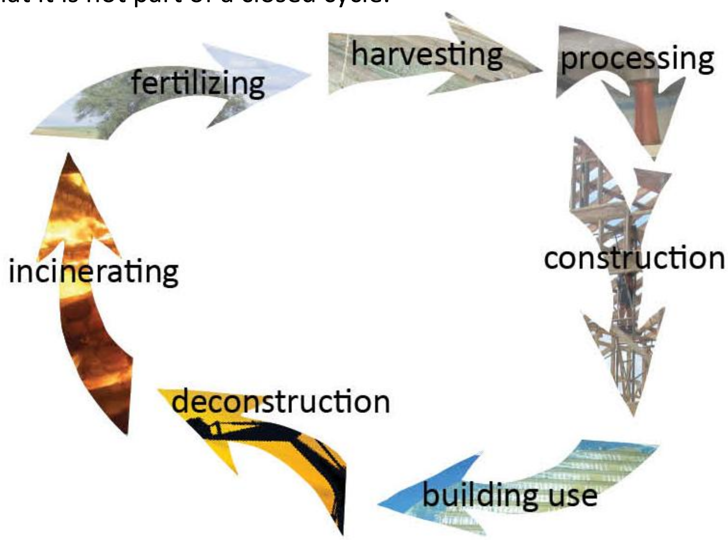


Figure 2.15, scheme of possible life cycle of natural glue

2.4.5.1 animal glue

Animal glue was the most common woodworking glue for thousands of years. It is created by boiling animal connective tissue. Hide glue is derived from animal skin. Today it is used primarily in special applications such as lutherie , pipe organ building, and antique restoration. Glass artists take advantage of hide glue's ability to bond with glass.

It has several advantages and disadvantages compared to other glues. Hide glue is delivered in granular state. Once mixed with water the protein will deteriorate so the maximum time to store the mixed glue is a few days. A thin substance will cause a longer drying time while thick glue will set quickly. The glue is soluble in water, useful for joints which may at some time need to be separated (Courtnall and Johnson 1999). The glue is applied around 60°C, typically with a brush or spatula. This also means that high exposure to heat or moisture must be avoided.

Hide glue joints do not creep under loads so they will not deform under heavy loads like PVA glue. Hide glue is supplied in many different gram strengths, each better suited to specific applications. Instrument and cabinet builders will use a range from 120-200 gram strength. This is stronger than the wood itself so the glue is not the weak point[1].

[1] In Wikipedia. Retrieved March 16, 2009, from: en.wikipedia.org/wiki/Hide_glue

Figure 2.16, Hide glue at room temperature, source: en.wikipedia.org/wiki/Hide_glue

2.4.5.2 casein glue

Casein glue was already used by the Egyptians for woodworking. It is made by dissolving casein, a protein obtained from milk, in an alkaline solvent such as vinegar. In contrast to animal glue it can be applied cold.

In wood bonding, casein glues generally are superior to true animal glues in moisture resistance and aging characteristics. Casein also is used to improve the adhering characteristics of paints and coatings. Casein adhesive deteriorates over the years after exposure to moisture in the air and temperature variations. [2]

Figure 2.17, Casein glue, source: socksandbooks.blogspot.com/2009/01/

2.4.5.3 starch

Starch is a white, granular, organic chemical that is produced by all green plants. Starch is a soft, white, tasteless powder that is insoluble in cold water, alcohol, or other solvents.

Adhesives are extracted from corn, wheat, potatoes, or rice. They constitute the principal types of vegetable adhesives, which are soluble or dispersible in water and are obtained from plant sources throughout the world. Starch and dextrin glues are used in corrugated board and packaging and as a wallpaper adhesive.[3]

Figure 2.18, Starch, source: Wikipedia.org

Corrugated board, Wikipedia.org, Pjetter

[2] In Encyclopædia Britannica. Retrieved March 16, 2009, from Encyclopædia Britannica Online: www.britannica.com/EBchecked/topic/97862/casein-glue

[3] In Encyclopædia Britannica. Retrieved March 16, 2009, from Encyclopædia Britannica Online: www.britannica.com/EBchecked/topic/563582/starch

2.4.5.4 soy

Some resins are derived from soy beans, a crop that is already grown in large quantities. Soy resin is not used in large quantity yet but it has good prospects. The poor water durability of many soy-based adhesives is primarily due to a limited amount of cross linking in the cured adhesive. A more cross linked structure should improve bond durability under wet conditions.

Figure 2.22, soy glue in particleboard and laminated wood, soynewuses.org

A test with inexpensive soy flour (SF), polyethylenimine (PEI), and maleic anhydride (MA) has shown that mechanical and moisture properties exceeded the requirements for interior applications (Huang and Li 2008).

2.4.6 other natural materials

Also other materials from plants and animals can be used for wire, insulation, construction or finishing. For example cardboard can be made from natural glue and wood fibres.

Figure 2.23, Byumba Refugee Camp and Paper Log Houses by Shigeru Ban, source: *shigerubanarchitects.com*

Agricultural fibres like hemp, flax and kenaf consists of bast like branches that are widely groen for fibres in rope or textiles. The hard core can be compressed to insulation blankets or even structural panels.

2.4.7 steel

There can be made economical beams with steel. This is possible since the industrial revolution.

Steel producers promote their material as a Cradle to Cradle material because it can be recycled.

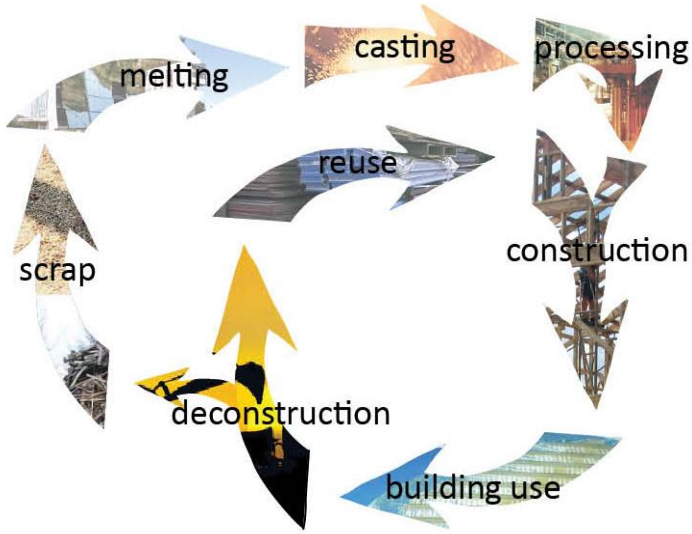


Figure 2.24, scheme of possible life cycles of steel

The biggest problem is the energy use for melting the metal to poor it into a new shape. A solution to reduce the energy use could be to melt steel with concentrated solar power. Also making a design that allows reuse will increase the lifetime of the steel elements so there is reduced energy need.

Figure 2.25, melting steel with concentrated solar power, source: www.geeksaresexy.net

2.4.8 polymers

Some plastics are recyclable such as PET bottles. There are also some Cradle to Cradle gold certified polymers.

2.4.8.1 Eco Intelligent® Polyester

Victor Innovatex, Inc has developed this fabric for seating, and panel. It is antimony free so it contains no heavy metals.

2.4.8.2 asphalt

The black substance in roads is not a certified material but can be recycled. Virgin bitumen material comes from oil refining leftovers. The bitumen is often used as roofing material and could be recycled for the same purpose.

Asphalt concrete has properties between asphalt and concrete. This open opportunities for structural use. C-fix from Shell for example is being used in coastal reinforcement and plumbing.

2.4.9 other technical materials

Alloys like aluminium are composed from different metals and have often superior properties. Recycling alloy scrap will mean mixing it to a gray mass. Wrought aluminium has more magnesium than most cast alloys allow. Removing the magnesium from the melted aluminium is expensive. So a separation of different alloys before melting them together is the best way to recycle it into the same quality.

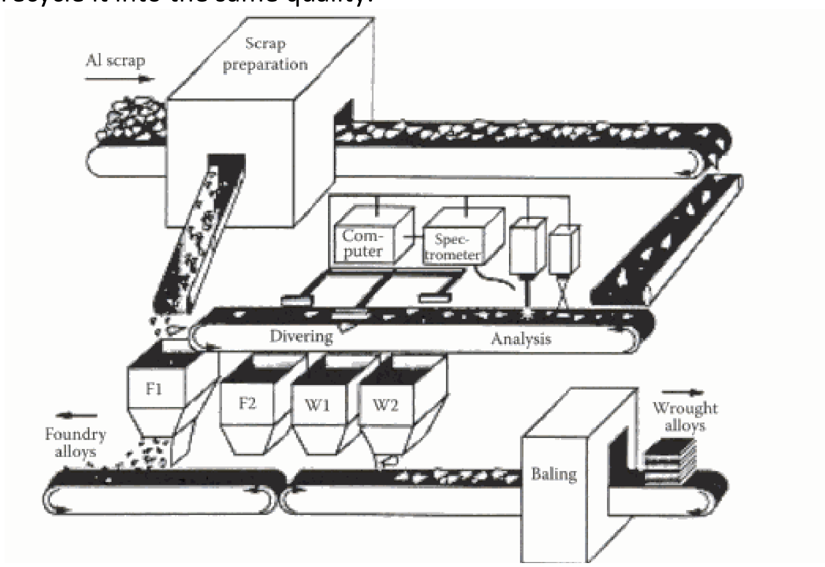


Figure 2.26, separation of wrought and cast aluminium alloys.

Coatings like zinc can be removed thermally or chemical and electrolytic ally (Rao 2006). Organic coatings like paint can be burned off from metals. Only non organic components like TiO_2 will remain and pollute the metal (Schlesinger 2006).

A combination of steel with biological materials is possible because the steel can be separated because with its magnetic properties. This makes it possible to close the circle.

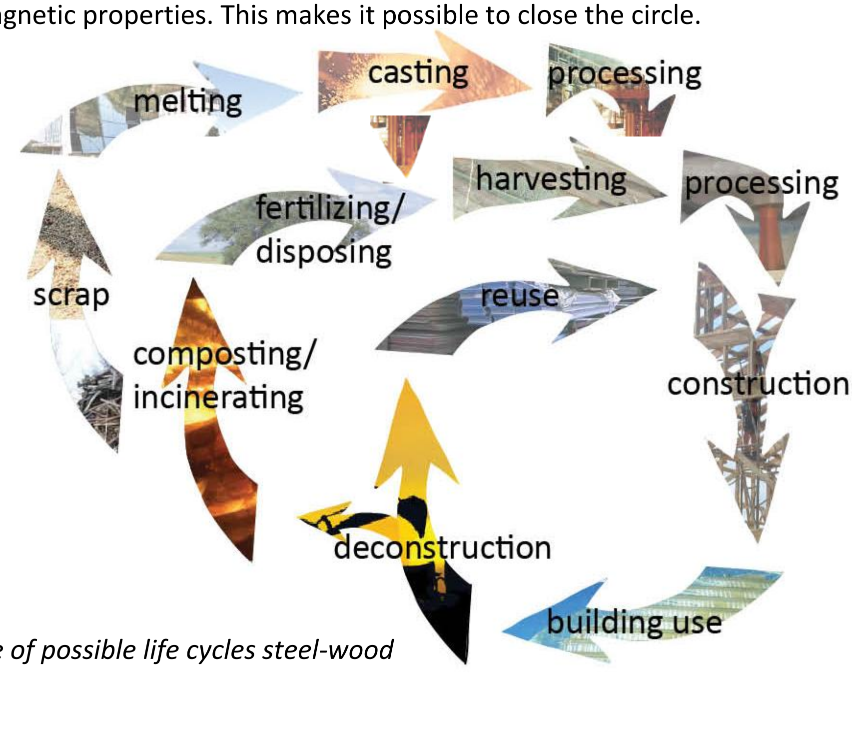


Figure 2.27, scheme of possible life cycles steel-wood

3 criteria

To reach the required level, there are some criteria that have to be met. These design and practical considerations will not be complete so common sense is also needed. The main purpose of the criteria is for evaluation of the end result.

3.1 functions

3.1.1 comfort

Main room temperatures and draft will be maintained for non residential use.

3.1.2 acoustics

For the outside walls a sound insulation of 20 dB will suffice.

3.1.3 fire

Constructions with all floors under 5 meter above ground level have no specific requirements.

3.1.4 humidity

Strength of constructions is sometimes depending on the moisture content. The relative humidity of the room is normally 10-20%. If there is a vapour transfer trough the construction because of a difference with the moisture pressure outside there can be a higher relative humidity. This can be controlled with damp barrier paper on the inside of the construction.

3.1.5 deformation

Deformation has to be reduced for visual and tolerance reasons.

3.1.6 strength

The construction has to follow Dutch regulations in NEN 6702/6760.

3.2 design

This paragraph is based on the design by NIBE. Only insulation values are determined here.

The main box measures 16 x 9 meters. The height and place of the windows can be read in figure 2.1. A dotted line means that another construction is connected there. The main box measures 15,4 x 8,4 meters effective floor space. The internal height of the sloped roof is 2,9 to 5,9 meters.

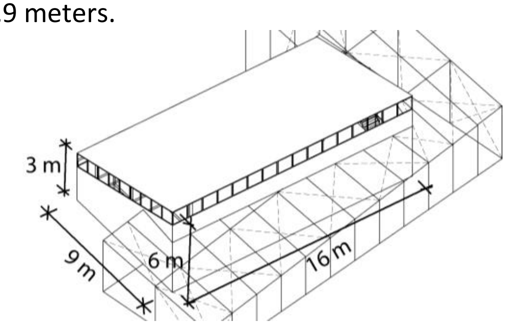


Figure 3.1, vertical section

3.2.1 building parts

3.2.1.1 roof

The roof must not be very dominant and almost floating above the strip windows. Thickness of the roof should therefore stay below 500 mm.

3.2.1.2 wall

Walls support the roof and have few openings for light and entrances. Surfaces can be used to exhibit reused materials like car tires and mattresses.

3.2.1.3 floor

The ground floor could span the total width of the building or rest on the ground. Low temperature floor heating can be integrated.

3.2.2 energy

Heating in winter could be solved with waste heat from a nearby composting facility. This is good in combination with low temperature heating in the floor. Ventilation can be natural with openable windows and grills. Mechanical extraction is possible at toilet and kitchen.

Insulation value of the heated room can be based on payback time of environmental and direct costs. An increase in stone wool insulation thickness of 150 towards 200 mm pays itself back in 5 years. So this insulation value of 5 W/m^2K can be defended in both economical and environmental perspective.

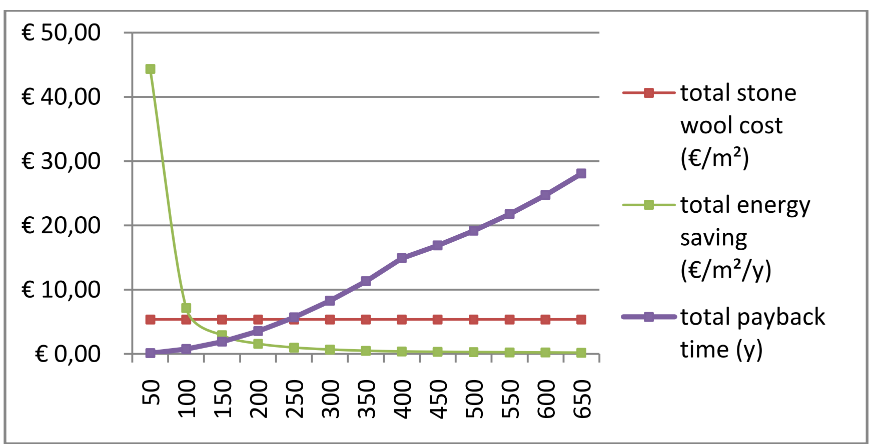


Figure 3.2, total material cost, energy saving and payback time at the time of June 2009, source stone wool cost: GreenCalc+, source energy saving: Consumentenbond.

Openings have a maximum heat transfer of 0,7 W/m^2K. Insulated window frames and triple glazing can reach this.

3.2.3 water

Rain water is stored for toilet and cleaning use. The resulting black water can be put in a helophytes pond to clean it. The water quality from helophytes filter is clean and without smell.

3.3 Material selection

The ambition is to integrate Cradle to Cradle as much as possible in the design. If possible the materialization will give a positive influence on its environment like a symbiosis.

Figure 3.3, This Dracaena Fragransv plant cleans the air. For a living area of 200 m^2 are 15 plants sufficient to remove harmful substances according to (WOL1996).

The best label of Cradle to Cradle certification, Platinum, would need involvement of all involved parties and is not relevant at this stage. Gold certification requirements are possible with material selection and designing with closed cycles on 100 parts per million. The Certification Program has under Gold criteria the following criteria that are relevant to a building design:

1 Health danger and environmental effects are minimized.

> This could be reached by applying only natural or technical materials. The second step is to minimize energy input and other negative effects. Variants can be compared with a Life Cycle Analysis. These hidden environmental costs can give an objective view.

2 Reutilization score during construction and demolition is at least 65.

> So materials should be able to be recycled or composted for reutilization.

3 At least 50% of energy use comes from the sun.

> A more practical criteria is to meet Passiv Haus standard (Fingerling 2004).

4 Water should leave the building cleaner than it enters it.

5 Ethical codes available and fair treatment of people involved.

3.4 boundary of research

Considerations from maintenance, building physics and other practical aspects will be part of considerations but are not the main subject. Following from the assignment this research will focus on the research of a material. This also includes material selection and design of the testing prototype.

Selection will be limited to the assignment of an innovative design.

Figure 3.3, breaking glass

As can be seen in the learning plan, ribs are the preferred overall structure for this design. This limits the amount of possible alternatives in this report.

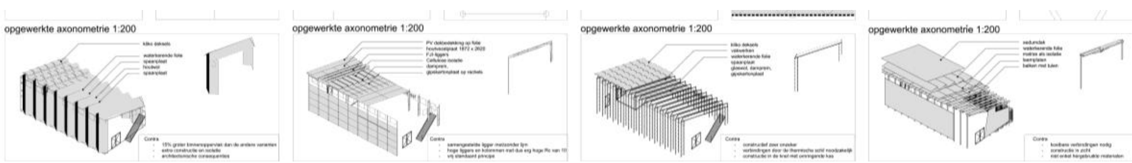


Figure 3.4, comparison of curved, rib, truss and tension alternatives at the P2 in attachment 1.

Not part of this research is to detail the entire building with types of finishing. The glasshouse part will not be detailed; it will only be taken into account for its load on the construction. Also building services will not be chosen. A possibility is to use waste heat from the nearby composting facility. Also a small wood stove could help in case this is not sufficient. Hot water could easily be made with an electrical heater. The first two are interesting to investigate further bit again this will not be done in this report.

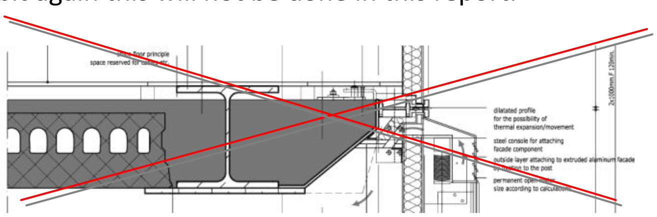


Figure 3.5, section of façade with air flow will not be part of this report

These topics will be dealt with:

- the bearing construction spanning 9 meters and connection to the columns
- connection of the enclosure to the construction
- developing a general concept for a 100% Cradle to Cradle roof

The functional unit is 1 m^2 roof including:

- boarding, insulation, waterproofing and inside finishing
- construction of beams and connections equally distributed over 1 m^2

4 methodology

The focus in this research is on the materialization of the building. Existing C2C methodologies explained in paragraph 2.3 are not very specific on how to do this.

That is why an own methodology is developed to materialize a Cradle to Cradle building. The following steps have been taken in all design solutions in part 5 of this report:

step 1: select existing system and determine technical or biological cycle

Figure 4.1, wood *and steel component, Q-concept*

step 2: investigate possibility of reuse for longer life span

Figure 4.2, Pavilion in the park, www.lifecyclebuilding.org

step 3 : select sustainable, healthy and efficient materials for target life span

Figure 4.3, cardboard guitar, chris gilmour

step 4: dimension construction and enclosure to fit the criteria

Figure 4.4, reed in its environment

step 5: detail for disassembling and reuse or recycle

Figure 4.5, *Mirra chair parts*

step 6: compare design alternatives with Life Cycle Assessment on environmental impacts

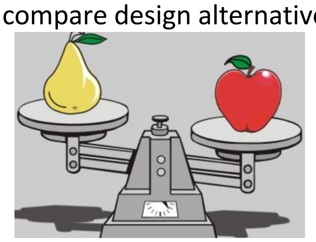


Figure 4.6, comparison of apple and pear

5 design solutions

Alternatives will be used to design within the criteria determined. Exploring existing traditional, industrial and combination solutions makes sure not to reinvent the wheel.

5.1 existing systems

The most used construction materials are concrete, steel and laminated wood. Concrete is down cycling if reused in new concrete so it is not a Cradle to Cradle material. Steel can be used but with keeping in mind that it will have to be collected during demolishing. Wood alternatives could be constructed with interlocking profiles or natural glue. The systems on the following pages meet the criteria of Cradle to Cradle criteria with technical or materials.

5.1.1 steel I-beams (Planjja)

Steel can be combined with other technical materials like glass to an economical construction. If the building loses its function the roof can be reassembled or melted for new materials.

The Plannja 200 roof can span 11 meters with steel profiles. The corrugated plates can't take in plane shear force. So for stability there are fixed connections, additional boarding or bracings needed. For this reason the best is to place steel I beams with bracings every 4,8 meter and span the space in between with 70 mm high corrugated plates.

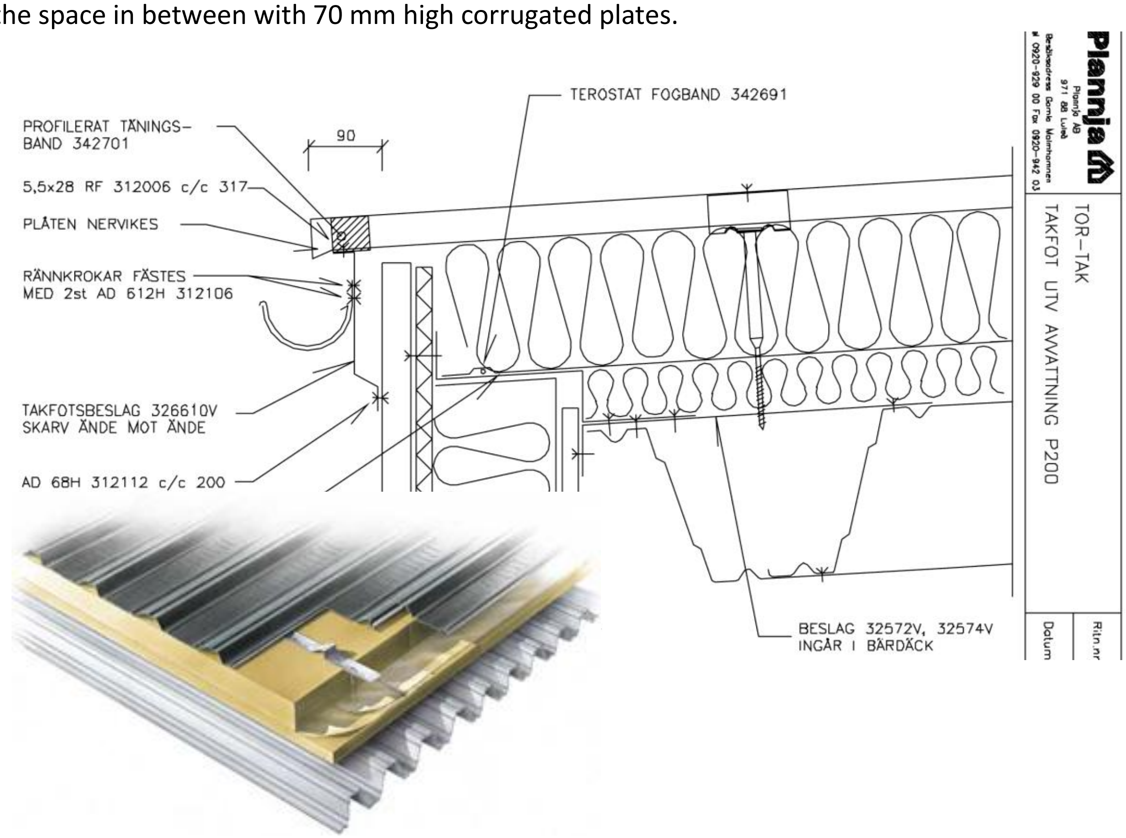


Figure 4.1, Plannja steel frame system from www.plannja.se

The steel corrugated plates can be perforated to improve sound absorption. Also a coated steel watertight roof is part of this system.

5.1.2 steel-wood hybrid (FlexFrame)

Steel is often used in combination with wood for construction and joints. The elements from FlexFrame have a steel main construction with a total height of 360 mm and are covered with wood board.

The construction height can be used for ventilation shafts and other building services. Then there would be insulation needed on top of the elements with an increased total thickness.

The insulation can also be placed between the steel main construction. The steel profiles have a thickness of 2,5 mm so they form a small cold bridge.

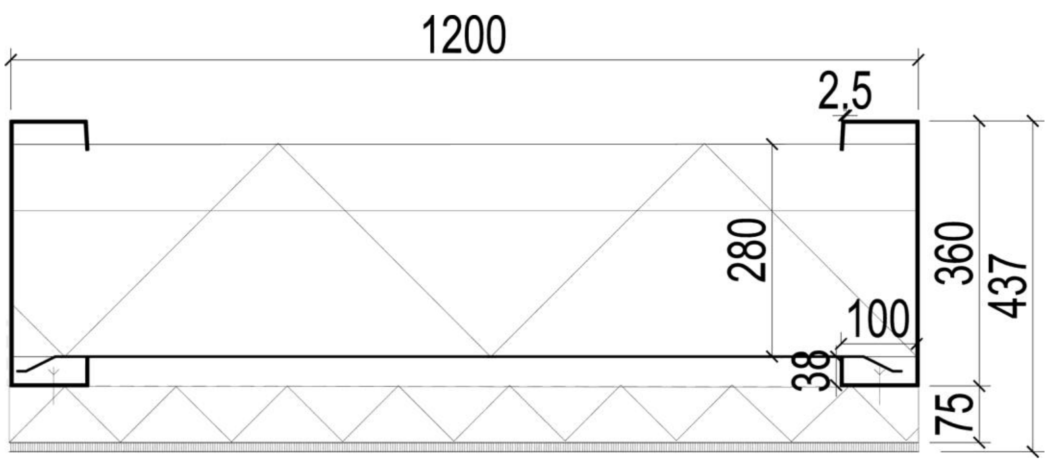



Figure 4.2, Steel-wood system from www.flex-frame.nl

Elements could include steel closing under the insulation, electricity wires, insulation and fibre board on top. A ceiling and watertight roof can be placed after the steel frame elements have been installed.

5.1.3 FJI beams

The I-shaped beams of Kerto flanges and OSB web can be filled with a thick layer of insulation. A common FJI-beam has a glue connection between web and flanges. Passive houses often use this construction.

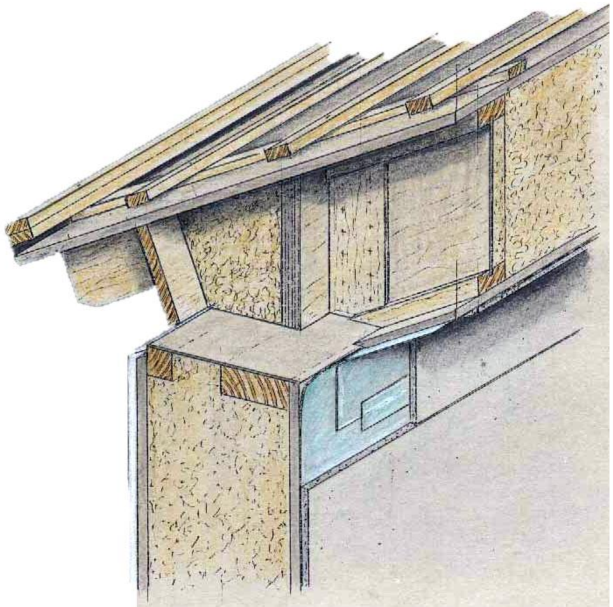
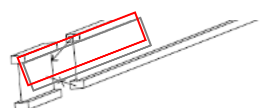
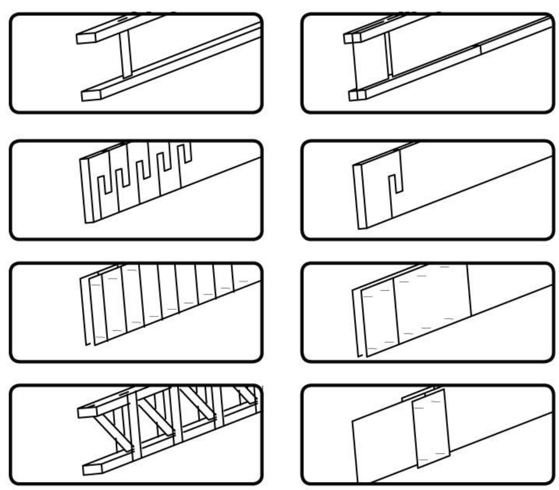


Figure 4.3, Connection of wall to roof with FJI beams (Fingerling 2004)

The I-shaped beam will have to carry bending moments, shear forces and resulting tension and compression. For the Kerto flanges, OSB web and connections is normally formaldehyde glue used. The research below shows other options to make a long I- shaped beam.



5.1.3.1 web joint



5.1.3.1.1 no web joint

If the flanges can take all shear force than there can be a gap in the web.

5.1.3.1.2 interlock

Interlocking shape can transfer shear force.

5.1.3.1.3 overlap

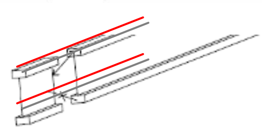
Overlapping can release gap stresses.

5.1.3.1.4 steel

Bolts, nails or cram plates can make a truss.

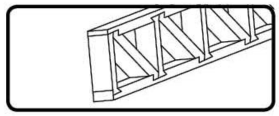
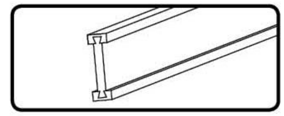
5.1.3.2 flange-web joint

An I-beam made from flanges and a web also has internal connections between flange and web.



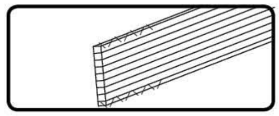
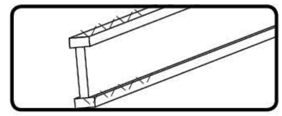
5.1.3.2.1 dove tail

Elements can be fixed in one direction with a dove tale. Fixation in the other direction could be with a wooden pin.

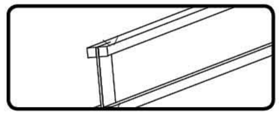
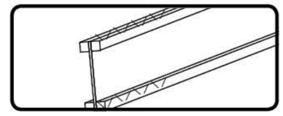
5.1.3.2.2 stacked

A thick web can have blunt connection with nails.

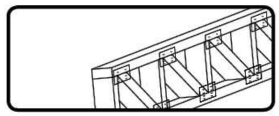
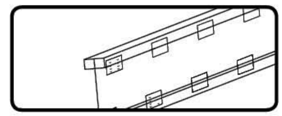
5.1.3.2.3 overlap

A groove in the flange can increase the contact surface.

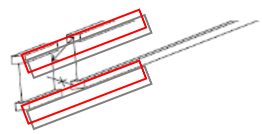
5.1.3.2.4 steel

Cram plates can make a truss or I-shape.

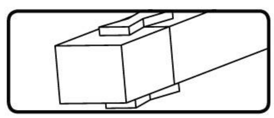
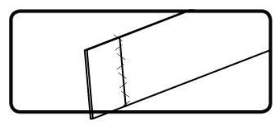
5.1.3.3 flange joint

If flanges can’t span the total distance they have to be connected with joints.



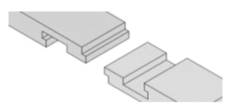
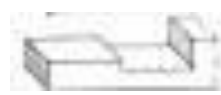
5.1.3.3.1 dove tail

A wedge shape makes a connection within the flange envelope possible.

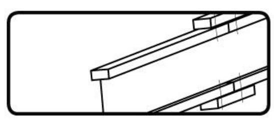
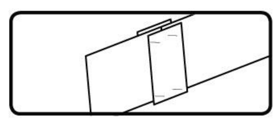
5.1.3.3.2 interlock

Interlock can transfer tension force.

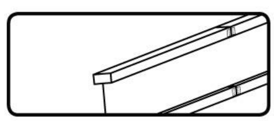
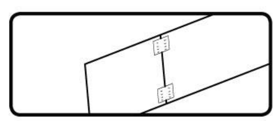
5.1.3.3.3 overlap

A double overlapping flange or small overlap can connect flange pieces.

5.1.3.3.4 steel

Bolts, nails or cram plates can make a truss.

5.1.3.4 no joint

Avoiding the use of glue and steel is effective to make the design Cradle to Cradle. With the use of glue is everything possible like the bio composite roof below.

Bio composites offer the possibility to make a system with no joints. A monolithic roof from soy oil composites could include finishing. This will make the roof less vulnerable against moisture. This design is developed for hurricane sensitive areas where losing roof tiles often results in water damage.

Figure 4.4, Section of a bio-composite roof source: M.A. Dweib et al., Composite Structures 74 (2006) p.37

5.1.4 wood joints

Building practice was sustainable until the industrial revolution. Scarcity of materials and cheap labour made complex details possible. Traditional systems are a source inspiration for sustainable construction. It could even be turned back into compost. Unfortunately these are applied in other ways so that it is not applicable in my design. Some concepts are possible to apply and fabricate in a more modern manner what will be shown in paragraph 4.2.4.

5.1.4.1 traditional Japanese architecture

Fine joinery is well developed in traditional Chinese and Japanese architecture. The post and beam construction has been used since ancient times for the good earthquake resistance. Stone or brick buildings would shake, crack or break, whereas timber frames absorbed the impact and flex of seismic loads better than any other type of construction.

Buildings came to be pieced together like giant wooden puzzles with beams and pillars, railings and window grids all locked in place without the use of nails. A roof span usually is composed of multiple layers like a truss.

Figure 4.5, interlocking exposed beams, *academic.csuohio.edu/makelaa/lectures/architecture*

5.1.4.2 wood frame

Dutch buildings such as warehouses and sheds have been built entirely in wood for ages. The joinery consists of pens and sleeves. A span with wood beams is around 6 meters. 9 meter is possible but would need special selected trees. The roof can be covered with laths and reed.

Figure 4.6, wood frames.

5.1.4.3 connections

Connection directions can be divided in parallel / perpendicular / diagonal.
Force directions can be divided in shear force / moment / tension / compression.

5.1.4.3.1 parallel connections

Splice joints are simple overlapping wood connections. They will have to be glued or nailed to be fixed in place.

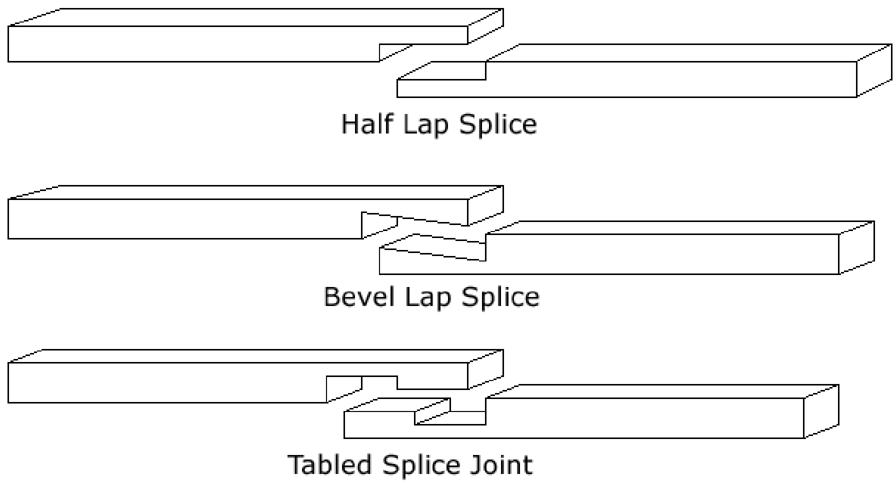


Figure 4.7, http://en.wikipedia.org/wiki/File:Woodworking-joint-splice.gif

The squire splice joint can attach beams to make them as one part. These wood connections are not intended to take bending moment forces (Wattjes 1925).

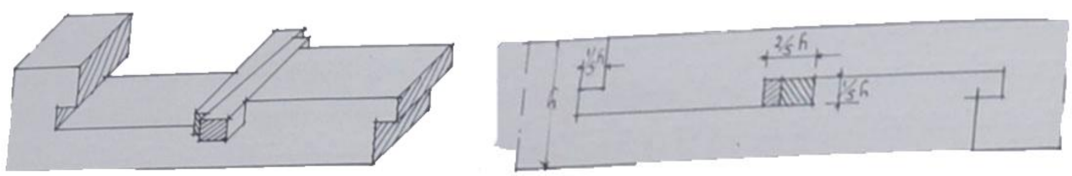


Figure 4.8, squire splice joint

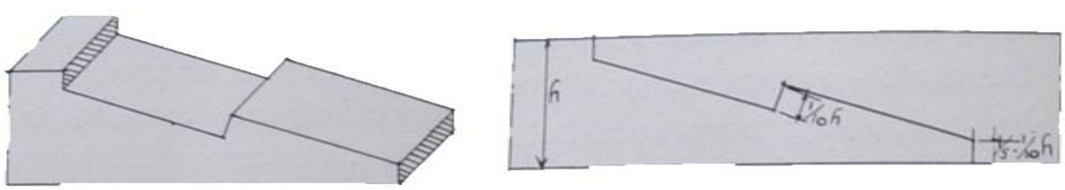


Figure 4.9, splice joint

5.1.4.3.2 perpendicular connections

hinge (can take shear force and compression)

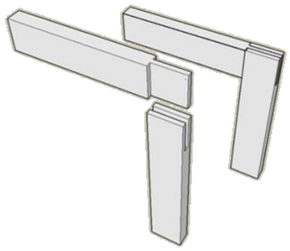


Figure 4.10, bridle joint, source: http://en.wikipedia.org/wiki/Bridle_joint

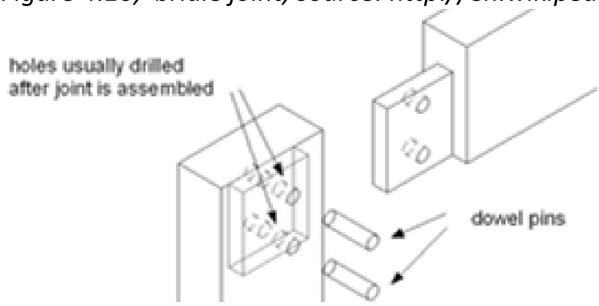


Figure 4.11, mortise and tenon

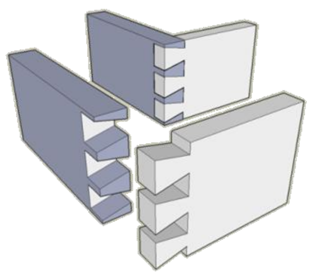


Figure 4.12, dove tale joint

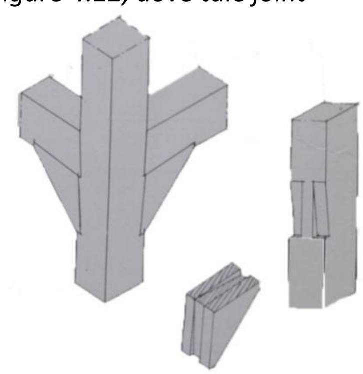


Figure 4.13, corner with continuous post (can take bending moment)

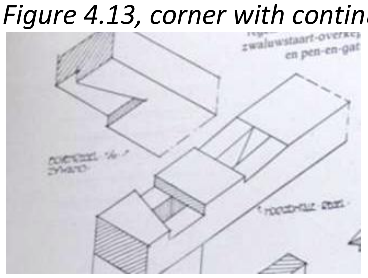


Figure 4.14, dove tale lap (can take tension/compression in one direction)

5.1.4.3.3 diagonal connections

hinge (can take shear force and compression)

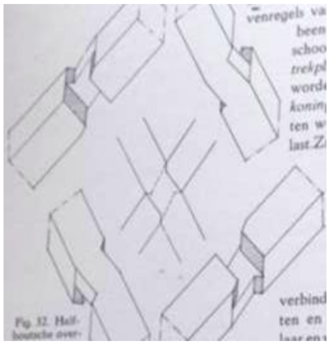


Figure 4.15 , diagonal lap joint with notches

Figure 4.16, diagonal lap joint

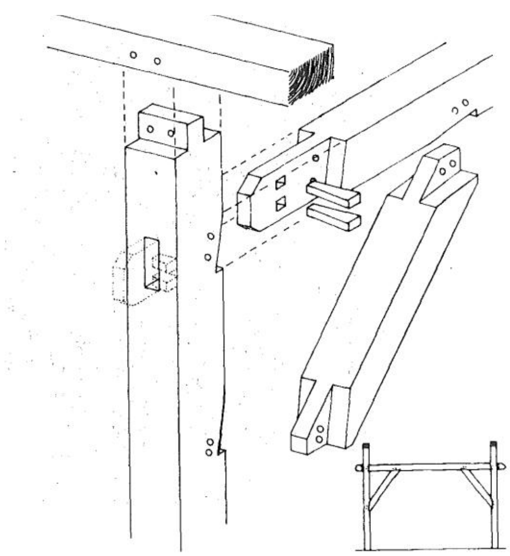


Figure 4.16, brace with mortise and tenon

5.1.4.4 conclusions

A wood frame with no other materials is possible. The result can be charming with the characteristic bracings but is also limiting.

Wood working is a craft but could also be industrialized. If application will occur in large quantities will be the question.

There are differences between soft and hard wood that raises caution of copying traditional forms. Also expansion of wood as to be taken care of.

Figure 4.17, old farm in the province Overijssel (for sale), //link.marktplaats.nl/246841698

5.1.5 massive wood (Q-concept)

Scandinavian houses are often built from massive wood logs. Corners can be connected by intersecting the wood logs.

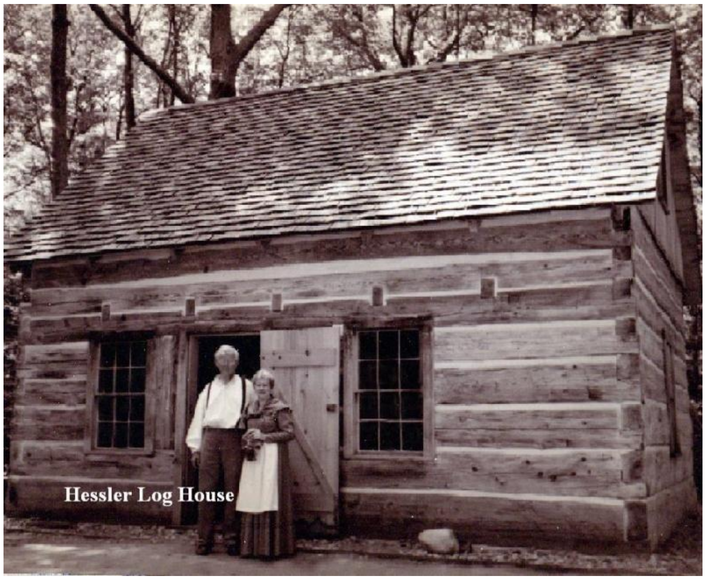


Figure 4.18, log house, source: www.omphistoricalsociety.org

The Q-concept is also purely made from wood. Wood beams make a solid floor. Wood pins prevent different bending of the beams. A span of 12.24 meter is possible.

Figure 4.19, Wood pins to form a wall or floor , sources: Inholz.de, www.kaufmann-holzbau.de

Figure 4.20, log wall, source: www.h-energiesystemen.com

5.2 system designs

The system designs in this paragraph fit the criteria set in section 3. More detailed drawings can be found in attachment 3. With the same functional unit it will be possible to compare them.

5.2.1 steel I-beams

5.2.1.1 system

A braced frame construction.

5.2.1.2 use span

The durable materials will make a longer use of components possible. A technical use of 105 years is realistic with components that last three building uses. The total environmental effects will be divided over this technical use for the effects per year.

5.2.1.3 materials

5.2.1.3.1 cladding

For the roof covering is aluminium a recyclable and durable material. It does not need coating for weather resistance. Small rails and screws can mount aluminium tiles or fold bands.

5.2.1.3.2 insulation

Aluminum as a lower radiance transmission than other materials. Even better are vacuum insulation panels that prevent transmission and convection but those are very fragile for leakage and more expensive. SuperFoil is a manufacturer of insulation with multiple layers of aluminum with small air cavities in between. 1m^2 of SF19 contains:

- Polypropylene Reinforced Heavy Outer Laminated Foil
- 2 Aluminum Mylar Coated Reflective Foil Layers
- 6 Thermo Foam Seperation Layers
- 8 Loft Quilt 80g/sqm Layers

Figure 4.26, SF19 insulation.

5.2.1.3.3 infill

Corrugated steel can be used for indoors. Sound absorption can be realized with small holes.

5.2.1.3.4 construction

A calculation www.bouwenmetstaal.nl showed that moment stiff connections results in very slender beam sections. The wind load is transferred with diagonals.

5.2.1.4 fit to criteria

5.2.1.4.1 construction

If the bay distance is 4 meter and the connection between column and beam is semi fixed, than IPE 220 beams are sufficient.

5.2.1.4.2 thermal insulation

SuperFoil19 is tested with a Rd value of 6.1 m^2K/W.

5.2.1.5 detail

Connection with only technical material is not that difficult. A disadvantage is the good heat transfer that will cause cold bridges.

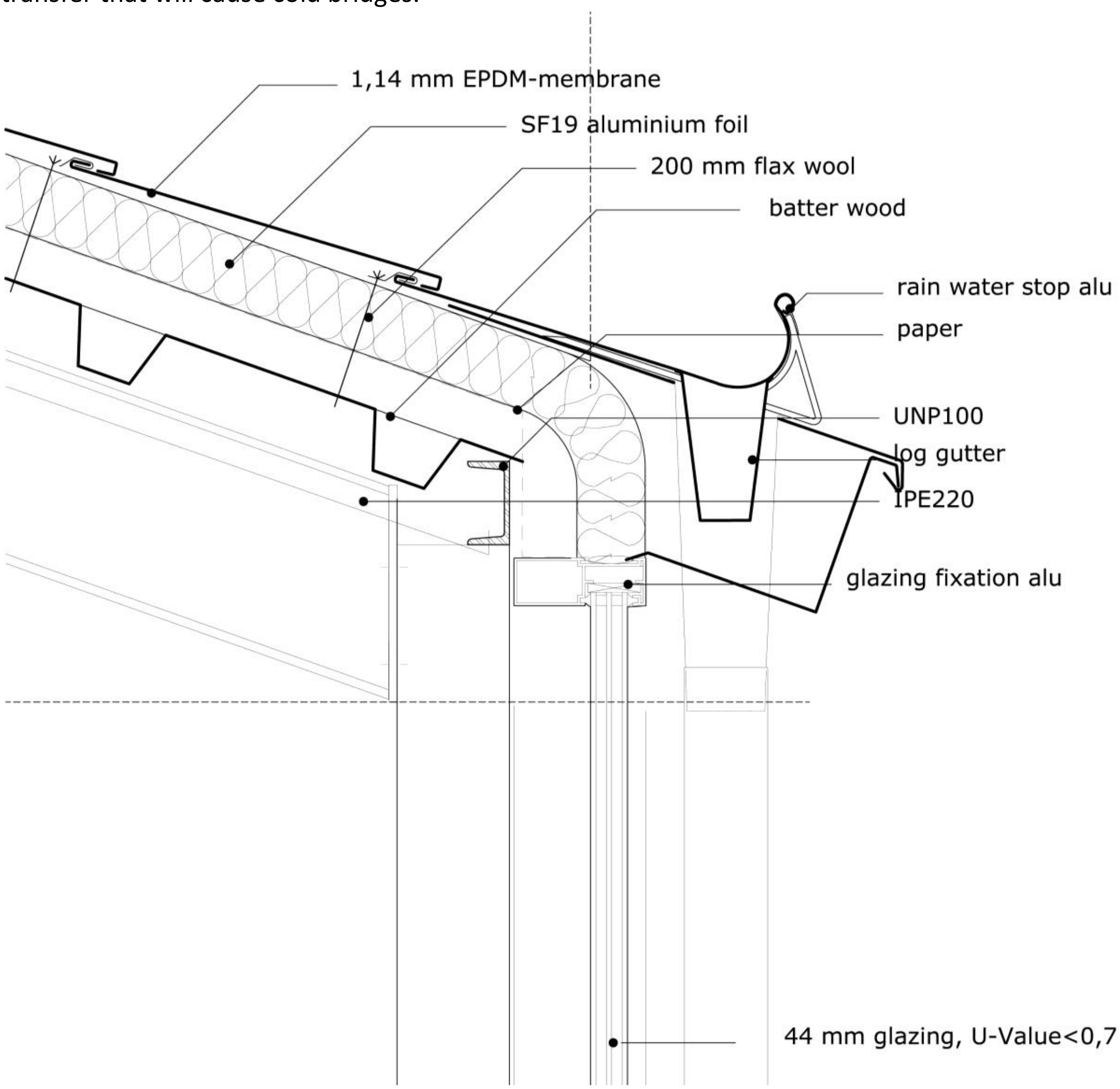


Figure 4.27, detail of roof technical option

5.2.2 steel-wood beams

5.2.2.1 system

Prefabricated elements with steel C360-profiles including ducts and finishing.

5.2.2.2 use span

Reuse is possible for one time, so with two building uses it has a use span of 70 years .

5.2.2.3 materials

5.2.2.3.1 cladding

For the roof covering is wood shingles a good environmental option. Oak or treated wood is preferred for durability. The wood shingles should be replaced after one building use of 35 year.

5.2.2.3.2 Insulation

Glass wool is a recyclable material and resistant to moisture and fire.

5.2.2.3.3 infill

At the bottom there are corrugated steel plates. On top of the elements is 18 mm straw board.

5.2.2.3.4 construction

Steel can span long distances with one element.

5.2.2.4 fit to criteria

5.2.2.4.1 construction

Elements are two meter wide with two steel C360/100/38 mm -profiles. The steel C profiles are placed mediated every meter.

5.2.2.4.2 thermal insulation

The FlexFrame system can fit the criteria if the insulation is thick enough. Because the steel profiles form linear cold bridges of 2.5 mm every meter the thickness of insulation has to be double of the thickness without the cold bridges. Together with 18 mm straw board and wood shingles on top there will be a mediated heat resistance of 5.4 m^2K/W.

5.2.2.5 detail

Connection with technical material is not that difficult. A disadvantage is the good heat transfer that will cause cold bridges.

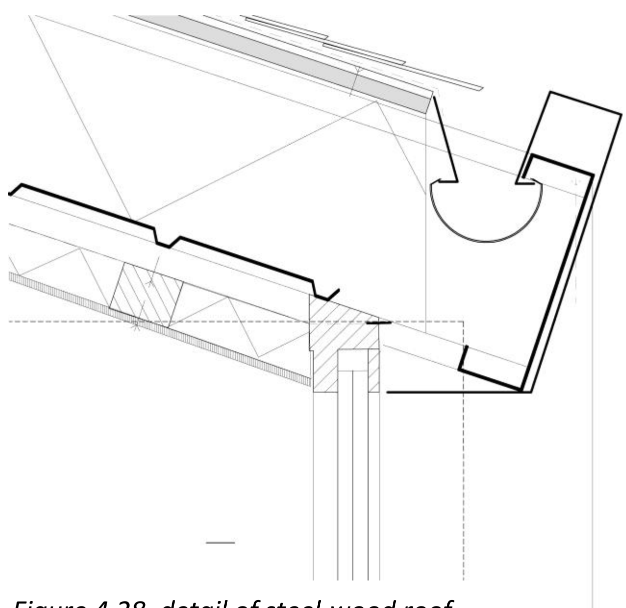
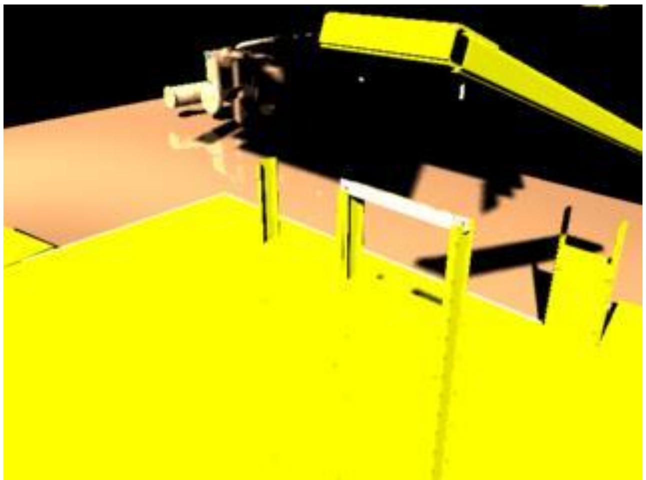


Figure 4.28, detail of steel-wood roof

5.2.3 kenaf core board

5.2.3.1 system

The difference with normal FJI beams is that it is made of extruded agricultural fibres. Kenaf is a plant originated from south Asia. It belongs to the family of bast plants just like hemp, ramie and jute. The seeds provide an oil that is used for food, cosmetics and bio fuels. The sterns consist of long outer bast fibres and fine inner core fibres.



The design that is elaborated here exists of kenaf core particles extruded to a tube. Under high pressure, heating to 200 degrees Celcius and steam, the kenef fibres release a natural binder that makes the internal bonding as strong as MDF.

5.2.3.2 use span

Technically these materials could be reused after 35 years. But this would need more labour than new materials. That is why only one building use is incorporated.

5.2.3.3 materials

5.2.3.3.1 cladding

For the roof covering is wood shingles a good environmental option. Oak or Plato wood is preferred for durability.

5.2.3.3.2 Insulation

Kenaf fibres can be blown in the tube elements like cellulose insulation.

5.2.3.3.3 infill

Agricultural board of 28 mm is the maximum thickness in the market. The outer sides of the tube act as structural flanges at the same time.

5.2.3.3.4 construction

Fibreboard webs and flanges act together as a composite panel.

5.2.3.4 fit to function

5.2.3.4.1 construction

To avoid the use of glue or steel, an extruded shape is a solution. See attachment 4.

Mechanical prototyping is used to give an indication of structural integrity.

.

A prototype scale 1:2 (3000mm) consists of:

- straw board flanges 3000x300x18 mm
- straw board web 3000x200x6 mm
- contact glue 0.1 litre

Figure 4.18, prototype with straw board and contact glue.

5.2.3.4.2 thermal insulation

The webs are negligible as cold bridge. The space in between can be used to place 200 mm fibre insulation that results in an Rc value of 5.4 m^2K/W. Agricultural fibres can be blown in the prefabricated elements. After the elements are filled the opening will have to be closed with kenaf board.

5.2.3.5 demountable

Connection between elements makes sure they do not deform separately. This connection is made with and overlap in the extruded shape.

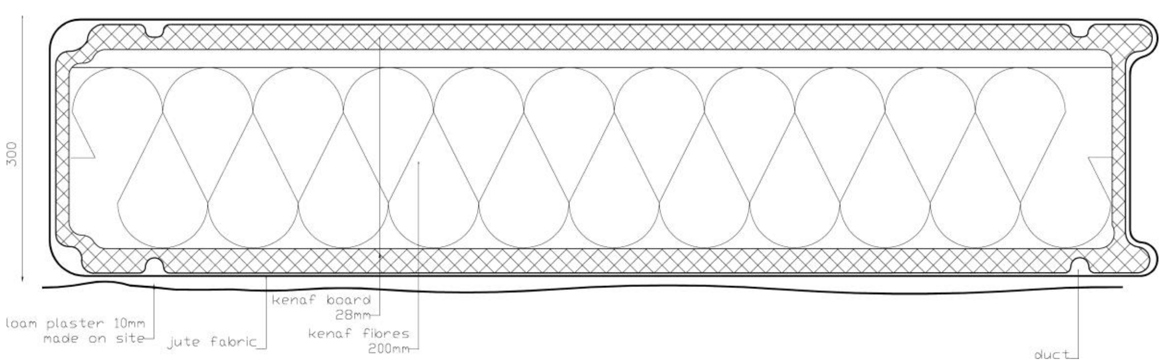


Figure 4.29, extruded straw board with connection between elements, scale 1:10

5.2.4 wood joints

5.2.4.1 system

The traditional wood frame is adjusted a little for more large scale use. The beam length is halved with the help of a hinge in the middle. Two diagonals make it a three hinge bay.

5.2.4.2 use span

Technically these materials could be used for 70 years. The bearing structure can easily be dismantled for reuse. The other materials except the EPDM foil can be composted.

5.2.4.3 materials

5.2.4.3.1 cladding

EPDM membrane is not really recyclable but has a very little weight. If it is not glued but mechanically fastened than the material can reused after dismantling.

5.2.4.3.2 Insulation

Flax wool is light, renewable and has a good performance.

5.2.4.3.3 infill

Jute bags can be tight between the rafters.

5.2.4.3.4 construction

Wood is a well known material. Properties like swelling are influenced by temperature and moisture content. Especially with joints in different fibre directions this should be taken into account.

5.2.4.4 fit to criteria

5.2.4.4.1 construction

A scale 1:5 model with stiff connections failed at the highlighted connection. It carried 12 kg in the middle of the span. A conclusion was to apply only hinge connections.

Figure 4.30, testing a scale model 1:5 with weights of system design 4

The wood frame is calculated in the computer program MatrixFrame. Deformation and stresses are acceptable with hinge connections. Testing of the hinge in the middle of the span could find out if this really acts as a hinge.

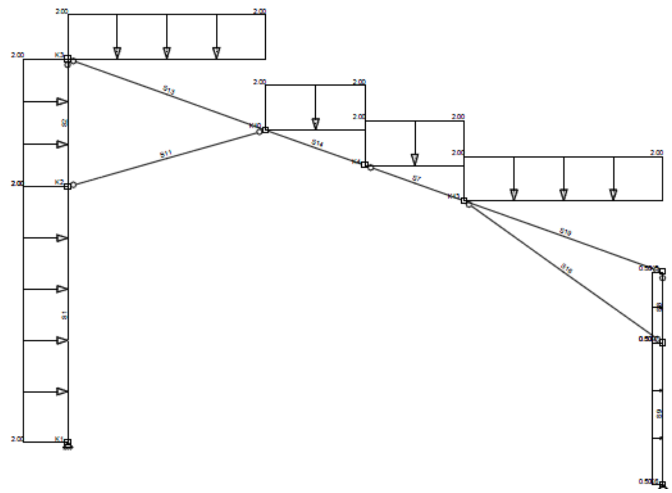


Figure 4.31, deformations with mechanical calculation in MatrixFrame.

5.2.4.4.2 thermal insulation

The 200 mm flax wool insulation results in an Rc value of 5.3 m^{2}K/W.

5.2.4.5 detail

Diagonal and perpendicular connections are with mortise and tenon. The mid hinge is a square splice joint.

Figure 4.32, A scale 1:2 prototype of the hinge connection showed that it is a very stiff connection.

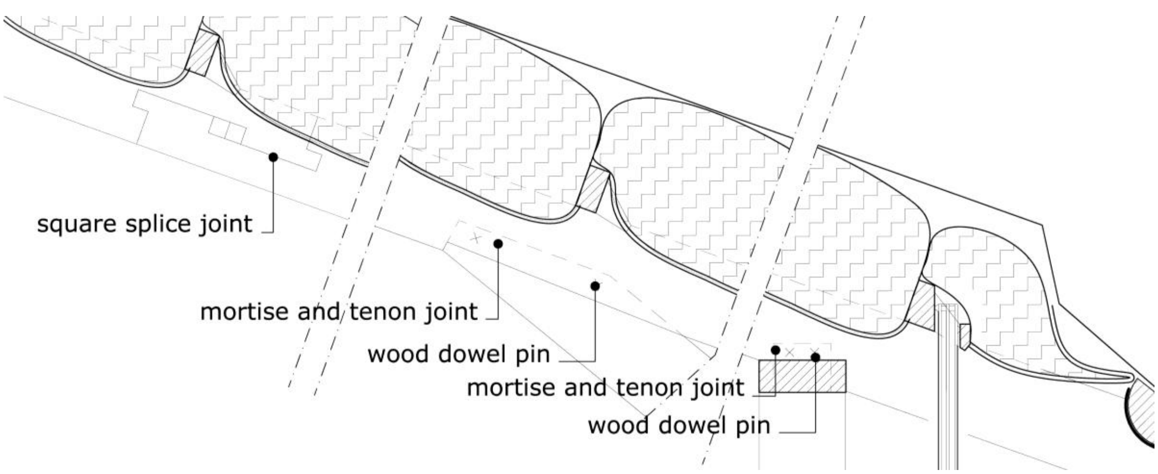


Figure 4.33, vertical details of wood frame connections.

5.2.5 massive wood

5.2.5.1 system

This design is based on the Q-concept. For a longer span than the wood beams it is possible to use shorter wood beams that overlap.

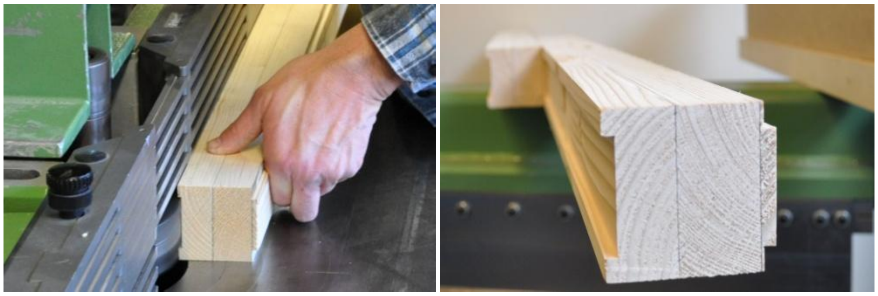


Figure 4.36, milling and connection of solid wood profiles

No other materials than wood are used. The wood profiles in figure 4.36 are fitting into each other. Wood pins could further enhance the shear force connection and take tension. Prefabricated elements of 1200 mm wide could be delivered on building site.

5.2.5.2 use span

The elements are not designed for reuse. This means an estimated use time of 35 years.

5.2.5.3 materials

5.2.5.3.1 cladding

Bitumen are recyclable and used on roofs. Light coloured gravel finish can be added.

5.2.5.3.2 Insulation

Wood fibre board can be manufactured without the use of glue.

5.2.5.3.3 infill

The solid wood fills the entire roof. This makes board infill not necessary anymore.

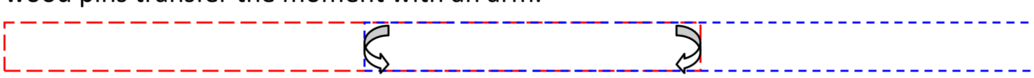
5.2.5.4 fit to criteria

5.2.5.4.1 construction

All wood parts work together for construction. Overlapping parts reduce the beam length.

moment	= 1/8*q*l^2 = 1/8*2,4*9^3 = 24 kNm	< M_{max} = σ*I/z = 121 kNm
deflection	= 27.4 mm	< U_{max} =45 mm

Connections between beams are wood pins. Because they do not cover the complete span, the wood pins transfer the moment with an arm.



m= M/5= 5 kNm	$f_{v;0}$= mz/I= 0.04 N/mm2	< $f_{v;0;rep}$ =3,8 N/mm2

The prototype scale 1:3 was designed to withstand a live load of 1kN/m^2, so a force in the middle of 2,3 kN. The failure occurred at 9,3 kN. This is four times more than the calculation. So the test gives a positive indication of the strength.

Figure 4.35, testing a scale model 1:3 of system design 5

5.2.5.4.2 thermal insulation

The thermal insulation of 280 mm wood is not sufficient. 120 mm wood fibre board makes the total Rc value 5.2 m^{2}K/W.

5.2.5.5 detail

There is a side beam needed to span the distance between columns and take the tension from wind load. This side beam is resting on a hole in the column. The roof also has a groove that is placed over the side beam.

The columns consists of beams from the wall that are longer than the other wall elements.

The roof is covered with bitumen and stone gravel that is stacked to the insulation board. After use this could be separated and reused.

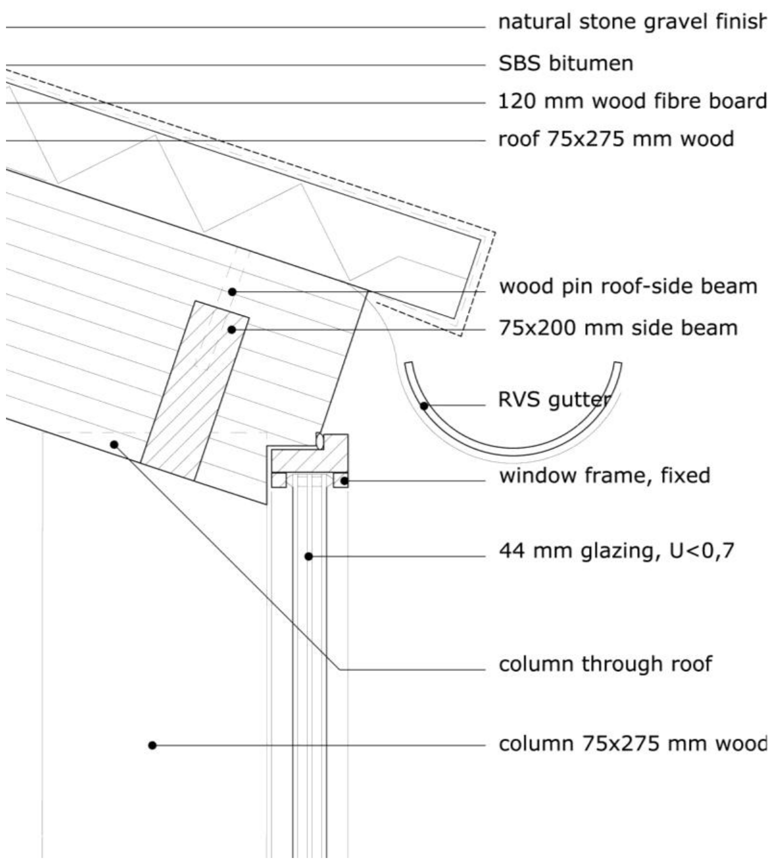


Figure 4.34, massive wood connection from roof to wall, scale 1:20

5.3 Life Cycle Assessment

The hidden environmental costs are derived by filling in the weight in GreenCalc+. Designs with a different life span than 35 years are compensated by calculating the environmental cost per year.

5.3.1 steel I-beams

steel corrugated	weight		hidden environmental costs	
aluminium fold strips	2,27	kg/FE	0,078	eur/FE
aluminium SF19 insulation	0,65	kg/FE	0,012	eur/FE
corrugated steel filling	9,36	kg/FE	0,122	eur/FE
steel beam IPE220 /4m	5,55	kg/FE	0,052	eur/FE
total	17,82	kg/FE	**0,26**	**eur/FE**

The most weight and environmental costs come from the steel filling.

The aluminium fold strips cladding is responsible for the biggest part of the direct (economical) costs.

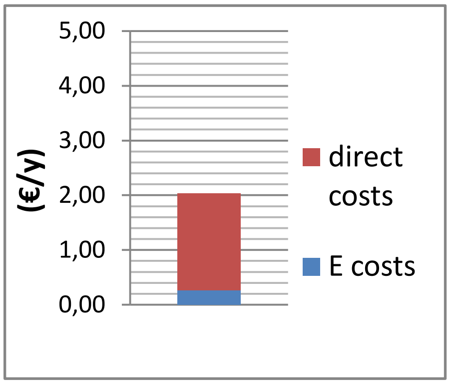


Figure 4.37, environmental and direct economical costs per year of option 1: steel I-beams.

5.3.2 steel-wood hybrid

steel-wood beams	weight		hidden environmental costs	
wood shingles (wrc) 30mm	14,4	kg/FE	0,050	eur/FE
plate straw 18 mm	8,10	kg/FE	0,006	eur/FE
glass wool 280 mm	14,00	kg/FE	0,019	eur/FE
steel plate corrugated	9,00	kg/FE	0,183	eur/FE
steel C360/100/38 x 2,5mm	12,21	kg/FE	0,138	eur/FE
glasswool 50 mm	2,50	kg/FE	0,003	eur/FE
total	60,20	kg/FE	**0,40**	**eur/FE**

Wood shingles have high environmental costs because the shorter use time of 35 years. The other parts have a use time of 70 years which means a reduction of environmental effects.

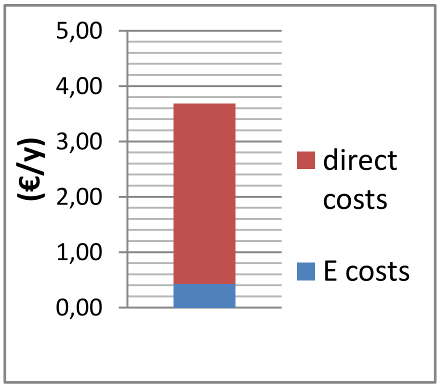


Figure 4.38, environmental and direct economical costs per year of option 2: steel-wood.

5.3.3 kenaf core board

wood-glue FJI-beams	weight		hidden environmental	costs
wood shingles (wrc) 30mm	14,4	kg/FE	0,050	eur/FE
flange 2x kenaf core 28 mm	30,80	kg/FE	0,022	eur/FE
kenaf 200 mm	21,00	kg/FE	0,002	eur/FE
web 0,2 m x kenaf core 28 mm	3,08	kg/FE	0,004	eur/FE
loam	1,56	kg/FE	0,004	eur/FE
total	71,04	kg/FE	**0,09**	**eur/FE**

Wood shingles have high environmental costs. The other materials are good despite the short use time. The data of kenaf core board is based on straw board.

Economical costs in red in figure 4.39 are relatively high. This is mainly because of the kenaf board.

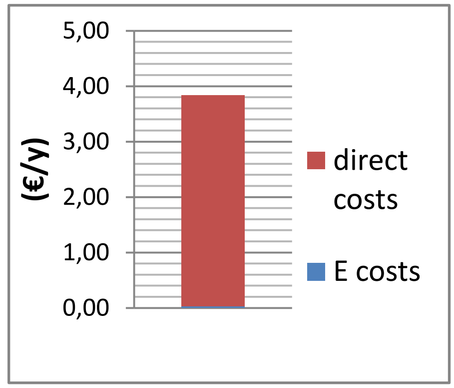


Figure 4.39, environmental and direct economical costs per year of option 3: kenaf core board.

5.3.4 wood joints

wood joints	weight		hidden environmental costs	
EPDM-membrane 1.14 mm	1,41	kg/FE	0,023	eur/FE
flax wool 200	10,00	kg/FE	0,014	eur/FE
jute	0,60	kg/FE	0,000	eur/FE
batters 60x50 /1,2m	1,13	kg/FE	0,003	eur/FE
beams 2x 75x275 /2m	11,34	kg/FE	0,007	eur/FE
loam	14,40	kg/FE	0,002	eur/FE
total	38,88	kg/FE	**0,05**	**eur/FE**

EPDM membrane is a very efficient roofing material but is the most polluting in current practice. Maybe if recycling of the thermoplastic material would be taken into account this would improve.

Economical costs are not very high if you take a normal budget for the amount of weight.

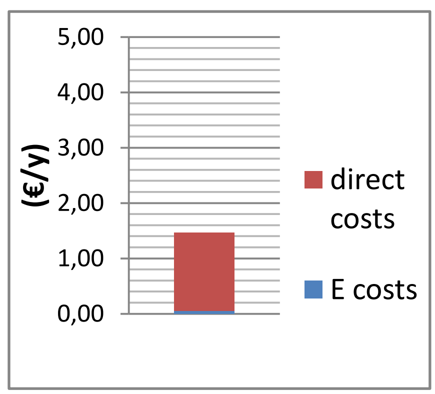


Figure 4.40, environmental and direct economical costs per year of option 4: wood joints.

5.3.5 solid wood

solid wood	weight		hidden environmental costs	
SBS 2x 3,5 mm mech.	4,9	kg/FE	0,110	M.eur/FE
solid wood 280x10000	126	kg/FE	0,256	M.eur/FE
reed fibre board 110mm	6,00	kg/FE	0,130	M.eur/FE
total	136,9	kg/FE	**0,50**	**M.eur/FE**

The heavy wood construction is not very efficient.
Transportation will be an issue with wood.

Heavy material use also reflects on the direct economical costs.

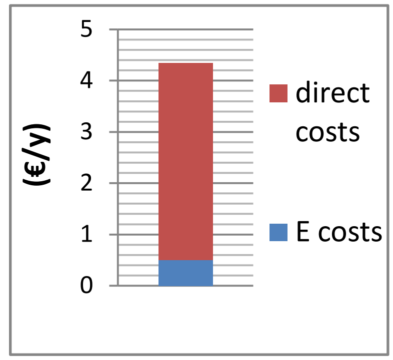


Figure 4.41, environmental and direct economical costs per year of option 5: solid wood.

5.3.6 conclusions

From the life cycle assessment follows that the wood joints option has the least hidden environmental costs. This is with a life span of 70 years but also with 35 years it would still be the best option.

6 conclusions

6.1 pavilion design

6.1.1 relevance of criteria

The design used for this research was not huge but mend more challenges than an ordinary row house. Some design elements that are not in harmony with other goals have been left out like the steel garbage lids on the roof. These can be included afterwards if they are really essential.

Designing with Cradle to Cradle is interesting. They can result in an unusual design with interesting architecture. Also ambitions of compostable or reusable buildings are good to communicate what is so special about this building.

6.1.2 comparison of system designs

The same functional unit requirements makes it possible to compare the system designs. System design 4 is not complying to the requirement of a thin rod package because of the bracings.

There is some uncertainty in use time, dimensions and environmental index. Especially the kenaf core construction still has some uncertainties and topics for further research.

The C2C bonus is the possibility of energy recovering during composting.

The table below compares known variables for an end grade. Higher numbers are better. Numbers are therefore normalized with best practice =1.

name	function	MIG*	C2C bonus	total +factor
1. technical	o	0,19 +- 10%	O	0,19
2. steel-wood	o	0,13 +- 10%	O	0,13
3. kenaf core tube	o	0,56 +- 10%	+	0,84
4. wood joints	-	1,0 +- 10%	+	1
5. solid wood	o	0,1 +- 10%	+	0,15

*Environmental index.

Because of not fitting the functional unit the wood joints are not chosen as final design.

Kenaf core tubes are the best option in total.

6.1.3 Motivation

Savings during the exploitation of a building can be easily defended during the design phase. More difficult are savings at the end of the life span because of higher component or scrap value. But with rising prices of raw materials and awareness of the environment some attention for the Cradle to Cradle ideas worth it. Improvement of human health conditions is of importance for the user of the building. With only a small decrease of absenteeism is a large cost saving possible.

6.1.4 evaluation

Using materials like before the first industrial revolution will mean a more effective use of the materials. This is not always possible today. And today's designs require forms that cannot be made from only natural materials. The only way out to materialize this design is to use technical materials like recyclable watertight foil.

Does this mean that this experiment has failed because 100% Cradle to Cradle is not achieved? In my opinion not because it shows that innovation can reach the destination at the end. This may be done in little steps but is must happen if we want to give our children the same opportunities that we have.

6.1.5 SWOT

strengths

- willingness of parties
- better performance than practice as usual

weaknesses

- not objective without quantitative comparison
- commercial background of certification

opportunities

- future benefit
- simplification of details with less cost

threats

- building regulations
- extra costs

6.1.6 further research

This research is not complete and raises more questions than answers. Some topics were out of reach of this research. Further research and development could make the system designs more certain.

6.1.6.1 system design 1: technical materials	
• insulation with aluminium layers or vacuum panels	(detailing expert)
• coatings that do not pollute underlying materials	(chemical/material science)
6.1.6.2 system design 2: steel-wood	
• construction with less cold bridges	(detailing expert)
6.1.6.3 system design 3: straw board beams	
• wood shingles with natural connections	(detailing expert)
• manufacture and use of C-fix foundation	(civil engineering)

• fibre beam extrusion	(material science/mechanical engineer)
• connections between beams	(civil engineering)
• moisture and long term effects	(material science/ civil engineering)
• market and feasibility investigation	(economy)

6.1.6.4 system design 4: wood joints

• squire splice joint performance as a hinge	(civil engineering)

6.1.6.5 system design 5: solid wood

• overlapping short wood parts in Q-concept floors	(civil engineering)

7 references

- Alexander. "gelatin and glue." p.131. New York: McGraw-Hill Book Companiy, 1923.
- Braungart, Michael & McDonough, William. *Cradle to cradle, remaking the way we make things.* New York: north point press, 2002.
- Courtnall, R, and C Johnson. "The Art of Violin Making." 63. London: Robert Hale, 1999.
- Dobbelsteen, A. van den, and B Grinten. "Cradle to Cradle en de Nieuwe Stappenstrategie – nieuw elan voor de duurzame bouw." *DuurzaamBOUWEN*, 2008.
- Fingerling. *Konstruktionshandbuch für Passivhäuser.* 2004.
- Haas, M. *DUBO keuk BCA-Boards (722.03.07.049).* Bussum: NIBE, 2008.
- Huang, Jian, and Kaichang Li. "A New Soy Flour-Based Adhesive for Making Interior Type II Plywood." *JAOCS, Journal of the American Oil Chemists' Society* , 2008.
- McDonough, et al. "Applying the Principles of Green Engineering to Cradle-to-Cradle Design." *Environmental Science and Technology*, 12 2003.
- Oost, A. en Kiers, P. "De Almere Principles – Leidraad voor stedelijke ontwikkeling op basis van Cradle to Cradle." *Nieuwsbrief Duurzaam Bouwen*, May nr. 2, 2008.
- Rao, Ramachandra. *Resource recovery and recycling from metallurgical wastes.* Elsevier, 2006.
- Reynolds, Mike. *Comfort In Any Climate.* Taos: Solar Survival Press, 2000.
- Schlesinger, Mark E. *Aluminium recycling.* CRC Press, 2006.
- Wattjes, prof. J.G. *Constructie van gebouwen*. Amsterdam: Kosmos, 1925.
- Wolverton, B.C. *How to Grow Fresh Air*. New York: Penguin Books, 1996.

websites:

- Wikipedia. Retrieved March 16, 2009, from: en.wikipedia.org/wiki/Hide_glue
- Britannica. Retrieved March 16, 2009, from: britannica.com/EBchecked/topic/563582/starch, britannica.com/EBchecked/topic/97862/casein-glue