Rebeauty

→ Nordic Built Component Reuse

New Practices for High-Level Reuse

English/

Material waste is the 'dark side' of renovation in construction and discarded materials and components potentially represent a triple capital related to economy, energy, and culture. The project explores, by devising and constructing 20 full-scale prototypes, new practices for high-level reuse of dismantled building components and materials at all product stages from sourcing to disassembly.

New commissions for products and methods confirm the commercial potential; LCAs confirm the assumption of environmental benefits of reuse; and the interest in prototypes and open-source dissemination of results will hopefully inspire the construction sector and users for further cultural development and implementation.

Dansk/

Byggeaffald er 'den mørke side' af bygningsrenovering og udskiftede materialer og komponenter repræsenterer potentielt en trefoldig værdi i form af økonomi, energi og kultur. Projektet udforsker, ved design og opførelse af 20 fuldskala prototyper, ny praksis for genanvendelse af byggematerialer på højt niveau og i alle komponenternes stadier fra nedrivning til ny produkters adskillelse.

Ny kommissioner for produkter og systemer bekræfter konceptets kommercielle potentiale, LCAer bekræfter formodningen om miljømæssige fordele ved genanvendelse, og den brede interesse i de bygge prototyper, samt open-source formidling vil forhåbentlig inspirere byggeindustrien og påvirke brugere til at implementere tanker og systemer fra projektet.

Vandkunsten

Content

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Preface

In the winter of 2012 Vandkunsten Architects entered the architecture competition for the renovation of 1001 atrium houses in the non-profit housing complex of Albertslund Syd. One of the most challenging tasks was the complete renewal of the ground slabs that required 80.000 m2 of solid beech parquet flooring to be removed. In an ordinary renovation practice these quality floors would be transformed into district heating in the local incinerator plant. However, given that our focus over the years has been to preserve resources in our building projects, we felt obliged to suggest a different solution, one in which the material was to be reused at a higher level. We proposed to convert the floor boards into a new interior wall cladding to cover the new highly insulating facade panels. The reused wood would so replace a standard interior cladding and in this way reduce the total environmental impact. To support our proposal we teamed up with researchers at TU-Delft and applied life cycle analysis (LCA) as documentation for the first time in a competition. We connected the LCAs to the energy consumption registered in the maintenance of the housing scheme as well as calculations of life cycle costs.

Our new method and way of thinking aimed at creating architectural and social benefits allowed us to successfully win the competition for this massive project. The project is currently ongoing. The subsequent course of events showed us, however, that numerous barriers must be overcome in order for component reuse to become a common practice: The tenants did not like the proposed changes, furthermore these were mostly considered a burden to the tenant administrator, and finally the authorities had no regulations to follow in order to approve of the solutions. The only way forward was to sell the flooring in the reuse market and this became a condition for the tender. The Danish recycling vendor Genbyg A/S made the necessary arrangements with the demolisher and overtook the task to remove the flooring. They now sell the cleaned floor boards on their website.

The Albertslund Syd experience inspired us to go further and we decided to designate part of our commission funds to conduct research in high-level component reuse. Through my own work at CINARK – Center for Industrialised Architecture at the Royal Danish Academy of Fine Arts, School of Architecture, I met Anne Sigrid Nordby and Catarina Thormark, the few but skilled Nordic researchers and pioneers in the field of Design for Disassembly. Together with Genbyg A/S we established a project group which was granted support by the Nordic Built innovation fund, and whose work is the core of this publication. We owe the Norwegian Nordic Built secretariat, the Danish EUDP, and Swedish Formas great thanks for their support and for their patience with our lack of routine in administration.

The project has been presented a number of times prior to this report: it has been exhibited at DogA in Oslo as well as the Building Green fair in Copenhagen; it has also been the theme of a lecture at Harvard University's Centre for Green Buildings and Cities. We hope that our work continues to inspire transformations towards a circular economy expected in the near future. This development is currently debated as strategies for business and technology. And for us it is highly interesting to rebeauty or explore the artistic potential of these strategies. So, if the alternative aesthetics of the project prototypes excite or provoke this is the intention. Without beauty there will be no sustainability.

— **Søren Nielsen**
Architect MAA, partner, Vandkunsten Architects

I vinteren 2012 deltog Vandkunsten i konkurrencen om renoveringen af 1001 gårdhavehuse i Albertslund Syd. Der skulle blandt meget andet laves nye terrændæk, og for at gøre det, skulle 80.000 m^2 massiv bøgeparket af høj kvalitet fjernes. I en almindelig renoveringspraksis ville de gode gulve rutinemæssigt blive forvandlet til fjernvarme i Vestforbrændingens store ovn, men da vi i en årrække havde arbejdet med at optimere ressourceforbruget i vores byggerier, følte vi os tvunget til at foreslå en bedre løsning - en løsning, hvor materialet blev genanvendt på højere niveau. Således foreslog vi at anvende gulvbrædderne i forbindelse med en facadeudskiftning, som smuk, indvendig beklædning af nye, højisolerede, præfabrikerede facadeelementer. Gulvene kunne erstatte et andet materiale, og dermed reducere miljøpåvirkningen af det samlede indgreb. Med hjælp fra forskere på TU-Delft, anvendte vi for første gang i konkurrencesammenhæng livscyklusanalyser som dokumentation, og koblede dem sammen med dokumentation af energiforbrug på driften og totaløkonomiske kalkulationer.

Metoden og tankegangen var ny, og fordi begge dele blev bragt i anvendelse med henblik på tillige at skabe arkitektoniske og sociale kvaliteter vandt vi konkurrencen om det kæmpestore projekt, som i skrivende stund er under realisering. Det efterfølgende forløb viste os imidlertid, at der mange barrierer, der skal overvindes inden genbrug af bygningskomponenter kan blive daglig praksis. Beboerne brød sig ikke om de foreslåede forandringer, for boligselskabet var det mest til besvær, myndighederne havde ikke regelsættet til at kunne godkende løsningerne. Vi valgte den mindst ringe løsning, nemlig at gøre det til en betingelse i udbuddet, at gulvene skulle søges afsat på markedet for genbrugsprodukter. Det blev således Genbyg A/S som fik en aftale med nedrivningsentreprenøren om at bjerge materialet. Genbyg afrenser og videreforhandler nu gulvbrædderne på deres hjemmeside.

Et andet resultat af erfaringerne fra Albertslund blev, at vi besluttede at anvende en andel af overskuddet på sagen til at forske i genbrug på højt niveau. Igennem mit eget forskningsarbejde på KADKs Center for Industrialiseret Arkitektur (CINARK) havde jeg tidligere stiftet bekendtskab med de få, men dygtige, nordiske forskere og pionerer inden for Design for Disassembly, nemlig Anne Sigrid Nordby og Catarina Thormark. Sammen med Genbyg A/S dannede vi det projektteam, som den fællesnordiske Nordic Built-innovationspulje til vores store glæde bevilgede støtte til, og hvis arbejde denne rapport omhandler. Vi skylder således norske Nordic Built-sekretariat, danske EUDP og svenske Formas stor tak for deres støtte - og tålmodighed med vores manglende rutine i administration.

Projektet har været præsenteret et antal gange forud for denne rapport. Det har således været udstillet på DogA i Oslo og på Building Green-messen i København, ligesom det har været fremlagt i forelæsningsformat på Harvard University's Centre for Green Buildings and Cities. Vi håber, at vores arbejde fortsat kan inspirere til den kommende omstilling til cirkulær økonomi, som kan forventes i en ikke så fjern fremtid. Denne udvikling bliver i dag hovedsageligt italesat som strategier for forretning og teknologi. For os er det imidlertid i ligeså høj grad interessant at udfolde disse strategiers kunstneriske potentiale. Hvis projektets prototyper pirrer eller provokerer med deres alternative æstetik er det således tilsigtet. Uden skønhed ingen bæredygtighed.

— **Søren Nielsen**
Arkitekt MAA, partner, Vandkunsten

Executive Summary

The Nordic Built Component Reuse project explores, by means of 1:1 mock-up prototypes, new practices for reuse of dismantled building components and materials at all product stages - sourcing, rehabilitation, design integration, construction and marketing - resulting in visions of new ways to organize, tender and trade reused building components.

Challenge

The project addresses material waste - the 'dark side' of renovation in construction. The demolishing practice in the Nordic countries today is highly efficient in terms of separating construction debris and minimizing landfill. However, discarded resources represent a triple capital related to economy, energy, and culture. The challenge is to find new ways to access this value and implement the Circular Economy in construction.

Project aims

It is the premise of this project that future construction practice must enable resource-preserving strategies, including:

1/Repurposing building waste from demolishing, dismantling, and refurbishment.
2/Reversible construction principles known as Design for Disassembly (DfD).

The ultimate ambition of the NBCR-project is to generate competition within the field through and apply an open-source approach rather than certified and commercialized methods. By establishing a strong architectural identity as well as profitable business for recycled components, we intend to inspire and assist the development of the circular economy in the Nordic countries. Furthermore we have intended to improve methods and quality of environmental evaluations of reused materials through the use of flow charts and expanded LCA work.

Methods

1:1 work has formed the core work and led to data, discussions, exhibitions, lectures, and publications. The transformational journey from 'waste materials' at hand to valuable new components was investigated through an array of methods. First, we investigated the current market status through interviews with industry experts. Based on specific properties and availability of large material groups, the team then used the Sfc-system to categorize waste components and map their potential applications. Then the team selected and applied Design for Disassembly principles and iterative, architectural design methods to develop multiple novel architectural concepts for facades and interior wall systems. from scrap materials groups of brick, concrete, soft flooring, steel, end wood.

We have designed and built new component systems from discarded building materials. The prototypes were to be beautiful, implement completely reversible construction principles, be sellable, and possible to manufacture through processes that are effective in cost and energy.

20 concepts were selected to be prototyped in full-scale following criteria including: material categories; feasibility, material amounts, and design aesthetics.
For five cases, all manufacturing procedures were timed and documented, and full LCA-analyses carried out.
Along with the physical objects, this allowed us to assess concepts in terms of economy, energy, and culture.
A second group of material concepts were developed further and illustrated.

Results

The physical results of the project are the 20 full-scale prototypes made from five groups of transformed materials and components. Five have formed key cases:

Brick

A new facade system for pantiles is fully designed for disassembly with a customized mounting system. Though challenged by a time consuming process and mixed availability, the tiles do weather beautifully like brickwork which adds to the cultural value of the material concept. The LCA is good for this concept which is in use in a building project for a client of Genbyg. **Figure 2**

Concrete

Principles for cutting and assembling concrete slabs displayed aesthetics of weathering and exposing concrete for facade panels. Due to safety and logistics, these prototypes were cast mock-ups and not cut from waste. Heavy equipment is costly and energy consuming. This results in poor commercial assessment and the LCA that shows that more energy is spent in direct reuse than in using new components. **Figure 1**

Metal

A new facade system uses rolled metal ventilation tubes and utilizes existing mounting systems for slate. The aesthetics of the metal surface appears culturally well-known and the concept has a strong story - two parameters that add to a strong assessment of the concept. Furthermore the alteration of tubes to sheets is simple which results in a positive LCA. **Figure 3**

Windows

For a facade screen with iron profiles and reused glazed windows the windows get same dimensions and an elegant aesthetics by cutting sides off the wooden frame of double glazed windows. Using simple wedges to fasten the frames on the iron profile, the new facade screen is fully reversible with beautiful detailing and a positive LCA comparison. **Figure 4**

Wood

New Nordic Wall is the wood-based version of the exposed brick interior wall dubbed 'New Yorker Wall' by Nordic real estate agents. It is a double-sided building block to stack and restack for interior decorations and room divisions. The sandwich components fit together with a tongue and a groove; they have a core of standard fire doors and cladding in a variety of wooden surfaces from old floors or facades. The LCA is good. **Figure 5**

LCAs and assessments

Theoretical results were made through double sets of comparable LCAs as well as extensive workflow charts conducted for key prototypes. All but the concrete concepts had strong LCAs. Prototypes have been broadly assessed for cultural and commercial value. In the commercial assessment of concepts ease of construction was compared with the cultural value for Genbyg customers. There are no clear conclusions as some beautiful concepts were assessed as poor due to embedded toxic materials, poor LCA or cost performance whereas the assessment of expensive prototypes rated high due to potential exclusivity with a market niche.

The physical results are supplemented with intellectual results in terms of deep insight and tested methods for analysis, design and assessment

The results are already in use by project partners as tools to inspire and assist clients as well as for design competitions and bids. New commissions for products and methods confirm the commercial potential and Genbyg has now established an in-house design studio and expanded their business model; LCAs confirm the assumption of environmental benefits of reuse; and the interest in prototypes and open-source dissemination of results will hopefully inspire the construction sector and users for further cultural development and implementation.

From the top
Figure 1/Concrete prototypes of cut concrete slabs.

Figure 2/Brick prototype of pantile facade system.

Figure 3/Metal prototype of rolled Spiro ducts as a facade screen.

Figure 4/Glass prototype /detail of facade screen prototype from double glazed windows.

Figure 5/Wood prototype of New Nordic Wall built from reused wood.

Introduction

Project idea

The project explores, by means of 1:1 mock-up modelling, novel practices for reuse of dismantled building components and materials at all product stages - sourcing, rehabilitation, design integration, construction and marketing - resulting in visions for new ways to organize, tender and trade reused building components. Aims are to devise and prototype new component systems from discarded building materials. The prototypes should be beautiful, implement completely reversible construction principles, be sellable, and possible to manufacture through processes that are effective in cost and energy.

By establishing a strong architectural identity as well as profitable business for recycled components, the idea is to move the boundary line between waste and value and inspire and assist the development of the circular economy in the Nordic countries. Furthermore we have intended to improve methods of environmental evaluations of reused materials through the use of flow charts and LCA analyses.

Relevance

The global interest in the Circular Economy has influenced the governmental agenda in the Nordic countries[1] and in the EU[2] industrial organisations have recently embraced the agenda.[3] The theme is covered in literature - mostly in intentional or theoretical terms. The technical theory behind resource preserving is already developed to a high level[4] but has never found breeding ground on the current market conditions. Business concepts like Cradle-to-Cradle (C2C)[5] have been commercially successful within a narrow field of recycling, but have not managed to devise reuse solutions in practice. The C2C is carefully adapted to an industrial economy in which dismantled components are defined as waste bereft of functional or social value, but merely available as raw material for recycling.

The project addresses the 'dark side' of building renovation - the material waste that is the consequence of current practice. The demolishing practice in the Nordic countries today is efficient at separating construction debris and minimizing landfill.[6] In present practice, however, waste materials are most often broken down to the lowest level of its potential: for combustion or for recycling as secondary material. Only a very small part of demolition waste is reused in a similar function or for other purposes without extensive degradation. Consequently resources embodied in processes of manufacturing and maintenance are wasted along with potential cultural, economic, and aesthetic values. Thus demolition waste potentially represents a triple capital that it is relevant to explore.

1 I.e. The Circular Economy is a buzzword influencing legislators and businesses across the World. When the Danish government launched the 2013 resource strategy "Denmark without waste", construction waste was named a major source of future resources which could and should be used as such. recommended in Norwegian technical building regulations (Teknisk Forskrift), §9-5 Waste: "Construction products which are suitable for reuse and recycling should be selected." The guidance specifies further: "Designing for reuse will help ensure that a building can be disassembled so that the materials and products can be used again. Through the design, it must be displayed specific assessments regarding reuse and recycling." (translated by author). http://dibk.no/no/BYGGEREGLER/Gjeldende-byggeregler/Veiledning-om-tekniske-krav-til byggverk/?dxp=/dxp/content/tekniskekrav/9/5/

2 EU Parliament: On Resource Efficiency: Moving Towards a Circular Economy (2014/2208(INI)) Draft Report (presently in consultation phase) 24.03.2015, i.e. p. 9: 2. 'Cascading use of resources is a way of maximising resource efficiency. It entails a systematic effort to first exploit materials for higher added value products and to then use them multiple times as resources in other product categories.'

3 Danish Industry, Environmental Policy Program August 2015. Also, C2C-principles have been implemented as part of the assessment criteria in two major architectural competitions (Posthuset 2013 and Lilletorget 2015) by Entra Eiendom, one of Norway's leading real estate companies. Posthuset 2013; http://www.arkitektur.no/nordic-built Lilletorget 2015; http://www.arkitektur.no/entra-competition1

4 E.g.: Thormark 1998, Crowther 2001, Durmisevic 2006, Nordby 2008, Sassi 2009

5 Based on the book published in 2002 by Braungart and William McDonough " Cradle to Cradle: Remaking the Way We Make Things"

6 Miljøministeriet, Miljøstyrelsen, Affaldsstatistik 2011, Notat 11.06.2013 (http://mst.dk/media/mst/Attachments/Affaldsstatistik2012.pdf)

Project aim and scope

The aim of the project is to inspire and influence the development of a construction practice for high-level reuse that supports and enables:

1/Repurposing of dismantled components from building renovation without degradation, and
2/Design for Disassembly (DfD). Construction principles that aim at future reuse of components.

The overall vision of this project is to inspire the agents of the construction sector to pursue a higher-level resource reuse that secure qualities in terms of culture, history, economy, and environment. The direct goal is to improve the foundation of business and income for the participating companies.

The most important focus of the project is high-level reuse as opposed to current utilization strategies. This project searches out the possible remaining functional and social values in the dismantled component and alternative reuse at a higher level is suggested. The project's scope is strictly limited to building materials; it is an attempt to address the conditioning structures and workflows within the building industry and the built environment..

Project background

With a strategy for reusing discarded material components; Vandkunsten won a 2012 competition for the renovation of a large Danish housing project.[7] Crucial challenges in regards to economy, technology, and culture, faced the implementation of the strategies as the competition brief was developed into the project currently under execution. The experience revealed that the construction industry is poorly prepared for a conversion towards a more effective and careful utilization of resources.[8] A widespread reluctance was found with industrial professionals as well as with the tenants. When comparing mock-ups of refurbished homes, inhabitants preferred the new and conventional material surfaces over the reused solutions; a preference partly due to a higher price of repurposed material components and in part due to a different aesthetics and tradition.

The idea for the current project was initiated here. It appeared to Vandkunsten and Genbyg that the economic, legislative and cultural structures are not yet mature for the necessary conversion and there is need for new and inspirational solutions, which manage to meet technical, environmental and cultural requirements as well as ripe business models to gear the market for the development. **Figure 7**

Team and collaborators

The project partners are Vandkunsten Architects (DK), Genbyg.dk (DK), Asplan Viak (NO), Malmö Högskola (SE) and Hjellnes Consult (NO).

Architecture master students have also contributed to the work. In 2014, Anna Meyer, in the fall of 2015, a group of students used NBCR as the foundation of their semester assignment "Recycling Station – design strategies for material reuse" by architecture students Lena Fedders, Amalie Brandt Opstrup og Line Tebering, Royal Danish Academy of Fine Arts, School of Architecture, Settlement Ecology and Tectonics . They worked as architectural research interns[9] and had their work spaces at the office of Vandkunsten for a full semester.
The group of company experts include: Danish Waste Solutions, Diatool Aps (Diamond Tools), Glarmester Aage Larsen (Glazier), Glasfakta: Expertise and counselling on glass, HJ Hansen: Scrap Dealer, RGS 90 A/S: Waste handling and recycling company, RoboCluster Innovationsnetværk: private-public robot-themed cluster, and Tscherning A/S, Demolition contractor

7 Albertslund Syd Gårdhavehusene, renovation of 1000 low-dense residences, including proposed reuse of dismantled original flooring as interior wall cladding. Arkitekten 2014/1.
8 I.e.: Ellen MacArthur Fondation: Towards the Circular Economy Vol. 1-2. Report 2012-13

9 Carried out as an InnoBYG initiative in September 2015-January 2016

Methods

The transformational journey from 'waste materials' at hand to valuable new components was investigated through an array of methods. First, we investigated the current market status through interviews with industry experts. Based on specific properties and availability of large material groups, the team then used the Sfc-system to categorize waste components and map their potential applications. Then the team selected and applied Design for Disassembly principles and iterative, architectural design methods to develop multiple novel architectural concepts for facades and interior wall systems. Materials were selected from materials groups of brick, concrete, soft flooring, metal, end wood.

20 Concepts were selected to be prototyped in full-scale following criteria including: material categories; feasibility, material amounts, and design aesthetics. For five cases, all procedures were timed and documented, and full LCA-analyses carried out. Along with the physical objects, this allowed us to assess concepts in terms of economy, energy, and culture.

A second group of material concepts were developed further and illustrated.
1:1 work has formed the core work and led to exhibitions, oral dissemination as well as publications.

A second series of illustrations depict scenarios and visions of transferred technologies and novel sourcing methods and machines that would enable increased reuse. These visions are introduced in the discussion chapter.

Architectural output and methods

Prototypes were developed by creative design methods.[10] Creative design can be described a generative regime of iterative series of tentative proposals oscillating between multiple instrumental and social media.[11] Media and scales vary and include:

10 Schön 1983
11 Yaneva 2005

Sketching/hand drawings, 3D digital modelling, CAD drawings

Reflective dialogues/between colleagues, at Skype meetings, through emails.

Scale modelling/multiple scales: cardboard, styropor, wood

Rapid prototyping; fibreboard, wood, foam plastic

Constructing in scale 1:1 using the 'right' materials

Documentation

The explorative analysis methodology described above is imbedded in the iterative process, which runs in numerous loops according to this operation-pattern: **Hypothesis** ⟶ **Experiment** ⟶ **Assessment** ⟶ (**New media** ⟶) **Repeat.**

The NBCR matrix combines existing systems

We developed an approach, a matrix for analysis of discarded material components and mapping of their possible future use. The method combines the practical SfB Classification and Coding System[12] with principles from Design for Disassembly (DfD).
Figure 6

SfB

The SfB-system (SfB = Samarbetskomitén for Byggnadsfrågor) was developed in Sweden in 1950 and has since been adopted by several European countries. The codes consist of numbers and letters in a three phased code that refer to building parts, structural principles, and material resource. It is simple to analyse existing building parts according to the system as well as to code the redesigned component. **Figure 8**

The established SfB-system corresponds roughly with Shearing Layers, a basic technical presumption of DfD. Shearing layers are often illustrated by the

12 The SfB-system (SfB = Samarbetskomitén för Byggnads-frågor) developed in Sweden in 1950. SfB is an operative system adopted and used by several European countries. Systems do vary between countries, and Norway for one has a different system.

Reuse potential_Concrete

Sfb Categories

Funktionstabel
(Bygningsdele og grunddele)

(1.) Bygningsbasis
(2.) Primære bygningsdele
(3.) Komplettering
(4.) Overflader
(5.) VVS-anlæg
(6.) El- og mekaniske anlæg
(7.) Inventar
(8.) Fri
(9.) Fri

Starting Point

Future Use

Funktionstabel
(Bygningsdele og grunddele)

(1.) Bygningsbasis
(2.) Primære bygningsdele
(3.) Komplettering
(4.) Overflader
(5.) VVS-anlæg
(6.) El- og mekaniske anlæg
(7.) Inventar
(8.) Fri
(9.) Fri

(1.) Bygningsbasis
(10) Terræn.
(11) Fri.
(12) Fundamenter.
(13) Terrændæk.
(14) Fri.
(15) Fri.
(16) Fri.
(17) Fri.
(18) Øvrige.
(19) Sum.

(2.) Primære bygningsdele
(20) Terræn.
(21) Ydervægge.
(22) Indervægge.
(23) Dæk.
(24) Trapper og ramper.
(25) Bærende konstruktioner.
(26) Altaner.
(27) Tage.
(28) Øvrige.
(29) Sum.

(3.) Komplettering
(30) Terræn.
(31) Ydervægge, komplettering.
(32) Indervægge, komplettering.
(33) Dæk, komplettering.
(34) Trapper og ramper, komplettering
(35) Lofter, komplettering.
(36) Altaner, komplettering.
(37) Tage, komplettering.
(38) Øvrige, komplettering.
(39) Sum.

(4.) Overflader
(40) Terræn, belægninger.
(41) Udvendige vægoverflader.
(42) Indvendige vægoverflader.
(43) Dæk og gulve, overflader.
(44) Trapper og ramper, overflader.
(45) Lofter, overflader.
(46) Altaner, overflader.
(47) Tage, overflader.
(48) Øvrige overflader.
(49) Sum.

(7.) Inventar
(70) Terræn.
(71) Teknisk inventar.
(72) Tavler, skilte og skærme.
(73) Opbevaringsmøbler.
(74) Bordmøbler.
(75) Siddemøbler.
(76) Liggemøbler.
(77) Boligtekstiler og afskærmning.
(78) Øvrige.
(79) Sum.

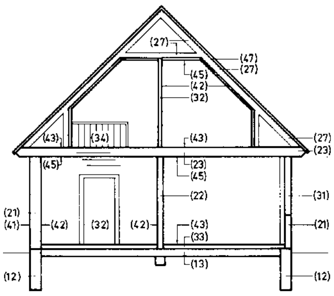
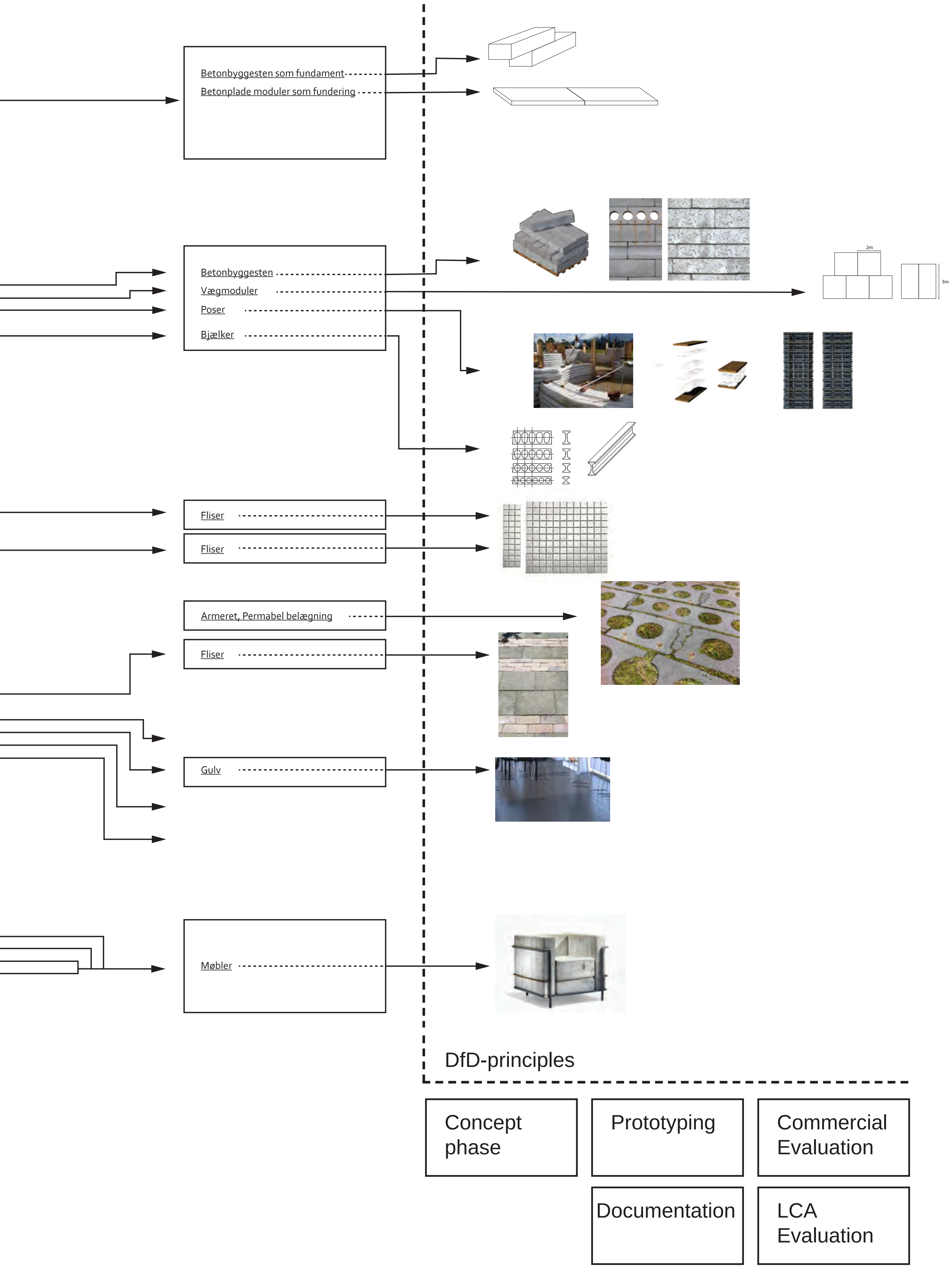
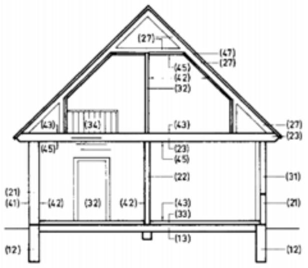
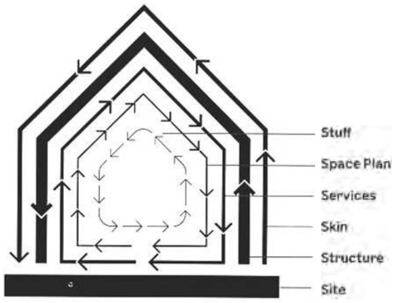


Figure 6/The NBCR Matrix, using concrete as an example for the explorative displacement of components within the classification system of building layers and components


Betonbyggesten som fundament
Betonplade moduler som fundering
Betonbyggesten
Vægmoduler
Poser
Bjælker
2m
3m
Fliser
Fliser
Armeret, Permabel belægning
Fliser
Gulv
Møbler
DfD-principles
Concept phase
Prototyping
Commercial Evaluation
Documentation
LCA Evaluation





From left
Figure 7/ Wall cladding at Albertslund Syd renovation, 2014, from repurposed floorboards. Vandkunsten.

Figure8/Diagram with SfB system codes
1. Ground sub structure
2. Primary structure,
3. Secondary Structure, Openings
4. Finishes
5. Services, mainly mechanical
6. Services, mainly electrical
7. Facilities
8. Fittings
9. Stuff - Ground facilities

Figure 9/Diagram of lifetime layer-structured construction (Duffy/Brand)

lifetime layers diagram that shows the relationship between functionality and lifetime of building parts. **Figure 9**

Following shearing layers, a building should be constructed so that an exchange or alteration of a building part can be performed without interfering with layers with longer lifetime to avoid waste of resources (materials, time, and investments).

Design for Disassembly

DfD covers a range of guidelines and recommendations.[13] In this report and in the architectural practice of Vandkunsten DfD principles are also named 'reversible design'. DfD-guidelines as a set of tools are not related specifically to reused materials and components, rather is it a precondition for future reuse.

DfD is simultaneously a technical discipline and an architectural design strategy: this means that architectural motifs can be generated by following the guidelines for organising building components and technical solutions for assembly.

13 Among others: Thormark 1998 (feasibility), Crowther 2001 (deconstruction), Addis 2004 (deconstruction), Dumisevic 2006 (transformability), Sassi 2007 (closed loop material circle), Nordby 2008 (salvageability).

In order to assure a building's ability to transform, building components should in general be assembled hierarchically according to lifetime layers - the longest lasting components behind the component layers with a shorter lifetime. Furthermore, in order to enable exchange of single components within a layer, components should preferably be assembled in parallel, i.e. attached independently of each other. Mechanical assembly devices such as bolts, brackets, screws or springs produce reversible connections enabling the disassembly process.

The application of the guidelines above to practical schemes can be studied in order to pinpoint the architectural identity that is generated as a consequence of DfD. Architectural identity can be analysed by searching motifs, i.e. characteristic compositional relationships and patterns between components.

We have loosely prioritized a set of technical design rules to be of particular relevance to architectural design. The order is not decisive. However, an initial estimation of consequences from ignoring the rule in terms of increased waste should assist a rough prioritization. In the development of each prototype observing the DfD-guidelines has played a key role as a framework for the design.

10 Technical design rules for disassembly

1/ **Reversible fixations** (mechanical) enable disassembly without damaging components.

2/ **Separability of building parts and component members and constituents.** This generally disqualifies composites, glued, cast, or other chemical connections.

3/ **Hierarchical assembly according to component lifetime.** Enables minimal interference in components with longer lifetime when exchanging others.

4/ **Accessibility to fixations.** Enables disassembly without damaging components.

5/ **Parallel assembly.** Enables local exchange of single components.

6/ **Manageable size and weight of components.** To enable changes and disassembly without crane-lifts.

7/ **High generality of components** (modularity, homogeneousness and uniformity). To increase reusability.

8/ **Minimum of mechanical degradation,** such as cutting, carving, and penetration. To minimise waste and increases component reusability.

9/ **Orthogonal geometries,** as opposed to skewed or curved. To minimise waste and increase possibility of component reuse.

10/ **Minimal number of component types and parts.** To ease processes of disassembly and of resource mining.

Using the SfB-system, we constructed a matrix as a generator for possible combinations between the original, first generation function of a component, and its second generation function **Figure 10**

Reuse of components falls in the following three categories.[14]

Recovery = reuse component in same function
Repurpose = reuse in another function
Upcycle = reuse after redesign and upgrading

The focus of the NBCR-project has been on repurposing and upcycling since the project idea is to move the boundary line between waste and value. In current demolition and waste-handling practice, components found suitable for preservation at demolition will typically be those that still contain functional and technical value and therefore possess possible sales value.

14 Sassi 2008

The combination matrix is a tool for displaying repurposing and upcycling potential by letting the components change from one functional layer to another. 'Downcycling' is the predominant pattern in current practice as components change from more permanent layers to more volatile layers. Eventually most waste components can be utilised for furniture design since the functional requirements are easier fulfilled with interior and moveable elements. It is by no means a coincidence that Genbyg has a growing side business from designing and manufacturing furniture.

Pragmatic selection of materials

The NBCR Matrix can be used for any material and component. Materials were selected based on one or more rough criteria such as Frequency, Volume, Accessibility, Potential, and Chance.

→ **Frequency**/ Materials and components with a short average lifetime[15] are frequently exchanged and can frequently be sourced. Metal and soft flooring concepts are based on frequently exchanged components.

→ **Volume**/ Some materials are heavily represented statistically[16] in terms of volume and weight. The concrete concepts are based on this situation.

→ **Accessibility**/ The stock supply at Genbyg depends on close relations and collaborations with demolition contractors and craftsmen, either long-term or short-term agreements:

1/ **Demolition contractors** allow Genbyg a limited period of time for dismantling valuable items. This period is often too short to source everything of value and there remains a reclaiming potential.

2/ **Individual craftsmen** independently transport items of supposed value to Genbyg driven by belief of a potential 'second' life of fully functional or beautiful building elements that would conventionally be discarded.

→ **Sales potential**/ Components and design with high sales potential and simple processing - low-hanging fruit were given priority. The Nordic Wall concept is the clear example

→ **Chance**/ The order in which prototypes were

15 Addis 2006
16 Miljøstyrelsen DK, Affaldsstatistik 2012, Appendix 2, table 10 p. 17, http://mst.dk/media/129664/affaldsstatistikken-2012.pdf

designed and built was substantially influenced by availability and spontaneously occurred possibilities, e.g. nearby demolition sites or random information about available waste materials.

Quantitative and qualitative approaches

Interviews were initially used for obtaining information about the current market conditions. When assessing the individual commercial potential of prototypes, interviews were conducted once more as an unstructured but efficient way to collect unreserved comments. A one-day workshop was held through which all prototypes were discussed.

Analyses of potentials and assessments of concepts were conducted through cross disciplinary discussion between participants of the project. Here different competences and views complemented each other in order to perform a full assessment. The method for the analysis an d the assessment was designed in order to capture as many aspects as possible such as environmental, economical, technical etc. The assessments are both quantitative (LCA) and qualitative, and are based on a prepared structure, see matrix **Figure 6**. We consider the topic a 'Soft System' Problem because there are divergent views about the definition of the problem. We apply qualitative analysis from soft system methodology,[17]
a methodology developed through action research.

This research design provides an analysis and an assessment of most of the different aims in the project. The included criteria are grouped according to 'upstream' and 'downstream' in the value chain of building components (see chapter on LCA). Upstream include the component deliveries in the building design phases, and downstream is building post-use or resource recovery processes related, which must both be optimised in order to preserve material and economic resources. **Figure 10**

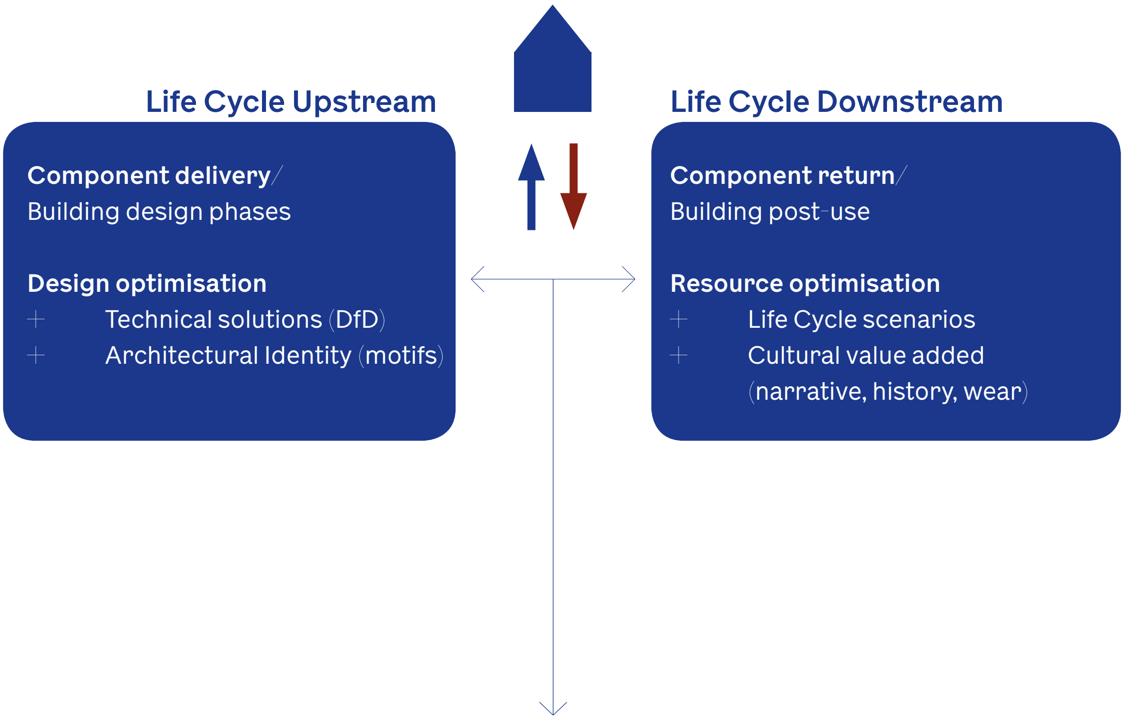
Design optimisation (Life Cycle 'upstream' process) includes DfD strategies and strategies for obtaining architectural identity in the design phases.

Resource optimisation (Life Cycle 'downstream' process) includes all dismantling and recovering processes and possible added cultural and commercial values embedded in the used components and material resources.

In the present context of high-level reuse, there is a close relationship between the resources and components delivered to new buildings and the end of life building scenario previously considered as 'waste' but increasingly considered valuable resources. There are different tools and values connected to novel design solutions and the worn materials and the more refined the one, the more refined the other.

A resource 'safety-net' can be provided by paying attention to this dual set of criteria. The criteria were subdivided into the following four categories for the prototypes assessment: Technical aspects, Environmental aspects, Commercial aspects, and Cultural aspects.
Figure 11 and see discussion chapter for assessment
The 'safety-net' has qualitative as well as quantitative aspects and was used during the design phases of the project. Several aspects, such as design and regulations, fall under more categories - design has to do with technical as well as cultural values and practices - and in the best solutions one cannot go without the other. Furthermore, there is no direct link between the Upstream and Downstream optimisations as resource deliveries and design processes overlap in high-end reuse.

17 (Checkland & Scholes, 1990, Checkland & Poulter, 2006) SSM is in the analysis of complex situations where there are divergent views about the definition of the problem — "soft problems" (e.g. How to improve health services delivery; How to manage disaster planning; When should mentally disordered offenders be diverted from custody? What to do about homelessness amongst young people?).



Technical/practical aspects	Environmental aspects	Commercial aspects	Cultural aspects
Skills and tools/ Education, technologya	**LCA**/ **Energy use (type, scenario, assumptions, amounts) for dismantling process (connections, dimensions, tools, time) and recovering process (tools, time)**	**Costs**/ **Time, transport, labour expenses, supplies expenses**	**Material properties**/ **Weathering, surface characteristics**
Construction/ **Connections, dimensions**	**LCA**/ **Material supplies, lifetime expectancies**	**Availability**/ **Occurrence, access, delivery, storage**	**Design properties**/ **Architectural motifs, customisation potential**
Design/ **Availability, tolerances, replacement parts, quality standards, warranties**	**Hazards**/ **Working environment, toxics**	**Sale**/ **Market, segments, strategies**	
	Regulations/ **Threshold levels, analysis requirements, responsibility**	**Regulations**/ **Quality standards, testing**+	

Figure 10 top/ The close relationship between lifecycle upstream and downstream phases of a building in a high-level end of building scenario in which resources are prevously known as waste.

Figure 11 bottom/ Table showing the elements of the resource 'safety-net'. All aspects must be considered

Project results

Brick, concrete, glass, metal and wood, a total of 20 full-scale prototypes were constructed in the project.

The 1:1 prototypes are the concrete results of the project. Based on the results of the project, the team has developed visions for architecture and new technology.

Material concepts were developed primarily from overall material categories: Brick, concrete, glass, metal, and wood. Based on the material categories, a total of 20 full-scale prototypes were constructed in the project.

Through collaboration with the city of Copenhagen, three graduate students and architectural research interns at Vandkunsten have developed future architectural use of the prototypes in detailed project drawings and illustrations. These illustrations along with numerous exhibitions, articles, lectures, and conferences and debates constitute the communication activities of the project and selected illustrations from their work is avilable in the appendix.

The following prototypes have been constructed/ Selected prototypes are introduced in the following. The primary cases that were seleceted for LCAs, are described the most.

Brick

Roof tiles as facade cladding

Concrete

Concrete floor slab bricks
Concrete wall element bricks (only visualised)
Concrete/Bag-element
Concrete/Bag-element gabion system (only visualised)

Glass

Window systems with rails
Double glazed, version 1
Double glazed, version 2
Glass brick
Float glass version 1
Float glass version 2
Waste window wall system

Metal

Spiro duct shingles
Screen woven from dry wall steel studs
Shingles fromprofiled sheets
Shingles from profiled roof sheets
PVC window frames
Sun-screens

Soft flooring

Vinyl
Rubber facade cladding shingle
Rubber screens

Wood

New Nordic Wall

Figure 12/Visualization of pantile facade

Figure 13/
Section of horizontal system with backside out

Figure 14-15/
Window detail of pantile facade protoype

Figure 14-15/
Corner detail of of pantile facade protoype

Brick concepts
Material group

Brick construction is the most traditional construction method and material in Denmark and roof tiles have been a well-known and long-lasting construction component for centuries as well. Due to the now primary use of flat roofs as well as the use of alternative and cheaper materials, roof tiles are phased out of the market and disappearing from the roofscape.

Sourcing potential

Every year 230.000 tonnes of brick waste is produced in Denmark. As Masonry remains an integral part of Danish building culture when afforded, reused bricks from masonry with lime-based mortar have become an established alternative on the Danish market of construction materials, reaching prices comparable with high-end new bricks. Bricks are reused as the same function as they are cleaned from mortar and reused as building envelopes the highest level of reuse imaginable. Roof-tiles are not reused directly as they are crushed and find use as secondary material in road construction as a stabilizing layer, mixed with crushed concrete. Pantiles are shaped to stack and they are as easily demounted as they are laid. As old roofs are changed, large amounts of roof-tiles are available to source.

Pantile as facade system

The aim for the material concepts developed for reusing pantiles was to maintain features as brick walls in terms of materiality and narrative.
The concept explores the beautiful and durable material of dismantled and sorted units by repurposing the roof-tiles as a vertical building envelope. Facade claddings are less exposed and vulnerable than roof claddings that are laid to stay for 50+ years. A pan-tile facade might add a generation to the total lifecycle of the component. The bond of the cladding can be linear and roof-like or alternatively demonstrate it's shingle-like qualities with a variety of patterns for overlapping.

Prototype

We developed a bracket to fit the hand-molded pantile. This type of rooftile was selected because it is widely common and available in Denmark as well as simple in its geometry.

Assessment

The creation of one standard facade concept is challenged by great variations of tile shapes. This means that custom solutions must be developed for each style of tile. The individual shapes are defined by the way the tiles interlock when stacked on a roof.

For this material concept, the business model can be isolated to be the design and production of specialized mounting systems for a series of tiles. Customers or contractors source their own tiles; they order the mounting system that fits the particular tile.

From top
Figure 16/Prototypes of Concrete Brick Facade

Figure 17/ Visualization of pavement based on prototype of Concrete Bricks prototype

Figure 18/ visualization of perforated facade in a parking facility

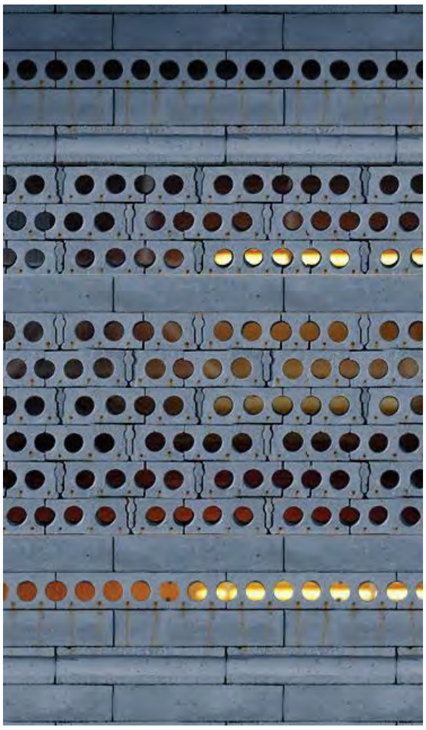


Figure 19/ Visualization of 'sack-brick' facade

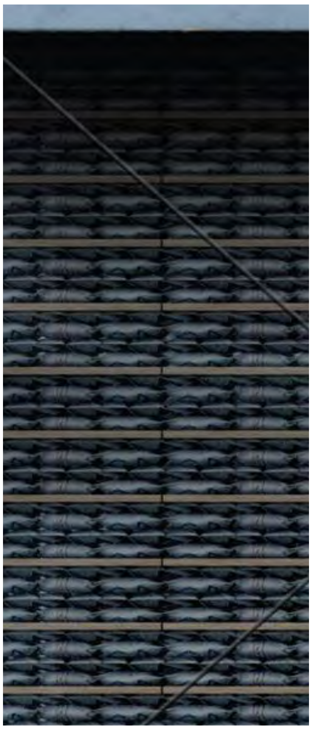


Figure 20/ Sack-brick detail

Concrete concepts

Material group

Concrete is the most widely used construction material and the material group represents the bulk of construction waste. The production of concrete is especially energy consuming due to the firing processes involved in making cement.

Concrete is the biggest challenge for any repurposing strategy because the material components have been designed, reinforced and quality secured for particular purposes. It is difficult to test reinforcement and the condition of the elements. Challenges for sourcing and direct reuse include furthermore that concrete structures are joint-cast, which means that even buildings built from prefabricated concrete elements cannot be separated undamaged as the conventional concrete construction systems require that joints between elements are cast together for optimal structural performance. In Denmark, more than 90% of concrete is reused crushed. At present, the most socioeconomically feasible use of waste concrete is for road and parking pavement bases where the rubble replaces virgin aggregate.[1]
The porous material can be contaminated with Polychlorinated Biphenyls (PCBs), a toxin widely used in construction materials between 1950s and 1977. PCB is another obstacle for concrete reuse.

Concrete slabs as bricks and pavement

This series of concrete concepts is inspired by formats of structural elements and we explore technical flaws as an aesthetic feature such as exposing reinforcement bars that causes rust to stain the facades **Figure 23**

Diamond blade saws are used to cut pretensioned concrete elements in factories. It is costly because the blades are rapidly worn when cutting the hard concrete and they require frequent maintenance and exchange.
After dismantling, the concrete slabs are sliced with circular saws with diamond blades.
The concept is to slice deck elements and use the slices as thin sheet panels for building envelopes or as pavement.

1 Energistyrelsen 2015

Figure 21/
Concrete rubble

Figure 22/
Visualization of cut bricks stacked in iron frames

It was not possible to test the slicing process on site in the project so prototypes are mockups cast in new molds and manufactured to test the weathered look and the general appearance of the concrete facades.

It is possible to produce products of decent aesthetical quality by cutting bricks as differently oriented sections through hollow core elements.

The concept faces a number of critical points. It is expensive to cut; it requires strict safety measures if cutting station is placed on the construction site; elements are heavy and may require lifting gear to handle. There are requirements for testing for toxins; there are technical challenges to ensure that the concrete is not damaged as well as the immediate issue concerning reinforcement and material composition: that the concrete is produced and reinforced to fulfil particular requirements that are far from the future use.

Technical obstacles

→ **Elements need empirical testing.**
Slized concrete may need reinforcement for another purpose.

→ **The prototypes have concrete panels that appear as traditionally fibrereinforced concrete.**
Need to develop effective sourcing/slicing/technology - imagined as the Slab Cutter Bot. **Figure 83**

Concrete rubble as sack-bricks

Concept

This concept is based on the condition that concrete is most easily sourced as rubble. The rubble can be stuffed in sacks as a kind of rubble-sack-brick.

The static properties are very passive and shape and dimensions are notoriously inaccurate. **Figure 18-20**

Figure 23/ Detail of facade prototype from slized concrete slabs. The weathering from reinforcement bars adds character to the surface

Figure 24/ Prototype built from glass bricks

Figure 25/
Detail of glass brick prototype

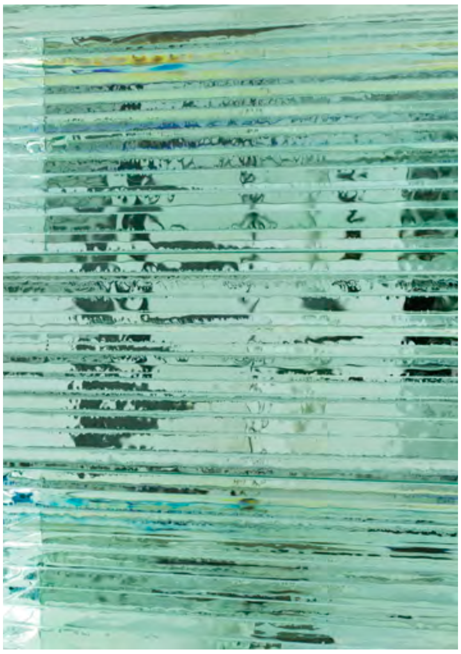


Figure 26/
Mock-up of facade screen with double-glazed windows and wires

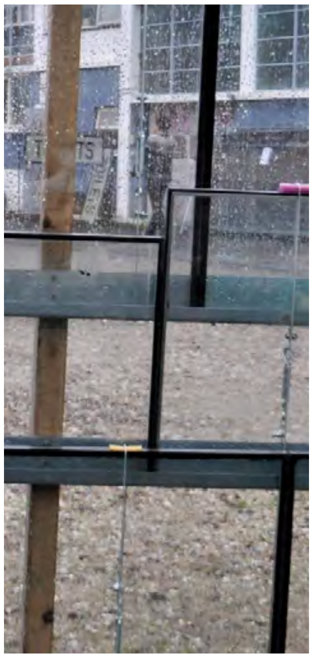


Figure 27/
Illustration of facade system with preused double-glazed windows and wire systemwindows and wires.

Glass concepts

Window production is a major component industry in the construction sector. Glass facades and windows mark the cosmetic face of architecture and the market constantly demands new functional and aesthetic opportunities to distinguish built projects. The technological development in ways to shape glass combined with the focus of development has lowered the life span of windows in most buildings severely compared to old wood-frame windows that could last centuries. Especially in the private consumer markets, glazed windows are a commonly replaced component leaving a large quantity of double-glazed windows as waste.
Windows are easily sourced as components. Presently, waste glass is melted and reused for the production of new glass sheets or glass-based insulation.[2]

2 https://www.a-r-c.dk/media/120916/vejledning_sorter-dit-affald.pdf p. 2

We have developed several ways to assign new function and aesthetic value to this group of material components.

Glass building bricks from waste window panes

Float-glass from insulating glass or single pane windows can be cut up – potentially in an automatized process – and assembled in brick-like units by means of low viscosity silicone.
PCB from old edge sealants can be cut out and collected. **Figure 24-25**

Glass building envelope from double glazed panes

Concept

Double-glazed windowpanes can be used for building envelopes when mounted on battens and fixed with adjustable wire-systems to provide flexibility. In this way differences in dimensions can become a part of the facade expression. **Figure 26-27**

Figure 28/ prototype of glass interior wall with ornamental wedge fixations

Figure 29⁄Two types of cut window frames during prototype production,

Figure 30⁄ Detail of prototype

Glass interior wall from repurposed windows

Raw material

Old wood-frame windows are overflowing the market for reused components. The quality of the wood is often very high and the dimensions most often comply roughly with traditional standards.

Concept

Exact dimensions can be obtained by planning the frames. This makes it possible to adapt window elements to a frame system of steel, wood or aluminium. The prototyped version uses wedges for fixation, a typical DfD solution to enable easy disassembly. **Figure 28**

How

The outer layer of weathered wood and paint is recut from all 12 sides of the window frame. This process is also functions to add value through trimming the window profile to a new and more refined, slender look. The wooden frames are given a traditional outdoor treatment such as paint or oil. **Figure 29-30**

Figure 31/Prototype of Spiro Wall made from flattened ventilation ducts

Figure 32/ Sourced ventilation ducts

Figure 33/ Photocollage showingthe Spiro Facade on Vandkunsten's Sømærk project (original photo by Adam Mørk)

Metal Concepts

Metal spiral ducts as cladding boards

Steel components are handled as scrap metal. The global demand for steel is so high that 100% of available steel waste is reused and go back into the material loop.

Spiral ventilation ducts are tubes made from lightweight sheets of metal and hung under ceilings. The dismantling process is simple due to the mechanical fixation systems. The surfaces of the ducts come in various qualities of electro-, or hot-dip galvanization.

Concept

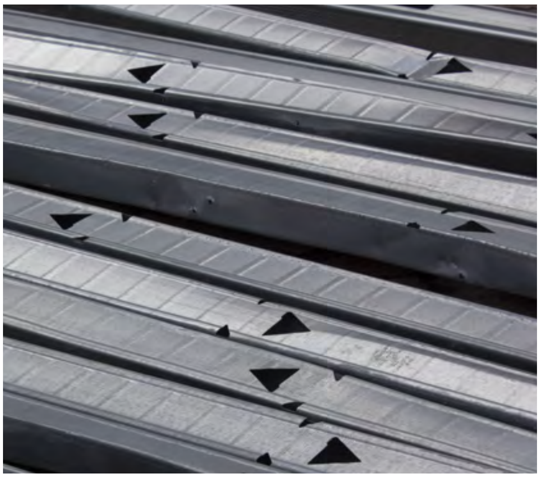
Cladding sheets are made from flatrolling dismantled and cleaned ducts and bending the ends. The result is a stable and durable metal sheet, which can be mounted on battens using a slate cladding system. **Figure 31**

The flattening process might take place on the demolition site, bringing down the volume of transportation. Sheets are cut to manageable lengths.

The mounting detail does not perforate any panels. The components can be flipped or demounted for cleaning or reuse.

Aesthetics

We really like the patterns of the facade. The diagonal lines form a new ornamental pattern on the surface. The concept is so simple and easily applicable. **Figure 33**



From top
Figure 34/ Illustration of metal acoustic panels made from repurposed cable trays

Figure 35/ Cable tray hanging in an office

Figure36/ Detail

Figure 37/ Metal studs from dry wall.

Figure 38/ Visualization of corridor with panels made from steel battens in a woven, sliding system.

Environment and economy

Cleaning the ducts may prove expensive in time as well as possible toxic waste to be deposited. Metal has a near 100% reuse ratio due to the high demand for metals at secondary qualities. Reusing spiro ducts as facades will postpone the energy consuming process of remelting but the high demand for steel may result in primary steel.

The mounting time is an economic factor for facade systems. The montage of the Spiro duct-prototype is made simple: a bracket holds the sheet without the need for holes. This makes the sheet reusable, easily mounted as well as properly sealed from air and water.
Variations in the sizes of ducts and thus sheets will impact the speed of montage but it will also increase the variations of expression.

Metal acoustic panels from repurposed cable trays

Raw material

Cable trays are used in offices and frequently discarded during renovation and refurbishment work. **Figure 36**

Concept

The perforated material is suited for acoustic panels in combination with a noise absorbent, and the profiling makes it easy to assemble a stable panel construction. An alternative repurposing of discarded cable-trays is as sun- or light-screens, where the perforation imparts a fabric-like expression. **Figure 34**

Top Figure 39/Prototype of folded metal shingle facade from scrap sheet metal

Figure 40/Folded metal sheet as metal shingle mock-up

Figure 41/Steel roofing sheets turned into facade shingles- to be used untreated or painted as illustrated in the prototype

Figure 42/ Visualization of architectural facade from reused sheet metal,

Figure 43/ Photo collage to visualize the implementation of the metal shingle concept.

Steel/braided thin/plate studs for partitioning wall cladding

Original component

The lifetime of thin-plate steel-studs in partitioning walls is short due to frequent refurbishment of office buildings in particular. As dry wall partitioning walls have short average functional lifetimes, large numbers of steel-studs are discarded and end as steel-scrap for remelting.

Concept

In case of the partition wall this is done in two ways; **1**/By reusing components from dismantled walls, and **2**/By designing a partitioning wall system, which enables easy dismantling and reuse.

Decorative and robust cladding can be produced by weaving flat studs that have been cleaned and flattened. The concept is imagined for interior purposes; walls and ceilings. **Figure 38**

Metal shingles from repurposed thin/plate profiles

Concept

Uneven sheets of thin-plate steel, zinc or copper can be flattened and cut to standardised dimensions, providing a basis for different shingle cladding systems mounted like shingles of slate or wood. The illustrations show raw sheets as well as folded shingles of a more ornate nature. **Figure 39-43**

Figure 44/Prototype of screen made from sheets of rubber flooring

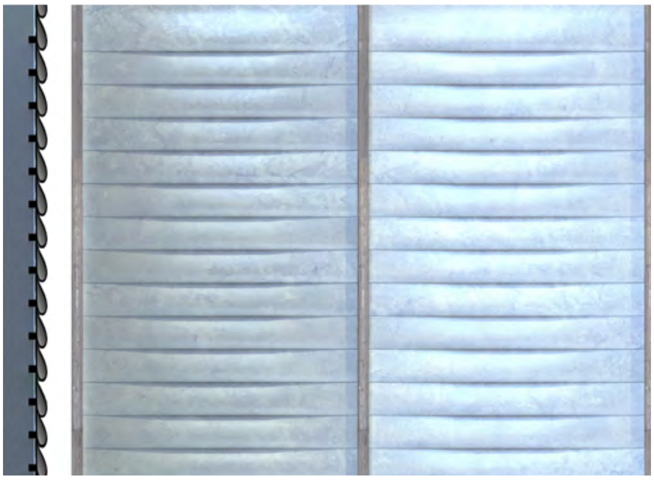
Figure 45/ Detail of prototype screen from woven vinyl flooring

Figure 46/ Detail of prototype screen from woven rubber flooring

Figure 47/Section of folded vinyl pocket facade

Figure 48/Facade of folded vinyl pocket facade

Figure 49/ Photo collage of pocket facade detail



Soft flooring concepts

Raw material
Vinyl flooring as facade panels

Figure 45-**46**/Facade concept reusing vinyl flooring **Figure 38**

Soft flooring concept/ Rubber flooring repurposed as shielding screens

Raw material
Concept

From top
Figure 50/ Connection detail of three wall elements

The New Nordic Wall assembled

Figure 51/ Wall element showing the three layers that shift to define the tongue and groove system

Figure 53/
Visualization of the New Nordic Wall

Wood concepts

New Nordic Wall system from door blades and floorboards

Concept

The New nordic wall is a wooden building block used as an alternative to the common gypsum wall, a building part with a short average lifetime. The system can be industrially manufactured reusing a wide range of interior door blades and scrap wood such as floorboards, windows, doors, panels etc.

The block consists of 3 layers of wood that are shifted mutually to create a tongue and groove system allowing the block to slide into each other to form a self-supporting wall.* The core element is cut from fire-rated doors that may be out of style but consist of high quality softwood such as fir. The thickness of the fire door becomes the standard width of the core ensuring that the tongue and groove will always fit nicely together. The 40x40 cm module is based on half the width of a standard door and a maximum weight of 11 kg for each panel.

Business concept

The sturdy blocks are suitable as take-back systems, leases or for rent as they can be used for short-term purposes such as fairs or other intermediate partitioning walls and screens. The blocks are easy to stack when building walls and the elements easily flat-pack on pallets after production.

Commercial potential

Economy

The concept is a simple way to use even small lengths in the Genbyg workshop. At Genbyg, the product story is often important for the customer experience. Each batch of wall elements can have their own story of the doors or floors of specific buildings in the city which will likely increase their value.

Business considerations

"The value of wood, and the business opportunity to sell it - in any way or form - at prizes comparing to new, depends solely on the story the redesigned product is able to carry. The story, the experience of the product, is the aesthetic and functional value we manage to add to the repurposed material by placing it in a new context"

— Jesper Holmberg Hansen
CEO Genbyg

* The design is inspired by the Norwegian concept of "Stavneblokka", by Gaia Trondheim. http://stavneblokka.blogspot.no

Life Cycle Assessment Screening of Repurposed Construction Products

Life Cycle Assessment (LCA) is a standardized method to evaluate the environmental impacts of products and/or product systems. In the Nordic Built Component Reuse project LCA has been used to compare the newly developed, but reuse-based building products with their new equivalents with the aim to show how the reused products compare environmentally and to identify which material groups will make the most sense to be reused from an environmental point of view.

54

For the assessment we have chosen to limit the calculations to only the impact category Global Warming Potential (GWP) as it is meanwhile commonly used and known as CO_2-impact.

55

The product systems were evaluated in the following order:

Metal Facade cladding made from used spiro ducts
— **Figure 54**

Wood Indoor walls made from used wood
— **Figure 55**

Glass facades made from used windows
— **Figure 56**

56

Concrete bricks made from waste concrete elements
— **Figure 57**

Brick Facade cladding made from roof tiles
— **Figure 58**

All products have been developed by Vandkunsten/Genbyg for potential use as substitutes for standard construction products. The analysed products are all presented and illustrated in project report. The hypothesis is that re-using building elements may provide savings in environmental impact, while delivering the same function as producing new materials. However, an investigation of whether inputs required during the re-use phase partially or fully outweighs the benefits is needed to ensure that the proposed solutions are beneficial in a life cycle perspective. Further, it is important to investigate whether current use of the waste products, is better or worse compared to the re-use scenarios.

57

Coarsely estimated inventory data in the assessment has been provided fully by Danish project partners Genbyg, and are included in the appendix. This includes energy use estimates for different operations in the deconstruction/wshaping/reassembly stage, materials, as well as time use estimates.

58

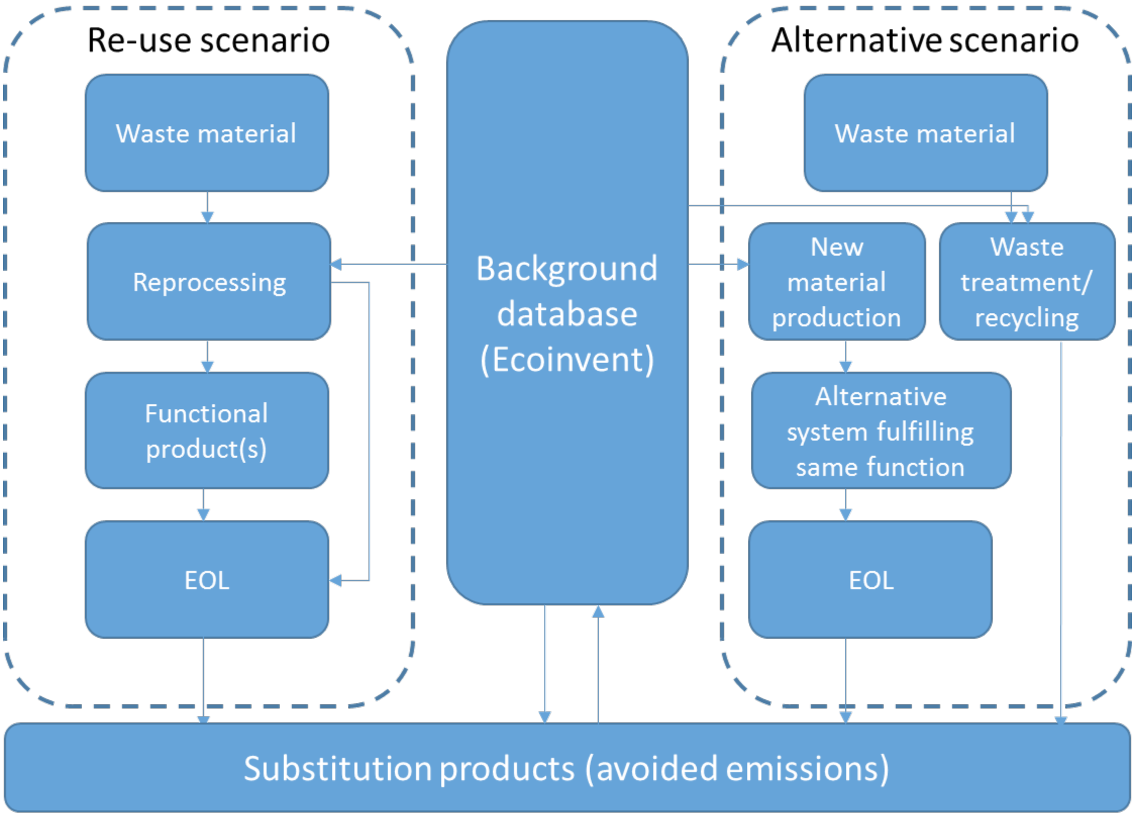


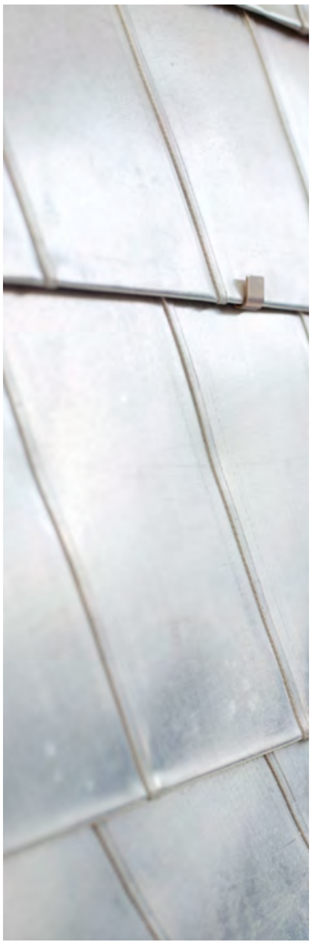
Figure 59/ Overview of comparison scope for the systems

Lifetimes for the analyzed products, as well as for substitution products, have been given by Genbyg. Maintenance and final EOL are assumed to be equal for replacement products and the re-use products. Due to lack of information, substitution assumption used at time zero, are also applied at end-of-life of the products. For future EOL of steel and aluminum this assumption is discussed where relevant. A default recovery rate of 90% for the building components in question is applied to all materials that are recycled. For heat recovery, an efficiency of 70% is assumed, and heat is assumed to replace heat produced by oil combustion. Aluminium and steel recycling replaces virgin material.

Therefore, virgin material is also used as the input for the alternative products where steel or aluminium is used. Glass is assumed to be landfilled, and concrete waste is assumed to replace gravel production. For all systems the re-use scenario is compared to one or more alternative scenarios. This implies that the alternative scenario includes waste treatment/recycling (w/ potential substitution of new material), in addition to producing the alternative solution itself. For the re-use scenarios inputs required from the building site, to finished product, are included. The reclaimed material itself is considered emissions free, since the emissions associated with their production are "sunk cost". Figure 1: Overview of comparison scope for the systems illustrates this set-up.

For operations that are certain to take place in Denmark, Danish electricity mix from Ecoinvent is applied. Otherwise European or global average data is used. General workshop inputs (building, energy) has been coarsely approximately by assuming 1 m² wall construction takes up 20m² of workshop space, for the indicated time use presented by Genbyg. Further, we assume 200kwh/m²-yr energy use in the workshop (in addition to the processing specific energy use).

The building itself is approximated by a hall building from ecoinvent with an assumed lifetime of 50 yrs, and estimated 1900 hrs of useful workshop time per year. Due to lack of data, all transport in the system (from collection site to workshop, or to waste collection site) has been assumed to be 25 km, and performed by either a small truck (to workshop) or large truck (to waste collection site).



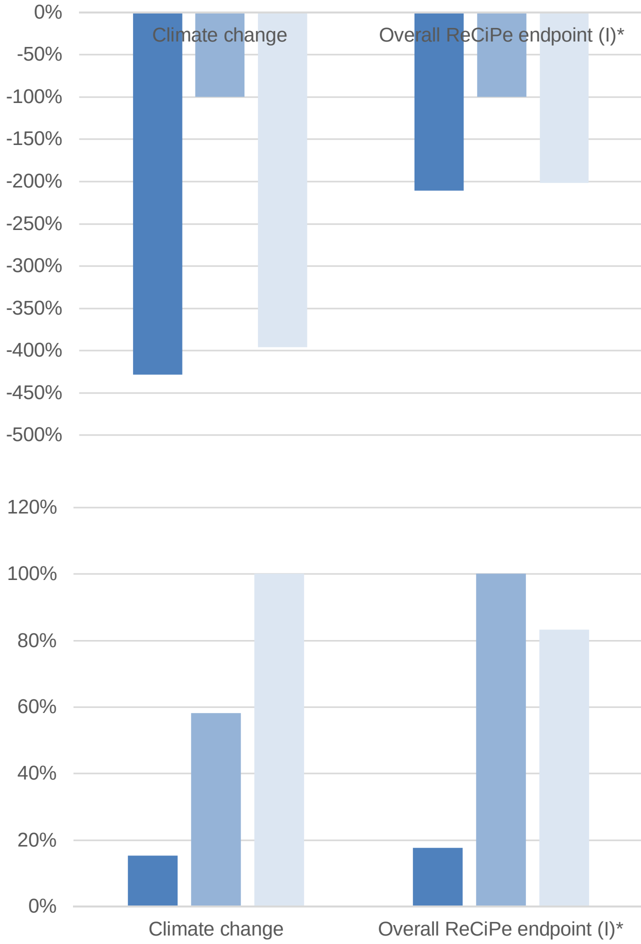


Figure 60/ Relative results for spiro cladding vs alternatives, including avoided emissions from substitution (top), excluding avoided emissions (bottom).

Spiro facade 1m²-yr
Steel facade per 1m²-yr
Aluminium facade per 1m²-yr

Ecoinvent v3[1] has been used as a background database, and Simapro[2] has been used for modelling the system. For impact assessment we use selected categories (climate change and a single score endpoint indicator) based on the ReCiPe[3] method. This contains "equivalency factors" for the different types of emissions, and aggregates the results on either a "midpoint" level (such as the GWP100 indicator for climate change), or endpoint level (in this case an aggregated, weighted indicator for total environmental impact). For cases where the climate effect of CO_2 emissions with biogenic origin may be significant, results are presented for both a "carbon neutral" assumption, as well as an assumption where biogenic CO_2 from the waste treatment has the same GWP-factor as other CO_2. For the weighted "total impact" indicator, we have included EOL biogenic CO_2 emissions with the same impact as other CO_2, as default.
Further, the indicator for total impact is "mPt", which does not have a specific physical meaning, but presents a result to be compared to alternatives. We have used the version "I/A" in the calculations, due to the short time horizon applied in this method, which we feel is closer to the current decision makers priorities, than other versions applying a longer time horizon, and additions, less proven, impact routes.

1 http://www.ecoinvent.ch/
2 http://www.pre-sustainability.com/simapro
3 http://www.lcia-recipe.net/

Results and discussion

Product/Spiro Cladding

The estimated lifetime is 40 yrs. For the alternative products a lifetime of 60 yrs (steel) and 40 yrs (aluminum) have been indicated. Further, 1,1 m² of steel sheet cladding is to deliver 1m² of useful cladding area. For aluminum, the area loss factor is given as zero. Assumed thickness of 1,2 mm for steel, and 1,5 mm for aluminum has been taken from a selected supplier on the web (Ruukki). Production of material, as well as processing in the form of sheet rolling, is included. This is a quite coarse simplification, but considered sufficient for comparison under the scope of the study. All results are normalized to a per m²-year basis. The absolute results for all solutions, broken down on production emissions, substitution (avoided emissions) and net emissions, are shown in Table 1: Production and substitution Figures for the re-use solutions and alternatives. Absolute Figures per m²-yr. Please note that the Figures cannot be used outside the context of this analysis. The absolute Figures give no meaning except in a comparison with the alternative solutions..

Figure 60/relative results for spiro cladding vs alternatives, including avoided emissions from substitution (top), excluding avoided emissions (bottom). presents relative rankings of the solutions. The results indicate that re-use saves emissions compared to producing new claddings, across for both the climate change indicator, and the aggregated impact indicator. The small (material) inputs into the re-use process, contribute little to emissions compared to the emissions of new material production. The results are quite sensitive to the assumptions applied to substitution. The difference between solutions is much larger if there are no avoided emissions in the recycling of the materials. At present, the global demand for low quality (secondary) steel and aluminium, is sufficient to absorb all available material. This justifies using primary material as input, as well as replacing primary material at recycling. However, in reality this may not be the case when the reuse-material cladding reaches either EOL, or the alternatives reach EOL. The avoided emissions may then not be there, if there is a surplus demand of scrap material compared to the need for low grade material for other purposes. Re-using material in new applications will then represent a change that will have an impact on the required new production for fulfilling the same function.

Product/ Wooden elements from used doors

Alternative product: Gypsum clad wall element
As for the other products, inventory data for constructing the used wood wall was given by Genbyg. For the alternative product gypsum clad wall, own assumptions were made, based on internal experience based Figures. It was assumed a material composition of 5 kg planks, 18,4 kg gypsum boards, 0,2 kg paint, and 1,65 kg of glass wool to represent 1 m² of the alternative wall.

The results in figure 63/ relative results for used door wooden wall vs alternatives, including avoided emissions from substitution (top), excluding avoided emissions (bottom), show that if we assume biogenic emissions of CO_2 to be “climate neutral” (which is current mainstream practice), the gypsum clad wall alternative scores better. This is due to the substitution assumption (heat from wood replaces fossil fuel combustion) in which the wood in the two cases combusted with heat recovery. Since the clad wall alternative has more wood in total, the avoided emissions are larger. However, for all other emissions occurring upstream the waste available, we apply the “sunk cost”-perspective. The (inaccurate) “carbon neutral” assumption for wood combustion rests upon an assumption that upstream uptake of CO_2 equals the CO_2 from combustion. We consider the “sunk cost” assumption to be just as relevant to carbon uptake in wood growth. This implies the relevant characterization factor for biogenic CO_2 from the waste wood is similar to any other CO_2 emitted, i.e 1. using this factor the re-use solution comes out considerably better.

This leads to a very interesting discussion on how to deal with products that potentially could be reused at a higher complexity level, but that have a high calorific value that in an EOL scenario actually would substitute fuels and by that will give a more favourable result for the LCA (EOL stage) where the materials are combusted contrary to a reuse scenario, where also further positive effects can or will occure (as eg. carbon storage/ delayed carbon emissions)
Note that in this assessment, we have not included

Figure 61/Indoor wall made from used interior wood

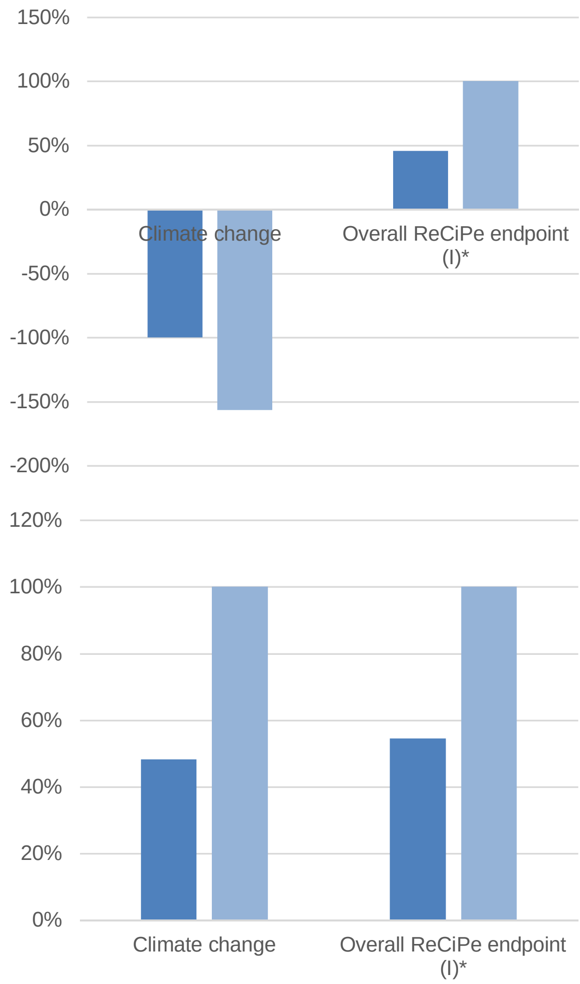


Figure 62/Relative results for used door wooden wall vs alternatives, including avoided emissions from substitution (top), excluding avoided emissions (bottom).

Wood wall 1m²-yr
Gypsum clad wall 1m²-yr

any positive effect for delayed emissions. This means that temporary storage of carbon in wood, is treated with the same impact factor at the end of its lifetime, as today. Recent studies have published characterization factors for temporary carbon storage as well as biogenic emissions (Guest, Bright, Cherubini, & Strømman, 2013)short rotation woody crops, medium rotation temperate forests, and long rotation boreal forests. For each feedstock type and biogenic carbon storage pool, we quantify the carbon cycle climate impact due to the skewed time distribution between emission and sequestration fluxes in the bio- and anthroposphere. Additional consideration of the climate impact from albedo changes in forests is also illustrated for the boreal forest case. When characterizing climate impact with global warming potentials (GWP. In favour of the re-use solution for wood is the argument about delayed emissions as a value in itself, as well as the fact that part of the wood material is still available in solid form at the end of life. Waste treatment options may be different at this point in the future, and climate impacts may be different.

Product

Used window glass facade
Alternative product/Glass facade

As for the other products, inventory data for constructing the used window based facade wall was given by Genbyg. For the alternative product new glass based wall, an estimated material composition was defined by Genbyg. The facade is mainly based on glass, with some aluminium and rubber components. The data is included in the Appendix. The composition of the used glass is both wood, glass and aluminium. We assume similar recovery rates and substitution effects for these materials, as for the rest of the re-use material, even though they are more embedded than other more “pure” components. For glass we have assumed no substitution and that all material goes to inert material landfill.

The relative results to deliver 1m²-yr facade covering are presented in **Figure 63**/ relative results for used window case vs alternatives, including avoided emissions from substitution (top),

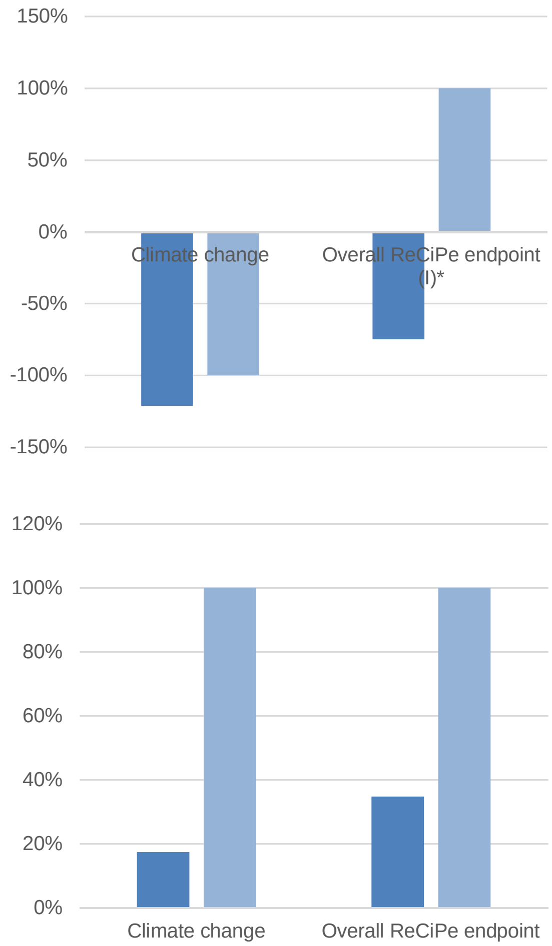


Figure 63/Relative results for used window case vs alternatives, including avoided emissions from substitution (top), excluding avoided emissions (bottom).

Used glass facade 1m²-yr
New glass facade 1m²-yr

Figure 64/Glass facade made from used glazed windows

excluding avoided emissions (bottom). Since there is a considerable amount of wood in the windows, we include the climate change indicator which treats those combustion emissions similar to fossil emissions. Whether including the substitution effects or not, the re-use scenario has lower impact than the new glass facade. The difference becomes larger if we include the climate impacts from wood combustion.

Product

Bricks from used concrete

Alternative product: Clay bricks or new (light) concrete blocks

The re-use scenario that uses used concrete elements to produce bricks, is the only re-use case where the re-use solution comes out significantly worse than alternatives. The reprocessing of the concrete requires surprisingly large amounts of energy, especially for the cutting process. This makes results very sensitive to the assumptions used for estimating energy use, as well as for the emissions intensity of the electricity mix.

We have applied a Danish market mix (from Ecoinvent) as input. Another approach could be to use a larger regional mix (for instance the Nordic average). This would

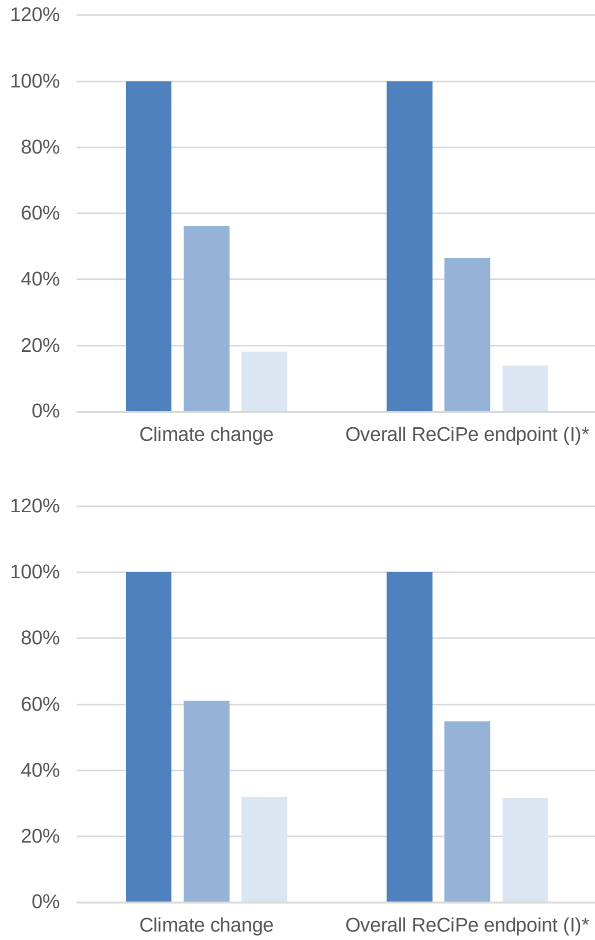


Figure 65/Relative results for concrete brick case vs alternatives, including avoided emissions from substitution (top), excluding avoided emissions (bottom).

Used concrete brick wall facade 1m^2-yr
Clay brick facade 1m^2-yr
Light concrete brick wall 1m^2-yr

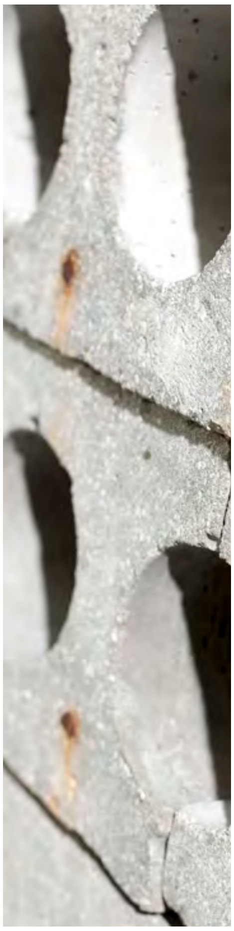


Figure 66/
Concrete bricks made from concrete slabs

shift results in favour of the reuse solution. Another deciding variable is the lifetimes that are applied. Estimated life times are as high as 120 yrs for the brick facade, and 100, and 80 yrs for the concrete bricks and re-use bricks respectively. Applying similar (shorter) life times for all materials would also shift results toward the re-use solution. Finally, the re-use wall weighs about 500 kg/m^2, which also explains why it comes out unfavourable. Processing such large amounts of material, when the same function is covered by much less (new) materials, disfavours the proposed re-use of the concrete elements, even though the alternative materials are emissions intensive, and the current recycling substitution is low quality gravel replacement.

It should be noted that we have not modelled any uptake of CO_2 in the concrete construction, neither during use, nor EOL. For EOL we assume the intended re-use as gravel replacement means less exposure to the atmosphere

Product

Facade from roof tiles

Alternative product: Steel sheet cladding or brick facade

Inventory data for the roof tile facade is included in the Appendix supplied by the producer. The estimated lifetime is 40 yrs. For the alternative products a lifetime of 60 yrs (steel) and 120 yrs (bricks) have been indicated. Further, about 48 kg used roof tiles is needed to deliver 1m^2 of useful cladding area. All results are normalized to a per m^2-yr basis. The absolute results for all solutions, broken down on production emissions, substitution (avoided emissions) and net emissions, are shown in **Figure 69** Production and substitution Figures for the re-use solutions and alternatives. Absolute Figures per m^2-yr. Please note that the Figures cannot be used outside the context of this analysis. The absolute Figures give no meaning except in a comparison with the alternative solutions..

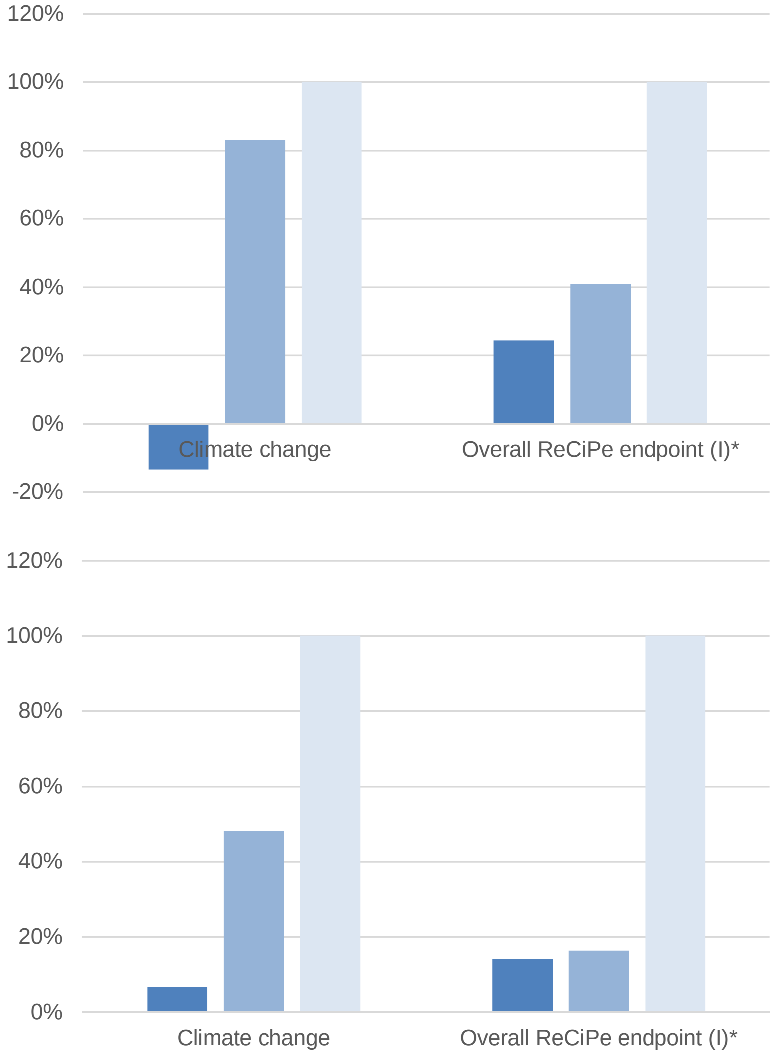


Figure 67/Relative results for roof tile case vs alternatives, including avoided emissions from substitution (top), excluding avoided emissions (bottom).

Tile facade 1m²-yr
Clay brick facade 1m²-yr
Stele facade m²-yr

Figure 68/Facade cladding made from roof tiles

Figure 67/ relative results for roof tile case vs alternatives, including avoided emissions from substitution (top), excluding avoided emissions (bottom). presents relative rankings of the solutions. The results indicate that re-use saves emissions compared to producing new facades, for both the climate change indicator, and the aggregated impact indicator. The small (material) inputs into the re-use process, contribute little to emissions compared to the emissions of new material production.

Impact category		Climate change	Climate change, incl biogenic=0,61	Overall ReCiPe endpoint
Unit		kg CO_2 eq	kg CO_2 eq	mPt
Used concrete brick wall 1m^2-yr	Production	0,78	0,82	62
	Substitution	-0,16	-0,16	-15
	Net	**0,63**	**0,66**	**47**
Clay brick facade 1m^2-yr	Production	0,48	0,48	34
	Substitution	-0,13	-0,13	-12
	Net	0,35	0,35	22
Light concrete brick wall 1m^2-yr	Production	0,25	0,25	20
	Substitution	-0,14	-0,14	-13
	Net	**0,11**	**0,12**	**7**
Used glass facade 1m^2-yr	Production	0,16	0,47	44
	Substitution	-0,77	-0,77	-59
	Net	**-0,61**	**-0,30**	**-14**
New glass facade 1m^2-yr	Production	0,91	1,34	127
	Substitution	-1,41	-1,41	-108
	Net	**-0,50**	**-0,07**	**19**
Spiro facade 1m^2-yr	Production	0,29	0,29	37
	Substitution	-1,42	-1,43	-390
	Net	**-1,13**	**-1,14**	**-353**
Steel facade per m^2-yr	Production	1,11	1,13	210
	Substitution	-1,37	-1,38	-377
	Net	**-0,26**	**-0,25**	**-167**
Aluminium facade per m^2-yr	Production	1,91	1,92	174
	Substitution	-2,96	-2,97	-512
	Net	**-1,05**	**-1,05**	**-338**
Wood wall 1m^2-yr	Production	0,22	0,96	80
	Substitution	-0,82	-0,82	-59
	Net	**-0,60**	**0,13**	**21**
Gypsum clad wall 1m^2-yr	Production	0,46	1,72	147
	Substitution	-1,40	-1,40	-100
	Net	**-0,95**	**0,32**	**47**
Tile facade 1m^2-yr	Production	0,06	0,18	26
	Substitution	-0,13	-0,13	-10
	Net	**-0,07**	**0,06**	**17**
Clay brick facade 1m^2-yr	Production	0,43	0,44	30
	Substitution	-0,02	-0,02	-2
	Net	**0,41**	**0,41**	**28**
Steel facade per m^2-yr	Production	0,90	0,92	187
	Substitution	-0,41	-0,41	-118
	Net	**0,50**	**0,51**	**69**

Figure 69/Table showing production and substitution figures for the re-use solutions and alternatives. Absolute figures per m^2-yr. Please note that the figures cannot be used outside the context of this analysis. The absolute figures give no meaning except in a comparison with the alternative solutions.

Discussion

'...glass facade, spiro facade and wooden interior wall, all show clearly that reused products can substitute new products with an environmental advantage compared to new products.'

General discussion of LCA and concluding remarks

From the results presented in the previous sections it is evident that reusing building materials is favourable in all those cases where the energy and/or material input for sourcing, processing and manufacturing of the "reuse material" is lower than the inputs necessary to produce new materials.

As for the chosen examples in this study, all reused products except the concrete bricks are favourable from an environmental point-of-view compared to the new products replaced.

The concrete brick example is interesting as it shows how difficult it is to find a reuse scenario for concrete at a higher "integration level", which not only returns a useful product, but is also favourable compared to the standard EOL-scenario in which concrete is crushed and replaces gravel. The assessment of the concrete brick wall shows app. 5 times higher impacts for GWP than the newly produced light concrete block, this implies that also a further optimization or upscaling of the reuse process will not render the reuse product considerably better compared to the available alternatives.

The three other examples, glass facade, spiro facade and wooden interior wall, all show clearly that reused products can substitute new products with an environmental advantage compared to new products.

The reuse process is low on energy and/or material input in these cases and the reused products replace new products that are – resource-wise – quite costly (as steel or glass).

More generalized this study shows that building materials where the current EOL-treatment has low substitution effects are most favorable to be reused. This is due to the low benefits from actually treating the materials at EOL. This will for example apply for materials that have low calorific values, demand larger amounts of resources in the treatment processes, or create emissions at EOL that could otherwise be saved.

Furthermore some of the proposed reused materials (e.g. spiro-facade) will directly replace a new product and hence reduce the total demand of new materials while providing the same service over the same expected lifetime. This one of the examples for which the reused products still turn out to be more favorable in an environmental perspective than the new product which already contains a great share of recycled material (e.g. steel or aluminium). The maintained "integration level" in the reused product can be named as one reason for this. In the Spiro Duct Facade, for example, the ducts have already embedded a larger share of the further processing that would be needed to produce facade cladding from virgin materials (rolling of metal, galvanizing, etc).

Upscaling

All product systems presented in this study are based on a large share of manual work in both the sourcing and further processing of the used building materials. The assessments of the processes as done by Genbyg clearly show that a high degree of labor-intensive manual work had been necessary to transform the used materials into a reuse product. (Note that the new products compared with are produced at a factory-scale). In a future scenario in which a greater demand for reused products is expected, these processes could be upscaled and industrialized or even automated. This might reduce the amount of waste produced and the overall resources needed.

Integration level

The integration level of a product describes how much input beyond pure ressources or eventual emission have been expended on the production of a building material. These inputs can be knowledge, development, complexity and/or other qualities that have been added by design that highten the value of a product. Normally products will get more specific with an increased integration level, that again will limit the marked at EOL. Material groups where both can be achieved, maintaining a high integration level while replacing resource intensive new materials can thus be seen as the most favourable products to enter the reuse process.

Lifetimes

Lifetimes have been identified to have a relevant impact on LCA calculations.

For this study lifetimes for the reused products have been assumed based on the quality of the reuse product, the future usage and the substituted new product. As the reuse products represent building materials at a quality level comparable to new products (due to the reuse process) in most cases equal lifetimes have been assumed.

As for the reused materials lifetimes not only are of a technical or functional nature, but also the aestethic or economical lifetimes are relevant. The reused products already bear patina from the earlier usage, which in the case of the examples in this study actually adds to the value of the reuse product and will be a factor to prolong lifetimes .

Cost-benefit and outlook

The processes needed to reuse building materials in the project are manual and relatively costly compared to the new – factory based – products. A high manufacturing

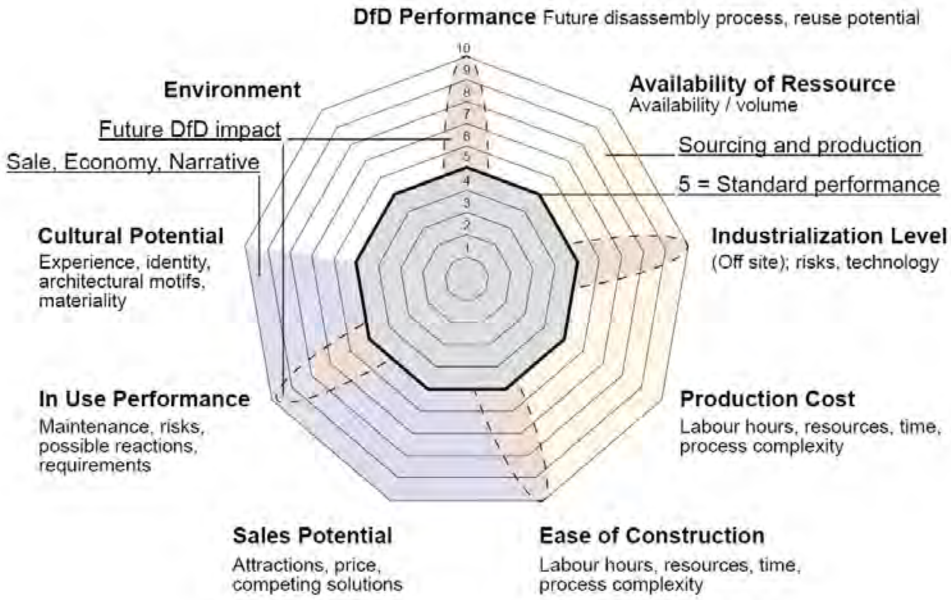


Figure 70/Assessment chart, main value categories –

The grey zone in the radar diagram indicates values below conventional performance (5). Other colors: While "Sourcing and production", and "Sale, Economy, Narrative" connect in groups of values, the impact of the DfD performance of concepts affect future cycles of reuse more scattered along the diagram.

se of the examples in this study actually adds to the value of the reuse product and will be a factor to prolong lifetimes .

Cost-benefit and outlook

The processes needed to reuse building materials in the project are manual and relatively costly compared to the new – factory based – products. A high manufacturing price may cause reduced demand, despite the lower environmental impacts of the reuse products. The future economical part has not been the main interest in this study, but it is necessary to point out that the economical surplus can be transformed into an environmental advantage. Furthermore, environmental impacts will be increasingly relevant in the future and thus all strategies to reduce future impacts should be welcomed and prioritized.

Broad Assessment of Results

As the LCA results show, it is possible to devise numerous material systems for reuse that are more environmentally friendly than using new materials. Concepts need, however, to score high on a range of parameters in order to be merchantable. Besides the environmental parameters previously discussed, the project has economic, technical, and cultural parameters embedded in each prototype as well as varying design levels for future disassembly. Each will influence sales perspectives and the commercial success and implementation of the system. A clear pattern cannot be seen at present yet. As a response to this challenge, obstacles and potentials for each prototype have been assessed in regards to the following categories: Availability / volume, Industrialisation preparedness, Production Costs; Sales potential; Ease of Construction; In-use performance; Cultural performance; Environment; DfD performance.

Each category has an assessment scale of 0-10 on which 5 represents traditional 'new' material solutions and conventional, industrialized processes. This means that 5 and above is promising in this assessment and values below 5 are more challenging: Assessed values can be viewed in the assessment table (Figure 80). On the Figure the dashed line indicates the level of standard performance of new components. Everything on or above this line is interesting to pursue and assessments above 5 indicates a better performance than the conventional alternative.

The multi-parametric assessment matrix includes important aspects of the project. A general look at the assessments shows that all selected prototypes perform well in categories of cultural potential and DfD performance. This can be explained by the explicit focus on aesthetics and DfD in the development of concepts. It also means that the matrix can be used to asses a range of other systems in the future. Some factors turns out to

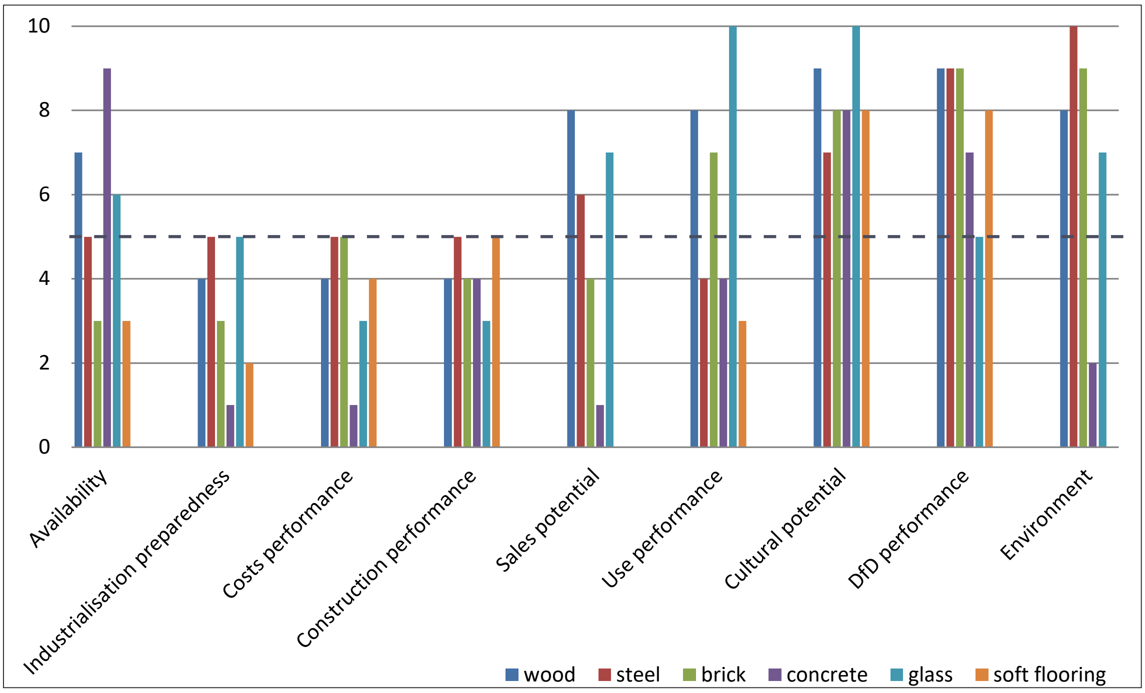


Figure 71/ Assessment chart, main material categories. The dashed line indicates standard performance of new components. Everything on this line or above performs better than the conventional alternative.

Availability/volume

Wood, steel, concrete, and glass are available resources; they are assessed on or above average for conventional products.

Industrialisation preparedness

(Off site); risks, technology

All but Steel and Glass are rated lower than traditional/new products. Productivity has not been the focus of the project and with the prototyping nature of the project this assessment is not that bad. With an increased volume in production, the industrialization value is expected to increase.

Production Costs

Labour hours, resources, time, process complexity Cost performance is assessed to be 5: comparable for new products for Steel and Brick, 4 for Wood and Soft flooring, which is below average. Glass is costly at 3 and Concrete is assessed to very costly at 1.

Sales potential

Attractions, price, competing solutions

At 6-8 Wood, Steel, and Glass are assessed to have high sales potential, at 4 Brick is under average, and at 1, the sales potential for Concrete is assessed to be poor.

Ease of construction (on site)

Risks, difficulty

At 5, all but Glass are assessed to perform on average or above average. This mean that the concepts are easy to assemble and mount on site and comparable to 'similar' products. Only Glass performs poorly here. It is a delicate product to be carefully stacked.

In-use performance

Including maintenance, risks, requirements, possible reactions At 7-10 Wood, Brick, Concrete, and Glass concepts are assessed to perform excellently in use with easy maintenance. Steel is assessed to will perform at the same level as other steel plate facades. Only Soft Flooring is assessed to work poorly in use.

Cultural performance

Experience, identity, architectural motifs, materiality

At 7-10 all concepts are assessed to have very high cultural value, much higher than conventional and comparable products.

Environment (LCA)

Based on the LCAs at 7-10 all concepts but concrete are assessed to perform very high above average. Concrete is the only concept with a poor assessment.

DfD performance

Future disassembly process, reuse potential

At 7-9 Wood, Steel, Brick, Concrete, and soft flooring perform very high. This is a consequence of the design principles. At 5, the DfD performance of Glass is comparable to a 'new' product.

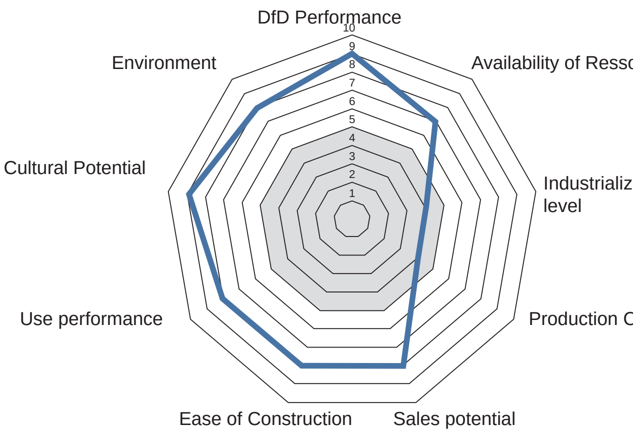


Figure 72/

Wood/Assessment of Prototype Performance

The assessment of the wooden Nordic Wall is positive over all. 5 indicates a traditional solution with new components.

Economically, the concept is estimated to be a little below traditional component (new drywall) in terms of industrialization level and production cost. All other parameters are estimated to contain a high potential.

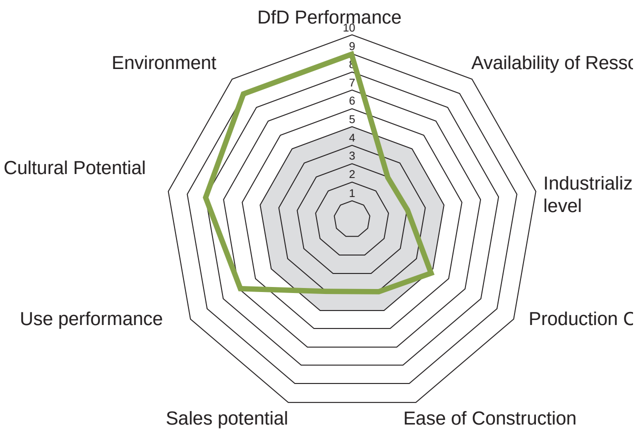


Figure 73/

Brick/Assessment of Prototype Performance

The assessment of the Pantile facade is not promising for a commercial breakthrough.
Four out of 10 parameters are assessed as lower than for a traditional cladding system from traditional cladding bricks or a steel facade.

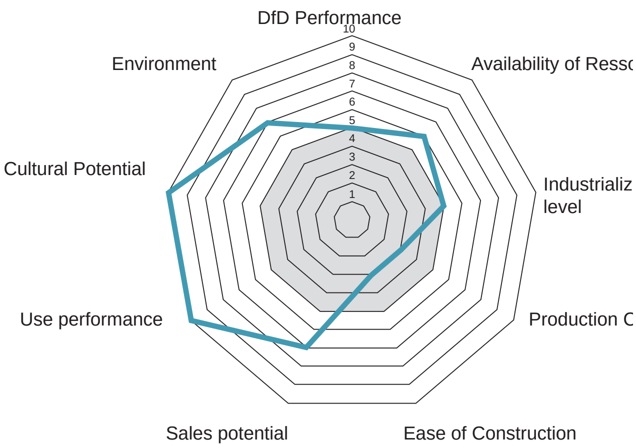


Figure 74/

Glass/ Assessment of Prototype Performance

The assessment of the selected Glass prototype is very positive in terms of cultural potential, use performance, sales as well as environmental performance (LCA). DfD, Availability, Industrialization are comparable to new products.
Cost of production and ease of construction are assessed to be low at this stage. These parameters can be improved and the high merchantability suggests that there is a niche market for this delicate system

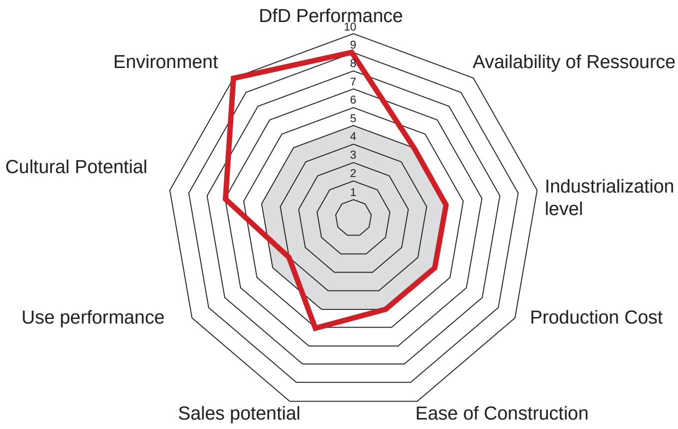


Figure 75/

Metal/Assessment of Prototype Performance

The assessment of the Spiro-facade can be labeled as the least negative as only in Use Performance with a 4 is assessed to be slightly lower than a new product.
At 5, the concept is assessed to be comparable with new product systems for Availabilty, level of Industrialization, Production Cost, and Ease of Construction. At 6, Sales potential is a little higher than conventional products and at 7, Cultural Potential is markedly higher than conventional cladding systems.

At 9 and 10, Spiro Wall is assessed very high environmentally, in terms of LCA and Design for Disassembly Performance.

The cultural potential includes aesthetics. Here, the Spiro Wall has a very familiar look with a novel twist and possible variety as well as subtle narrative of its former use.

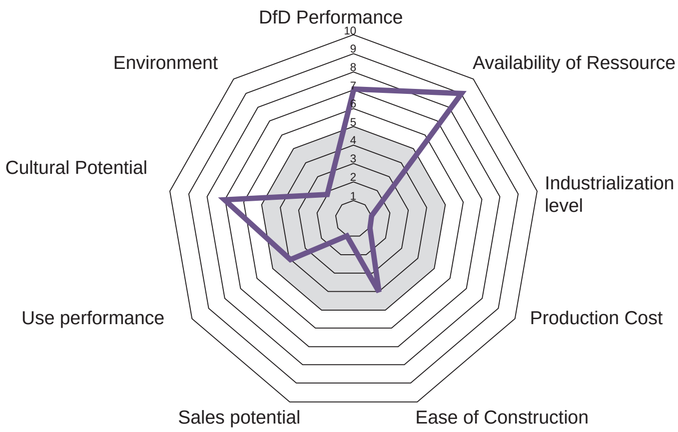


Figure 76/

Concrete/Assessment of Prototype Performance

The assessment of the selected concrete system is poor as 6 out of 9 parameters are assessed to be lower than new brick walls made from clay bricks or light concrete bricks. With 1's for Industrialization Level, Production Cost, Sales Potential, and 2 for Environment, assessment is very bad. In contrast to the other expensive but marketable concepts the concrete brick prototype performs poorly on most parameters; production cost, industrialization level, sales potential, in use performance. The DfD performance as well as the cultural potential of reused concrete left to weather are rated high.
Concrete does constitute the largest volume of construction waste discussed in the project. Unfortunately concrete has a poor LCA. On top, concrete is expensive to repurpose and consumes more resources than the existing downcycling practice due to use of heavy equipment, engineering resources, on-site manpower, and safety precautions. Furthermore, technical challenges are added when cutting and reusing concrete without taking reinforcement in consideration Finally, reusing concrete face technological challenges to scan for PCB and other toxic materials.

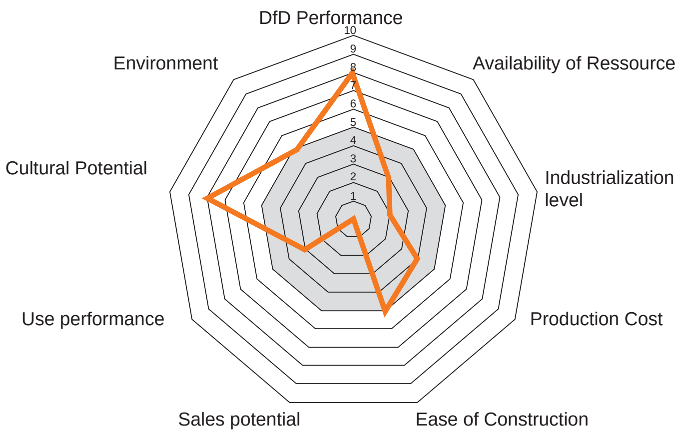


Figure 77/

Soft Flooring/Assessment of Prototype Performance

The assessment of Soft Flooring is poor for several reasons.
5 of 9 parameters are assessed to be performing markedly lower than conventional products.
As a consequence of toxic fumes from Vinyl flooring, the product cannot be resold and the Sales Potential is 0.

Existing business

- Small scale manufacture of one of-furniture design from repurposed materials for design pieces and individual furniture. Sold via web-shop and commissioned in custom dimensions.
- Resells 'fun' objects and material or components as sourced, in web-shop

New business/service

- Custom-made large-volume system products such as walls or facades.
- Design and production contracts via own independent design studio.
- Prototypes and manufacture in expanded workshop

Figure 78/ Existing and expanded business models of Genbyg

be so-called 'knock-out' criterions, which means that products are ruled out when they cannot comply with regulations and technical standards. Others are assessed to be appropriate but on conditions, such as to be used for interior purposes only. While the parameters are comparable, the value listed for each prototype are more relative to specific situations and premises and cannot necessarily be compared.

Concrete remains the problem child

A preliminary conclusion, which can be made until technological inventions possibly changes the current conditions, is that concrete is extremely expensive to repurpose and, what is worse, the resources saved by salvaging are less than those needed for rehabilitation processes. A preserving dismantling of concrete includes excessive use of heavy equipment, engineering resources, on-site manpower and severe safety precautions. On top of this is the ubiquitous toxicological risk of containments of PCB from sealants soaking up in the surrounding concrete.

This is regretful given that concrete constitutes the largest volume of construction waste. The NBCR-team has spent time and effort proportionate to concrete's share of the total amount of construction waste, and yet it has not been able to suggest a single feasible repurposing solution. Further research is needed within the field, and/or a long needed reconsideration of whether concrete and the way it is assembled deserves its current dominant position.

Utilization of project results

Physical results, in terms of concept prototypes as well as methods and experiences gained through the process, are utilized by the project partners, Genbyg, Vandkunsten, and Asplan Viak.

Utilization of results by Genbyg

For Genbyg, the project has been a direct catalyst for new projects and services and thus influential to the business development:

→ **The Nordic Wall concept prototype is currently in production at the Genbyg workshop and for sale on their web shop.**

→ **20.000m^2 of a variety of wood reuse concepts have been commissioned for Copenhagen Towers.[1]**

→ **The pantile facade concept has been commissioned and is manufactured for a new built.[2]**

→ **The company has established an architecture studio and hired architects to work with design and manufacture of component repurpose design.**

→ **The company has established a 1000 m^2 workshop, directly derived from the project.**

→ **Genbyg uses project results to accelerate the expansion of their products span.**

1 Lendager Architects for Norman Foster Architects
2 Both comissioned by Danish design firm Lendager Architects

The NBCR-concepts can be described as 'prepared system components' in between objects and components resold in the condition as sourced, and those used in furniture. **Table 78**

Genbyg's position when engaged in commissions has furthermore been strengthened by the experience obtained during the project:

Knowledge of barriers regarding logistics as well as the documentation and assessment of workflows enable Genbyg to more accurately calculate the price of customized commissions as well as suggest the environmental impact of reuse in particular cases. Furthermore, the project has shown that it is not simple to compare new components with repurposed components with neither clients nor contractors. It is a new practice and mutual insights and experiences must be gained across the sector for its full implementation. In the future, strategies for sourcing and repurposing components in projects will require early involvement by Genbyg

Utilization of results by Vandkunsten

While material concepts may prove applicable in future Vandkunsten projects, the most direct utilization of results for the architecture studio is at present using the analytical tool as well as the documentation of workflows relating to the LCAs.
The analytical tool can be used with clients to analyse existing structures for reuse of resources of cultural, economic, and environmental value.
The concepts have been developed further by students in the project "Recycling Station – design strategies for material reuse" made under supervision by Vandkunsten. Construction drawings as well as numerous visualizations from the project are important tools when bidding for projects and developing ideas for clients.
The LCA work further strengthens Vandkunsten's aim to provide evidence for the economical, the environmental, and the social sustainability of projects.

Utilization of results by Asplan Viak

For Asplan Viak, the documentation of the 1:1 prototypes are a display of possibilities for clients and can their principles can be translated to individual projects and reusable resource. The work may also contribute to positioning partner Asplan Viak in the field of circular economy, with regard to R&D projects as well as to building transformation projects with environmental goals.

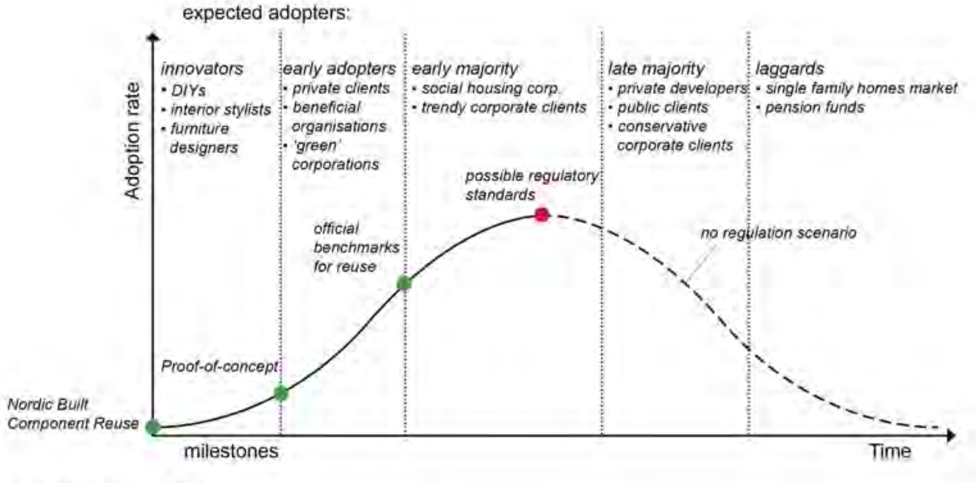
The concrete prototypes and the accompanying image material are visually persuasive which assist the credibility of the ideas. Asplan Viak has used the material in a series of presentations for business as well as students. Work is carried out to pursue further R&D projects related to recycling and the Circular Economy.

DfD principles are not presently applied in Asplan Viak projects. Yet, updated knowledge of the principles increases chances of winning relevant projects. Furthermore, the LCA results of the prototypes contribute and broaden the company portfolio of LCAs.
For Asplan Viak, the cross disciplinary approach of the project has been inspirational in general and specifically in the Nordic context in which Danish companies seem to pioneer the Circular Economy.

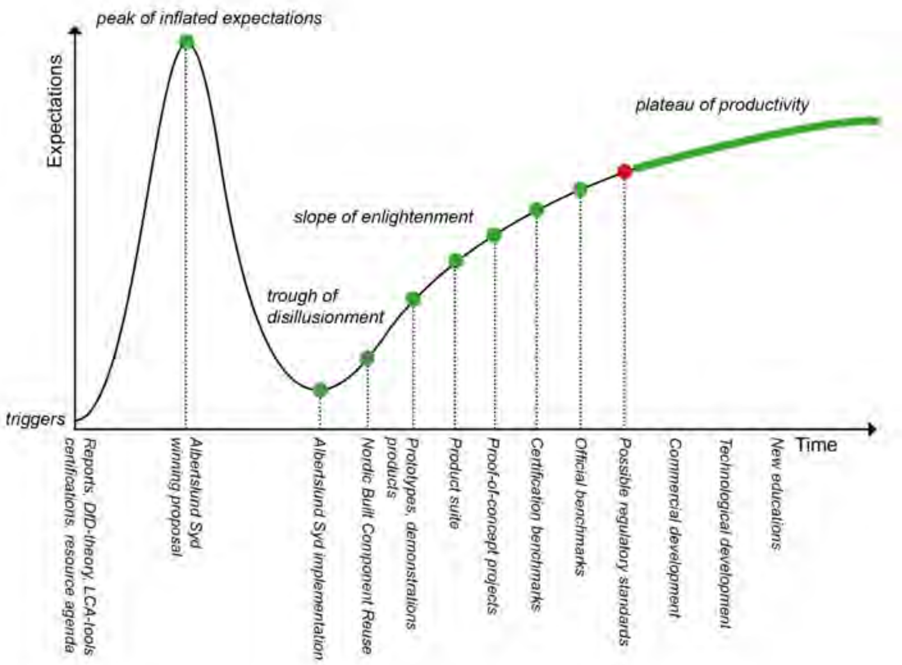
Legislation to assist Market adoption and hype-cycle

Expectations and perspectives from the NBCR project are rooted in experiences from similar development processes through post-WWII history as implied in **Figure 79-80**. A well-known example is the 'construction' of the Danish concrete industry through a carefully orchestrated political process that combined commercial interests and cutting-edge technology of that time with public regulation and centrally controlled urban planning.[3] This master plan provided a solution to the contemporary housing shortage and resulted in a major upheaval of construction methods. The current and future resource shortage could be solved applying similar legal tools and we would like to see the NBCR-project inscribed in such an ambitious plan across sector and industries.

3 Eva Boxenbaum; Thibault Daudigeos / Institutional factors in market creation: Concrete theorization of a new construction technology. I: Academy of Management. Proceedings and Membership Directory, 2008



Adoption cycle diagram



'Hype-cycle' diagram

Figure 79/Adoption cycle diagram, adapted from Gartner, www.gartner.com

Figure 80/'Hype-cycle' diagram, adapted from Gartner, www.gartner.com

Evolving of the project

The development period of the NBCR project was approximately 18 months. This short-term perspective resulted in an efficient and intensive collaboration process. The explorative and making-based nature of the project has led to great enthusiasm all through the team.

The project evolved roughly according to the set schedule. The overall structure of the development process remained intact throughout the period, whereas some of the titles of the milestones changed. In autumn 2014 an opportunity for exhibiting in Oslo appeared, which on the one hand speeded up the process before the event, but heavy logistics caused some exhaustion on the other.

Figure 81/
Facade concepts for reused vinyl fail due to environmental reasons.

Figure 82/
Flowcharts used for LCA and assessment of manufacture process as well as level of industrialization – see the appendix

Figure 83/
Repurposing concrete requires heavy amounts of energy and reuse scenarios for concrete fail as they are significantly poor environmentally.

The workshop production of mock-ups evolved unexpectedly efficient. The team received help from sympathizers who volunteered to track down waste material or kindly offered their consultancy, and from talented architect students whose semester curriculum included reuse strategies.

An internal design competition was held at Vandkunsten (December 2014 – January 2015) in order to gain a maximum of design ideas. 18 entries were assessed by the NBCR-team as a jury. Two entries were selected for realisation as full-scale prototypes. Both were metal concepts (acoustic panels from waste cable trays(page 35) and facade shingles from thin plate metal waste), while four others received honourable mention but were not executed as prototypes.

Problems, failures, risks and shortcomings

Feasibility

Commercial feasibility was the highest risk of the project. In fact only the the Nordic Wall has developed into a marketable product at Genbyg's web-shop . One reason is that a stable delivery is hard to maintain. This challenge has led to a new business model that is based on custom made to order and system principles rather than fixed products.

Failure

In creative and innovative processes that have shaped this project, successes emerge from numerous accounts of trial and error - and failures are inevitable. Hence, some concepts failed and were ruled out by poor LCAs or cost-evaluations, others by the environmental evaluation even though they lived up to other quality parameters for becoming a marketable product. **Figure 81-82/**

Logistics

Handling the odd size waste materials and managing the workshop logistics proved a challenge for the team. Between Vandkunsten and Genbyg, there was
not the necessary available workshop space. We hired a shipping container and fitted it with tools as a workshop venue. It quickly became too small and much time and effort was spent on logistics.

Technology

Technology has been an unexpected challenge as we were unaware of which technologies that could enable a feasible production line; they may not exist yet; or have not yet been applied for the purpose. In such cases, we envisioned and illustrated possible technological scenarios that may be pursued in further projects.
Assessing commercial potential related to repurposing and upcycling waste components is significantly dependent on the time perspective. As an upcoming branch of the building materials market expectations are closely related to

the development scenario for regulations and technological innovation. The NBCR-project unfolds under premature market conditions and thus aims more for preparing the market than for exploiting an existing potential.
The assessment scheme planned to be developed with qualitative and quantitative input proved too complex and difficult to compile. Evaluation based on data such as the flowcharts and LCAs were simple but the assessment of cultural or commercial potentials have so many unknown factors. The initial assessment matrix and descriptive cobweb diagrams are included nevertheless to enable input and discussion of this point with actors in the sector.

Based on the experience of the team, a series of technological visions were created that combine existing technologies with our context of repurposing building materials. Naïve as a 'Slab Cutter Bot' **Figure 84** might appear (imagine the mandolin slicer tool from your kitchen drawer sized to slice concrete slabs on site),

While working on the prototypes it became clear that numerous operations necessary for practicing reuse could be carried out more efficient and economically viable if supported by technologies. Some exist today, others need further development or transfer from other industries. Therefore, as a part of the project, the team have spent some work on defining and visualizing the anticipated technology. On the following pages are a few visions that we have illustrated: the Slab Cutter Bot that slices concrete elements on the demolitions site, the sorting plant, the scanner of toxins in building materials, and a close-up of the wood sorting and cleaning factory.

Dissemination of results

The material nature of the project has allowed it to be displayed and discussed at exhibitions and conferences in Scandinavia and the United States. The prototypes themselves have been exhibited in Oslo, and at different venues in Copenhagen and are presently on display at the Vandkunsten office. A list of dissemination activities can be found in the appendix.

Basis for further development

What's next

To establish an actual practice of reuse, more demonstration projects will be required, initially on an experimental basis, later as full-scale implementation in construction projects. An eventual successful full-scale implementation will stand out as a proof-of-concept test, leading to more similar projects in which the know-how will become refined. (See the adoption cycle diagram).
We see the project as an agent that contributes to preparing the ground for a market development through inspiration and discussions of the initial physycal demonstration models.

Demonstration strategies for certified buildings

Applying the NBCR-strategies with clients can enable projects to achieve certifications with DfD demands. The next step is demonstrating the results of the project in practice.
The physical prototypes, images, and the illustrations have been discussed in a number of seminars as will be listed in the appendix. These concrete suggestions of future scenarios and LCAs have led to engaging major public clients in a dialogue to find a small building project where the NBCR-products and ideas can be demonstrated.
The products, prototypes, ideas, and methods will now be deployed in up-coming assignments. Each partner in the team will have individual approaches and opportunities to continue parts of the project

— deepening particular aspects or widening the scope, whether it is demonstration projects, ordinary commissions, decoration purposes, improved sales infrastructure or analytical tools. It is likely that partners of the team will collaborate in the future. We have projects in the pipeline and will be able to suggest site-specific material concepts in future bids and competitions.
The NBCR-project point forward to new projects: For extra validity and aid the implementation of reused material components, LCA models need further development. The market for LCAs is growing, yet LCA models do not anticipate a reuse cycle prior to incineration. Nor do LCA incorporate the impact of aesthetics on the lifetime of buildings and compo-nents. This means that LCAs for new materials sometimes will achieve better results than they ought to.

Benchmarking perspectives

A way of phasing in standards pre-regulatory is through industrial certification systems such as DGNB-DK or BREEAM-NOR. The certification systems set even very ambitious targets for single parameters, and provide reliable assessment procedures. In a proof-of-concept scenario one or more certification system is very likely to be involved. The certification systems constitute important tools for establishing benchmarks for what is possible. They are, however, not capable of influencing the wider market.

Educational perspectives

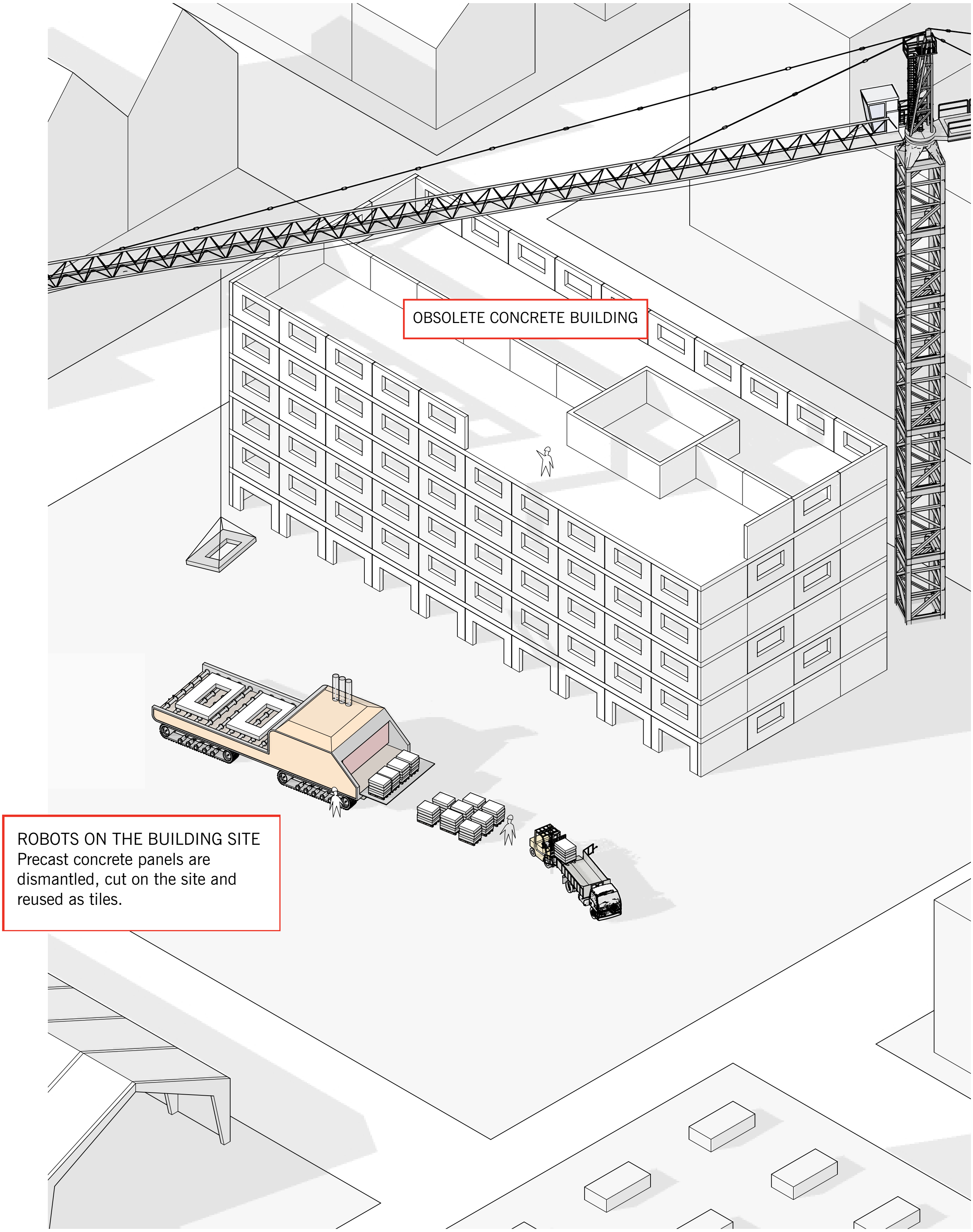
During the initial research, which involved interviews with a number of professionals in Danish demolishing industry, it appeared that no post-high-school education has demolition as part of its training curriculum . Skilled demolition as a precondition for reuse is dependent on industry initiatives, which are in turn dependent on harsh market mechanisms. As opposed to industries such as agriculture, pharmaceutical or energy, the demolition profession has not yet been able to nurture its innovation from institutional research. Through our exploration of the diverse and complicated conditions applicable for high-level reuse, the idea of a regular master-level education evoked - e.g. a 'Demolition Engineer', a specialty uniting central aspects; environmental hygiene, safety, reversible construction, instrumental skills and logistics. As a start, technical schools and universities might begin to integrate knowledge on demolition in the respective disciplines, and thereby creating the basis for a faster innovation.

Current market

With a voluminous home market for building renovation there is a strong potential for developing methods, tools and knowledge, which might in turn spread to markets outside the Nordic region. The traditional architectural design process operates on the background of a product market with a stable stock of familiar products in well-known dimensions and of reliable qualities. With a practice of reusing components from one building to the next there is a need for more flexible methods for designing the geometry and describing the construction work. At present, reselling and reprocessing reused building components is a market niche, mostly valid in the private sector. It might be rapidly scaled up when methods of industrialization are employed.

Technological perspectives

While working on the prototypes it became obvious that many operations necessary for practicing reuse could be carried out much more efficient and economically viable if supported by the right technology. The team has defined and visualized a number of technological scenarios and discussed them with stakeholders. The ability to defining the problem might be of equally importance as mastering the skills for engineering the solutions.



Detail of large drawing showing scenarios for future repurpose practice. Concrete elements from a n obsolete building is fed into the Slab Cutter Bot and cut into smaller elements.

From right
Figure 84/ Visualization of the Slab Cutter Bot

Figure 85/ Traditional breakdown of a concrete building

Figure 86/ / Detail of visualization showing the terrazzo-like surface of cut concrete

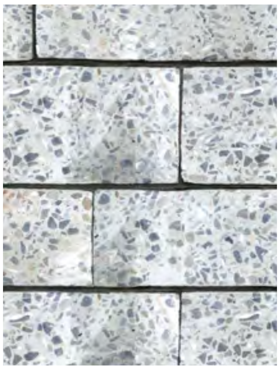
Figure 87/ A circular saw is used for traditional adaptation of concrete elements.

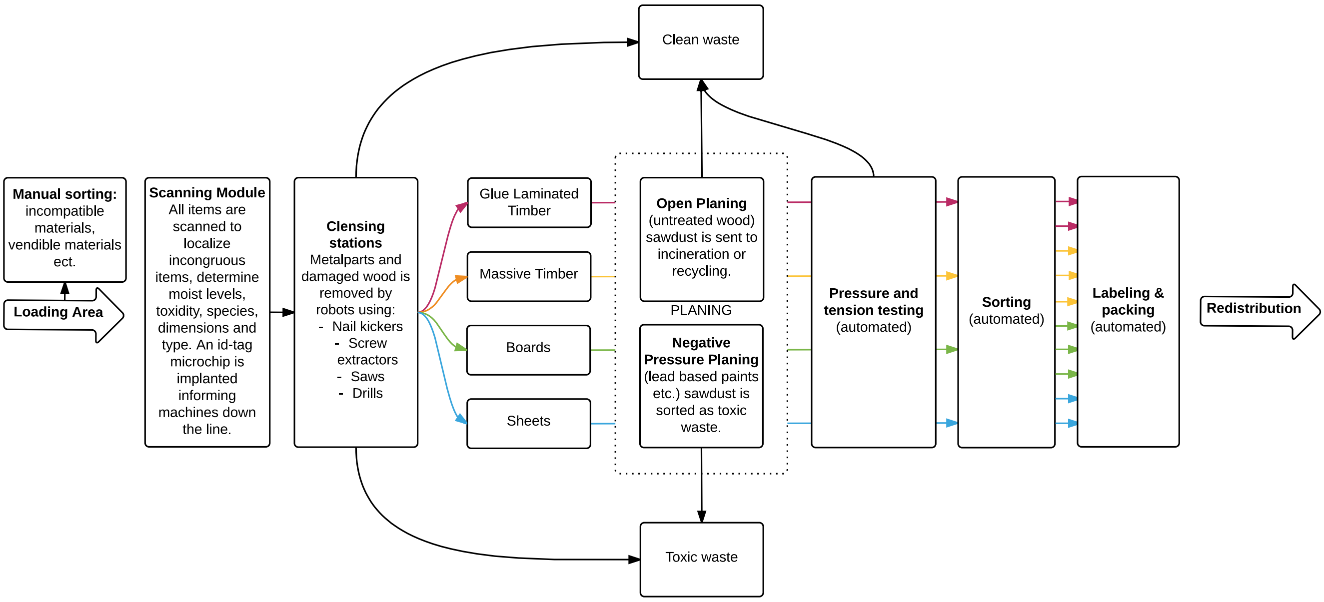
Vision

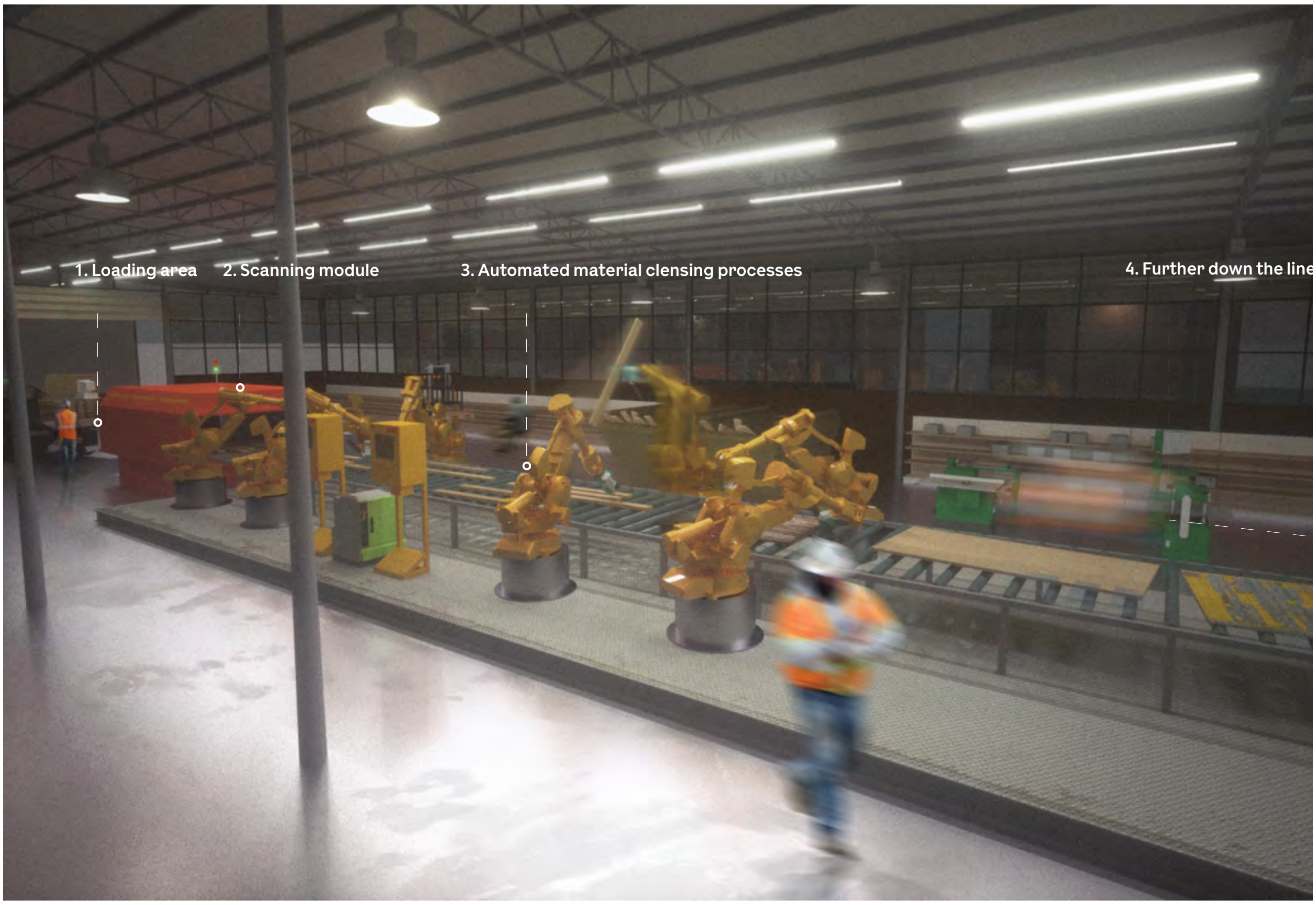
The Slab Cutter Bot slices concrete on the spot

The Slab Cutter Bot is our vision of a transportable machine that slices concrete slabs into sections, blocks or tiles and stacks them, ready for transportation to be reassebled on a construction site nearby.

This machine already exists in stationary setups. It seems like an easy development to mount a diamond wheel saw bridge on wheels and add a stacking mechanism at the end of the conveyer.
The "Slab cutter bot vision", is thus a transportable machine that cuts concrete element walls into sections, blocks or tiles and stacks them, ready to transport and reuse on a nearby building project. This machine would make it possible to minimize labour and transport associated with the refactoring process.







From top
Figure 88/ Diagram of sorting and scanning in the Wood Reuse Plant

Figure 89/Imagined wood reuse plant

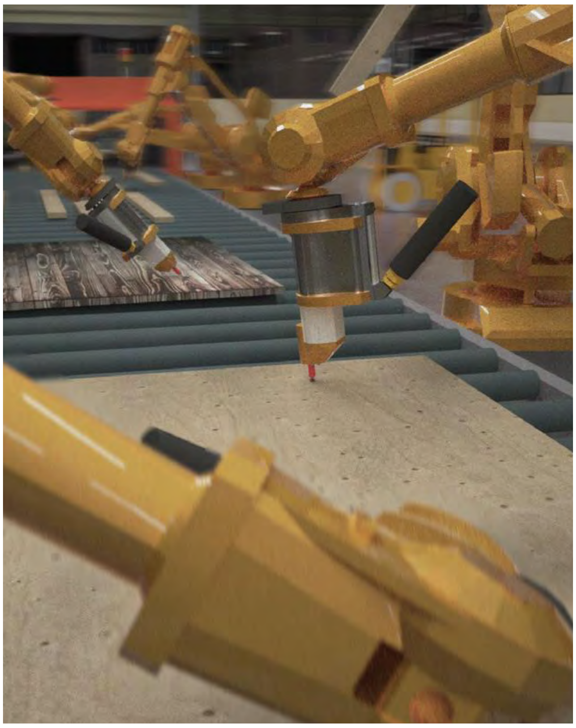


Figure 90/ Detail/ Optical scanning modules test and classify the wooden members.

Figure 91/Detail/ Wood of all sorts is processed and prepared for a second life.

Vision

Wood Reuse Plant

The wood reuse plant is our vision of an automated plant for handling and sorting of a variety of scrap wood material.

At t he wood reuse plant timber and wood sheets are brought in and fed into an automated factory line. Scanning modules test, measure and qualify the wood members and other machines handle the wood based on the information gathered from the scanning modules. Some pieces of the wood are immediately disqualified due to lack of strength or after identification of toxic content.
The processed wood can then be redistributed to be resold and reused.

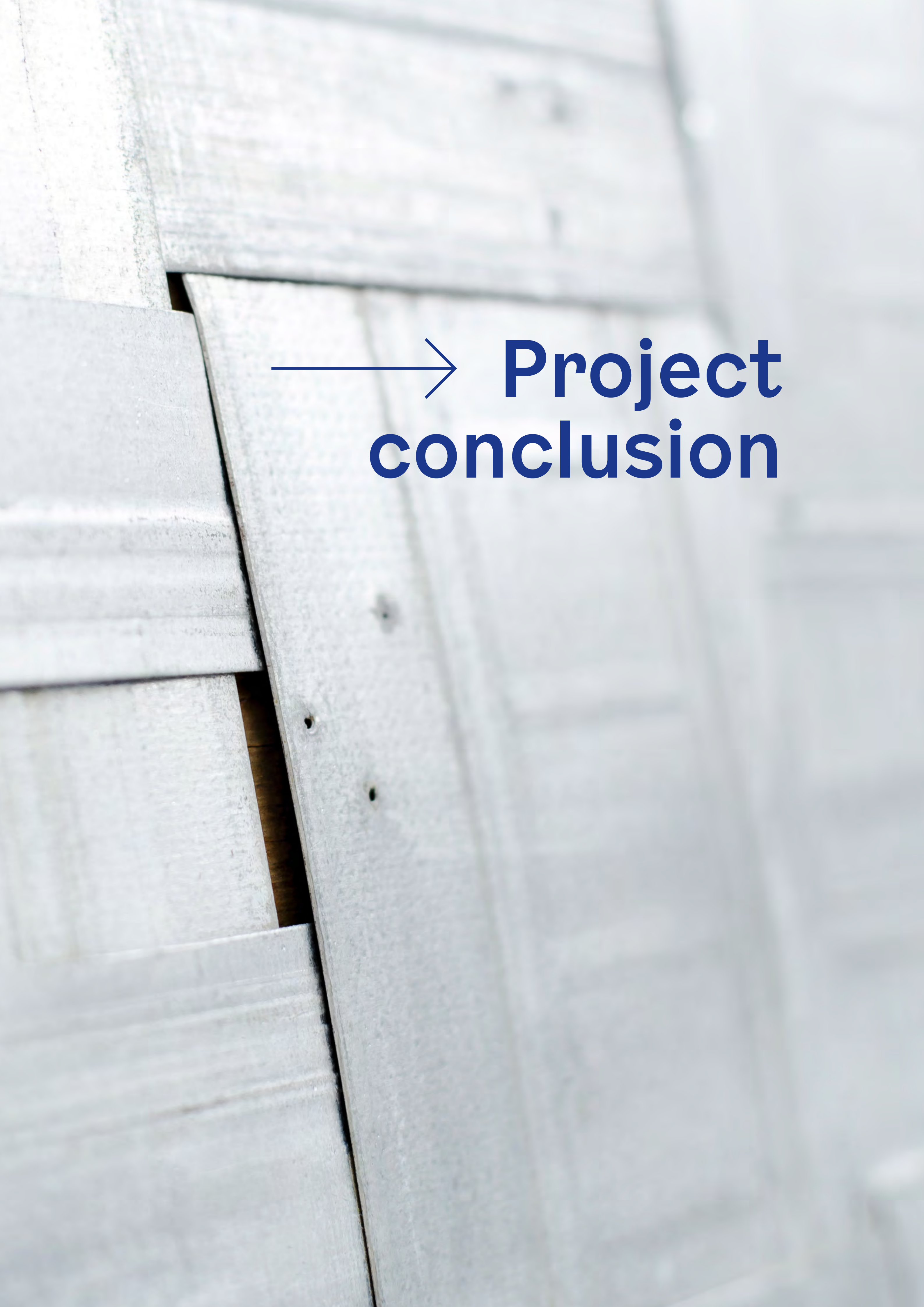
The processed is imagined as shown in the diagram to the left, described in the following and illustrated on the previous and this page. **Figure 88**

1/Loading area
Harvested wood is brought in and is loaded into the scanning module.
Wooden materials are scanned. Shape, weight, composition, coating and finish is registered.

2/Scanning module
All metal parts are mapped and categorized in order to determine the most optimized removal method for the machines.

3/Automated material clensing processes
5-axis CNC machines with multible toolsets are instructed by the scanning module how and what to do with the incoming wood.
Through a coordinated robotic ballet, the machines cooperate to remove nails, screws, bolt and brackets. Some metal parts are removed with drill and screw bits, others are cut off if the removal process is uncomputable.
Subjects are discartedif they are assessed to be too damaged.

4/Further down the line
Machines pressure test the wood and the members are planed, packed and labelled.
The wood is then sent back in circulation and is eg. sold at the DIY markets.



→ Project conclusion

Through design and construction of 25 scale 1:1 prototypes of material concepts for walls and facades, and parallel design sessions suggesting the concepts in specific contexts, it was found that selected components currently defined as waste, could be transformed into high quality architectural design. It was concluded in three of four conducted LCA evaluations that in 4 out of 5 cases repurposing components impact climate and environment significantly less than with use of new components. Unfortunately, cost connected with rehabilitation processes often exceed the price of new products, which is mainly due to the high degree of human labour. Narrow niches in the current market for customized material components does however show opportunities for a long-term development towards a more widespread reuse of waste components and development of new technology to automate processes.

As the project challenges the regimes of current regulations and market conditions, numerous obstacles and dilemmas have been revealed, including:

→ **A technological gap, where a mutual dependency exists between the critical demand for secondary products and the invention of more advanced demolition tools.**

→ **A technological challenge in documenting compliance with current critical limits for toxins in waste as well as technical quality.**

→ **A cultural gap, where the aesthetics of wear and tear challenge normal expectations towards buildings' appearance.'**

→ **LCAs are difficult to obtain in the field of reuse because of the numerous variables and the difficulties in documenting the exact processes.**

These obstacles disregarded, novel architectural, technological and commercial potential results from the resource-preserving strategies, including compositional and material qualities obtained through increased construction tolerances and ornamental motifs from the assembly systems.

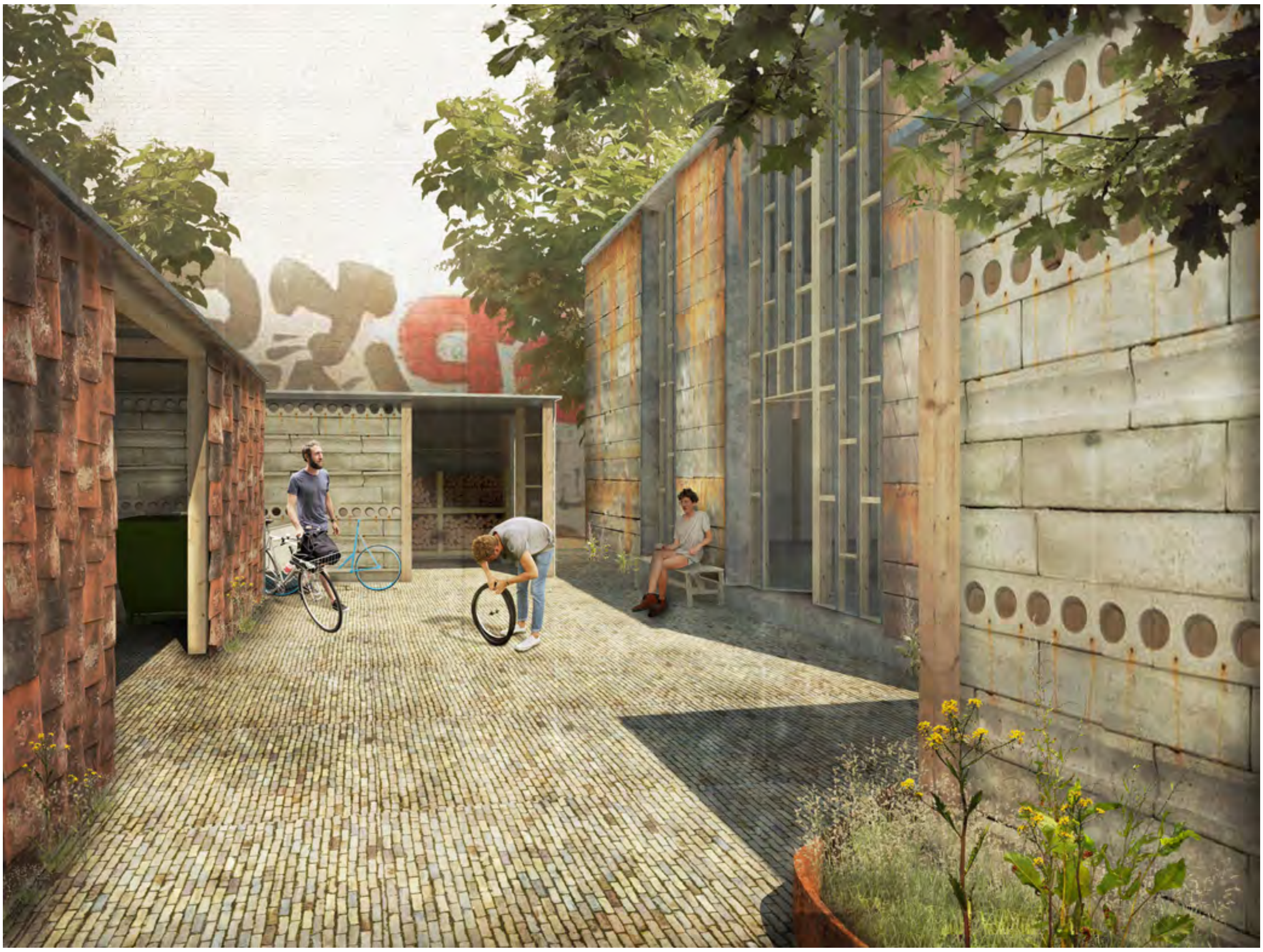
The cross diciplinary approach

While the LCAs are interesting, the cross disciplinary collaboration for obtaining the data can be concluded a necessary premise for the developing useful and comparable LCAs.

From the feedback we have received in displaying and discussing the prototypes, it can also be concluded that material prototypes has a strong impact on visualizing unknown territory in building culture and practice, in fact physical prototyping as well as applying a combination of quantitative and qualitative methods is crucial when complex, pushing cross diciplinary boundaries.

In the transformation towards a circular economy re**beauty** can be added to the list of slogans, reuse, reduce, recycle. It seems to us natural to develop the aesthetics and the entire culture of reuse along with the economical and the environmental impact. One cannot go without the other. Without beauty, no sustainabilty.

Appendix



Visualizations of use of concrete brick cladding in context

Figure 92/Visualization by students Lena Fedders, Amalie Brandt Opstrup og Line Tebering.

Figure 93/Visualization of concept

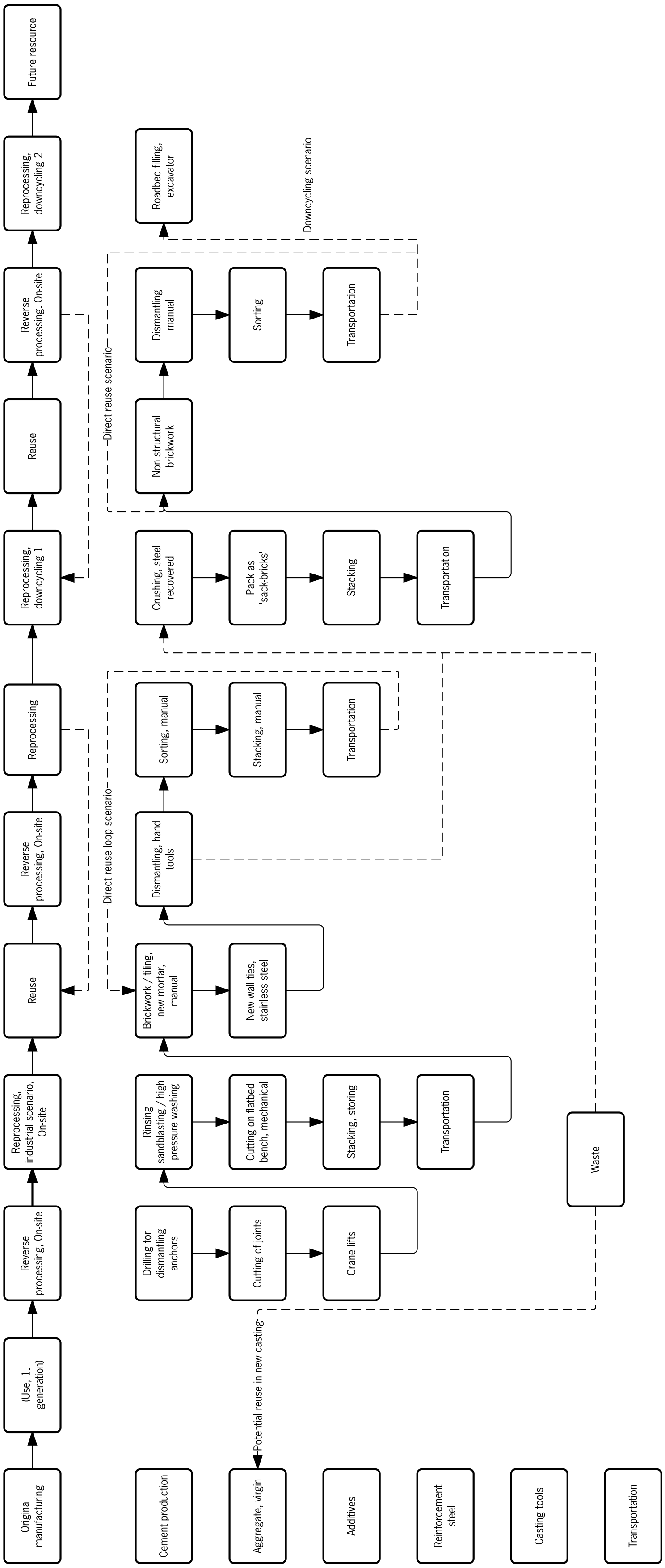
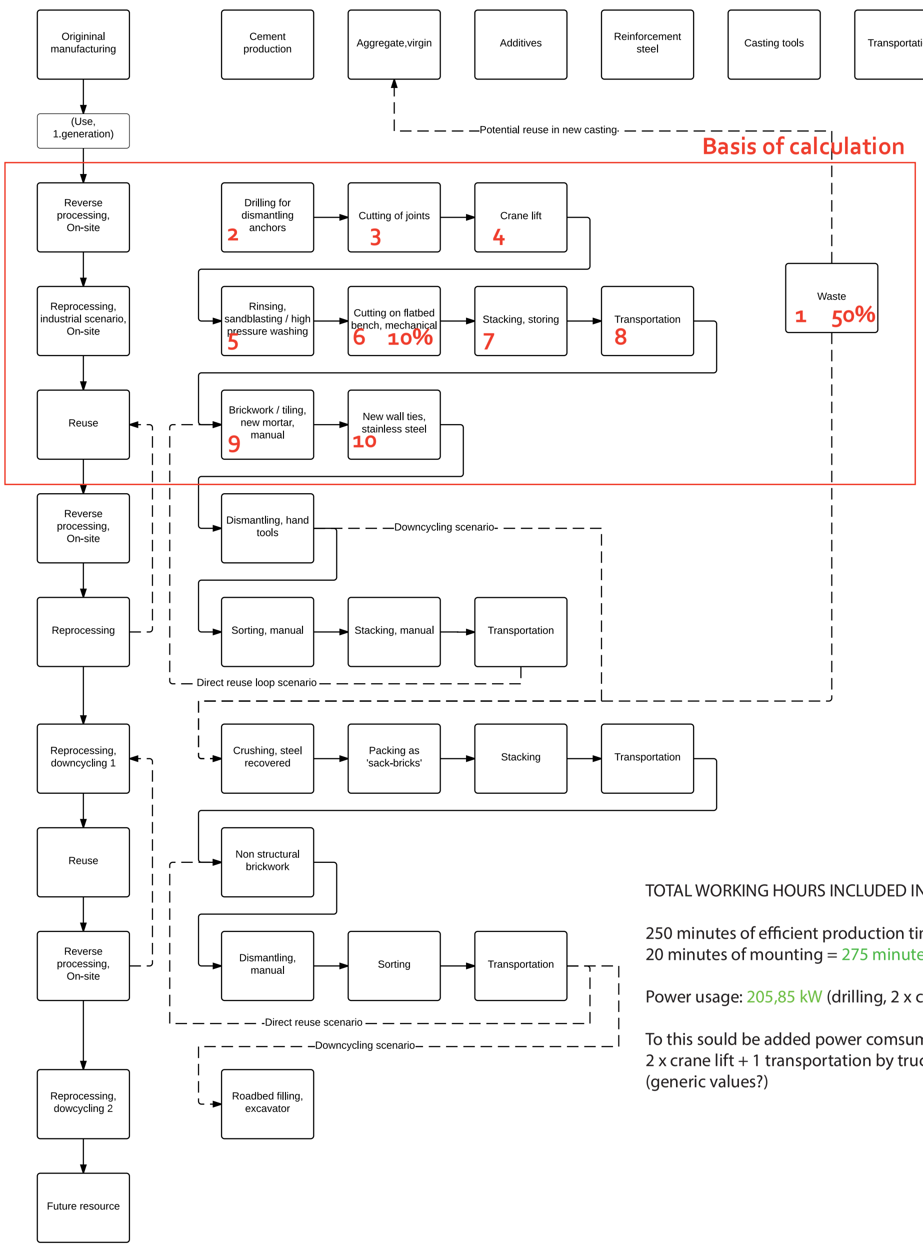


Figure 94/Concrete bricks made from concrete slabs

Figure 95/Flowchart for the prototype bricks made from concrete

CONCRETE BRICK WALL



TOTAL WORKING HOURS INCLUDED IN PRODUCTION OF 1 M²

250 minutes of efficient production time + 5 minutes of transportation + 20 minutes of mounting = 275 minutes embodied work hours pr. m²

Power usage: 205,85 kW (drilling, 2 x cutting, rinsing)

To this sould be added power comsumption of:
2 x crane lift + 1 transportation by truck
(generic values?)

INDSATSFAKTA

Some parametres have been used from the research paper by Danish Miljøstyrelsen "Udredning af teknologiske muligheder for at genbruge og genanvende beton". These values are marked by (*) since they represent the best estimate when no other source has been available.

Estimate of standard production of concrete elements:
CO2-fodaftrykket ved produktion af et europæisk gennemsnitligt letbetonelement med en densitet på 1,95 ton per m3 og en tykkelse på 15 cm er estimeret til 52 kg CO2-ækvivalenter per m2 (Betonelement-Foreningen, 2014).

2) Drilling for dismantling anchors - 30 minutes
Drilling 6 holes x 5 minutes = 30 minutes
with hammer Drill 850 W
Power usage = 425 Watt

3) Cutting of joints - 60 minutes (cutting 2 metres at 30 cm thick panels)
Concrete with diamond tip blades for cutting out wall panels: 19 kWh, energy usage: 19kWh/m2

+ usage of diamond tip blades has to be taken into account.
(it's all very expensive equipment, the portable saw is about DK 200.000)

4) Crane lift - 15 minutes?
Power usage by lifting 977 kg of concrete
An estimate of 15 mins. for lifting 1m2 of concrete panel of existing building is a generalisation of the value.

5) Rinsing, sandblasting / high pressure washing - 15 minutes
Rinsing should be done at minimum 3000 PSI/207 bar
14 kWh engine = 3,5 kWh
Water usage is 19 litres/minute = 285 litres/m2
(Data input from Concrete powerwashers)

6) Cutting on flatbed bench, mechanical - 120 minutes
Cutting concrete panels into blocks of 20 cm width (4 cuts of 1 m)
Flatbed concrete saw uses 40 kHw = 80 kWh

cutting time is very dependent on the elements.
6 m cutting (30 cm thickness) will be about 3 hours
(data input from Danish concrete cutting company Diatool).

Is there a generic value for cost/energy going into production of these blades?

7) Stacking, storing - 10 minutes/m2
Power usage for crane lift after cutting/rinsing process - is this a generic value?

8) Transportation - 5 minutes/m2
Only 1 transportaion input, since scenario is processing concrete on-site
Transportation is 1 delivery to new building site from deconstruction site.

9) Brickwork / tiling, new mortar, manual - 20 minutes/m2
5 metres of wall edges have to be laid with new mortar.
Est. time is total for brickwork/laying mortar/mounting wall ties.
Difficult to estimate at - is this a realistic amount of time going into erecting this type of concrete brickwork wall?

10) New wall ties, stainless steel - 0 minutes
10 new wall ties pr. m2
Weighing about 50 g x 10 = 500 gram

Figure 96/Complete chart of material lifecycle for Concrete brick wall

WORKING HOURS

We have discussed and estimated the amount of minutes of labor for each step of production.

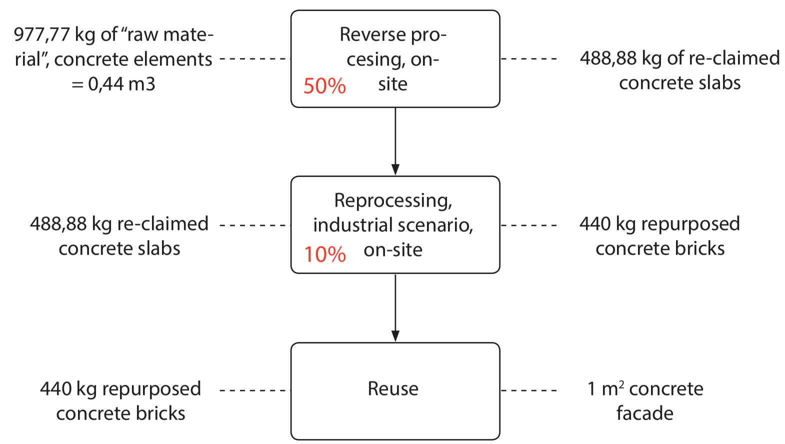
Assumptions about waste in reclaiming process and processing is based on calculations from the report "Udredning af teknologiske muligheder for at genbruge og genanvende beton" by Teknologisk Institut for the Danish Governmental department Miljøstyrelsen.

The estimate is still rather pessimistic about time consumption to keep it realistic.

WASTE PRODUCTION
1) Re-claiming stage - 50% (*)
50% waste is the estimate that the concrete will be un-reclaimable becuase of natural wear and tear, irreparable damage and off-cuts when dismantled, transport damaging etc. This value will be drastically lowered when Design for Deconstruction (DfD) is implemented as a standard design principle.

6) Cutting to standard dimensions - 10 % waste
We estimate that the reclaiming process earlier on has sorted out a lot of the irreparable concrete slabs and the registration/technology aspect minimizes waste at this step as much as possible.

CHART OF PRODUCTION OF COMPONENT FOR 1. GENERATION REUSE



Material usage for 1m² of recycled concrete brick wall
Calculated based on a 'facadeudsnit' as this:

1000 mm

200 mm

1000 mm

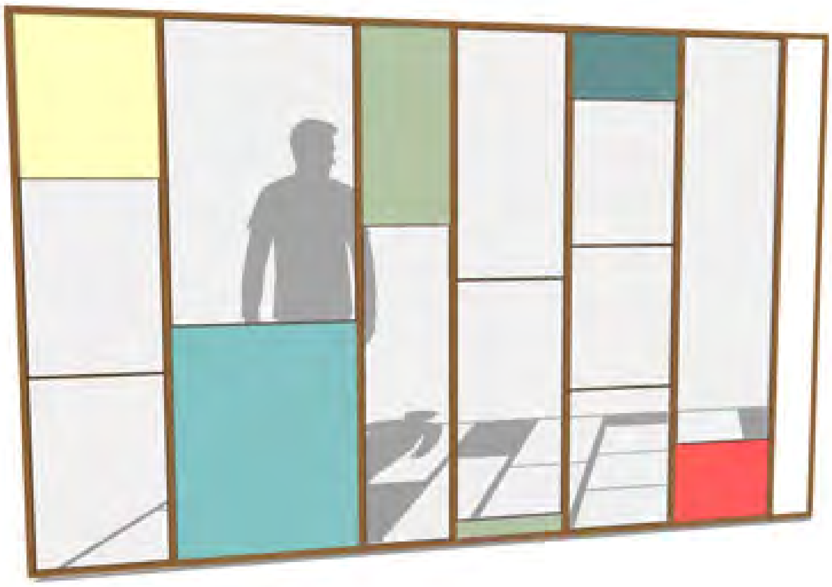
200 mm thickness

Concrete density
2,2 ton per m3 (average)

= 0,2 m^3 concrete bricks

weighing 440 kg

Figure 97/Chart of production of component for 1st generation reuse/Concrete brick wall



Conceptual sketch

Conceptual sketch/ for glazed window +facade

Figure 98/Visualization of the concept used in a project. Work from "Recycling Station – design strategies for material reuse" by architecture students Lena Fedders, Amalie Brandt Opstrup og Line Tebering, Royal Danish Academy of Fine Arts, School of Architecture, Settlement Ecology and Tectonics

Figure 99/Conceptual sketch

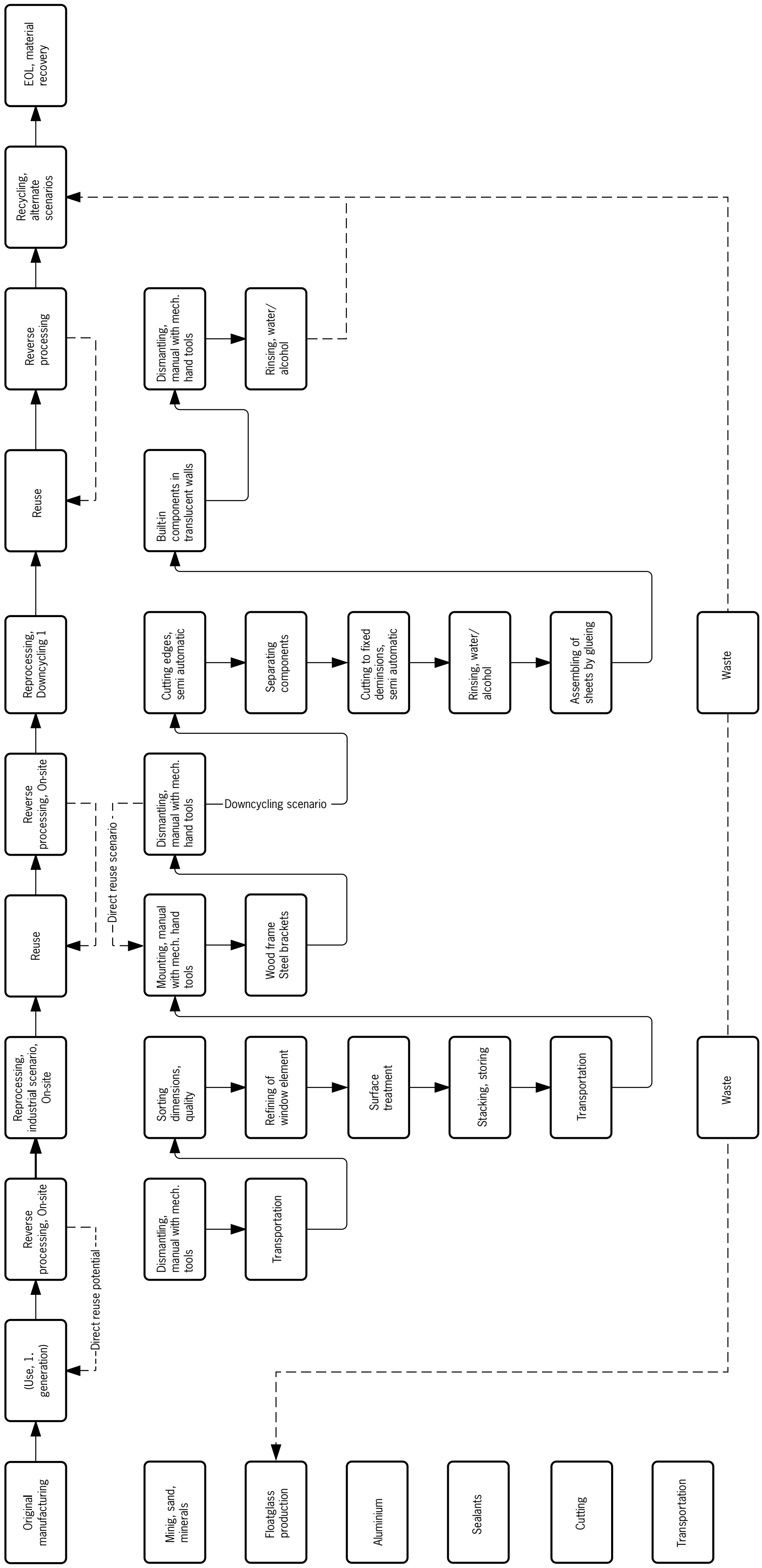


Figure 100/Flowchart for the prototype glazed window facade

Figure 101/Glass facade made from used glazed windows

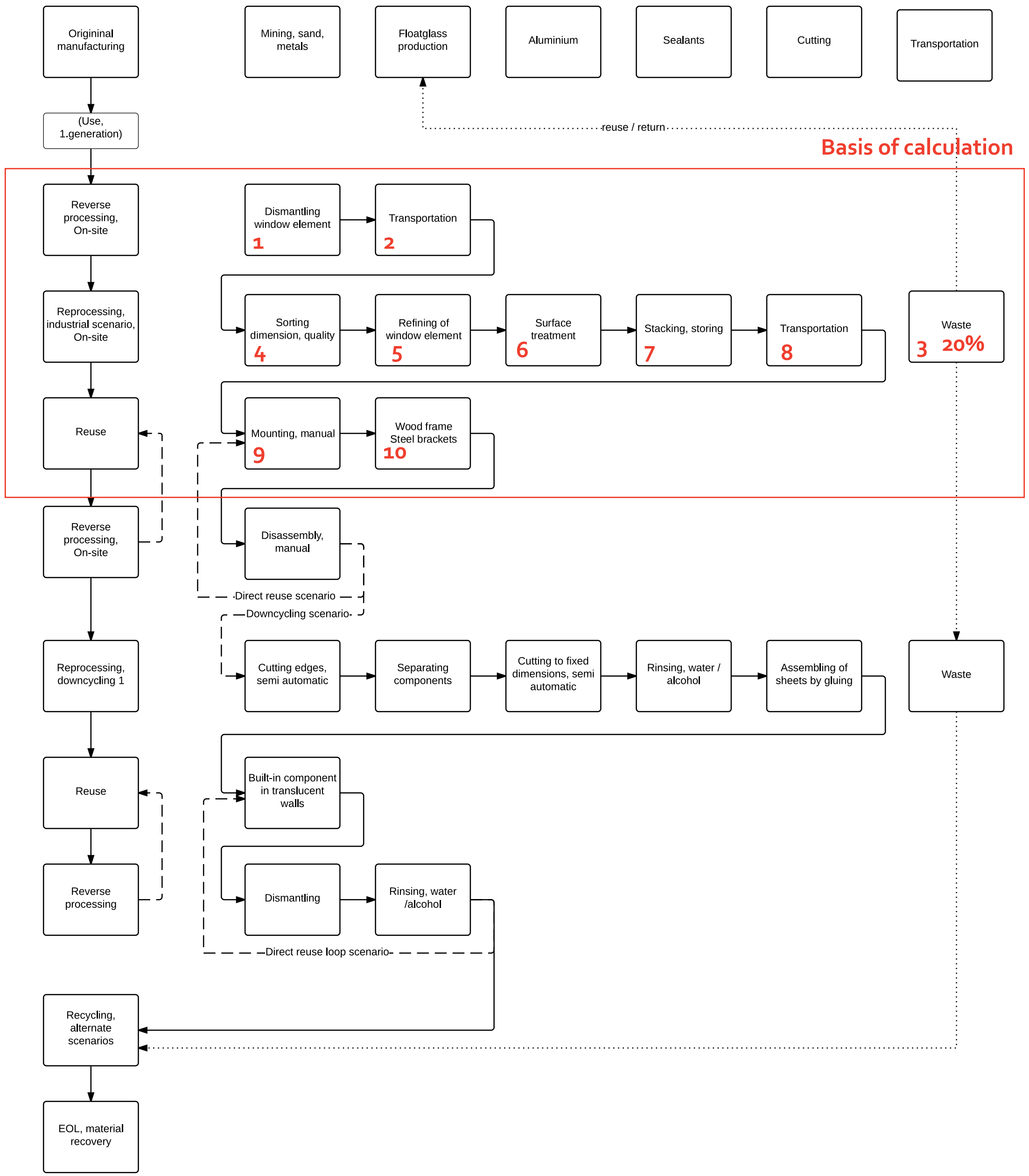


Figure 102/Complete chart of material lifecyclw for glazed window facade

INDSATSFAKTA

Calculation based on processing of 4 windows (50x50 cm) = 1m2 of new window surface

1) Dismantling window elements - 5 minutes
Dismantling frame
4x4 screws = sec.s of drilling
DeWalt machine 14,4 V
250 Watt
Carrying 4 windows to car

2)Transportation - 2 minutes
fx. 25 km by lorry, Mercedes Sprinter 316 CDI 163 HK (typical in Cph)
Max. load 1.400 kg
Own weight: 2214 kg
Diesel consumption when emtpy: 12,6 km/l, when fully loaded, maybe 8 km/l
Energyclass F

4) Sorting according to dimensions and quality - 2 minutes
i.e Unloading from truck, carrying to storage, cataloging

5) Refining of window element - 4 x (3 x 1 minutes) = 12 minutes of cutting
Windows are cut on 12 sides by table saw to clean up surfaces and re-dimension/re-shape the element.
Table saw is:
Paoloni P45
Main Motor Power: 5,5 kWh
12 minutes of cutting = 1,1 kW

6) Surface treatment - 4 x (1 x 2 x 2) minutes = 16 minutes
The frames can be treated with a number of oli, paints, laquer or stains
For the prototype we used stains (a walnut colored pigment), waterbased product and sealed with 2 layers of linseed oil

7) Stacking and storing - 4 minutes
We estimate a small amount of work effort goes into the logistics of the windows, cataloging, describing the (to website) and making the sale with customers.

8) Transportation - 6 minutes
We estimate a higher ratio of transportation time at this point because the number of salvaged components will be lower.

9) Mounting - 20 minutes
The prototype solution we propose here is a 1m2 (4 windows 50 x 50 cm)
Preparation of 4 x 1m battens (lægter) for new frame, 10 minutes

10) Wood frame, steel brackets
Are there generic material values for these?

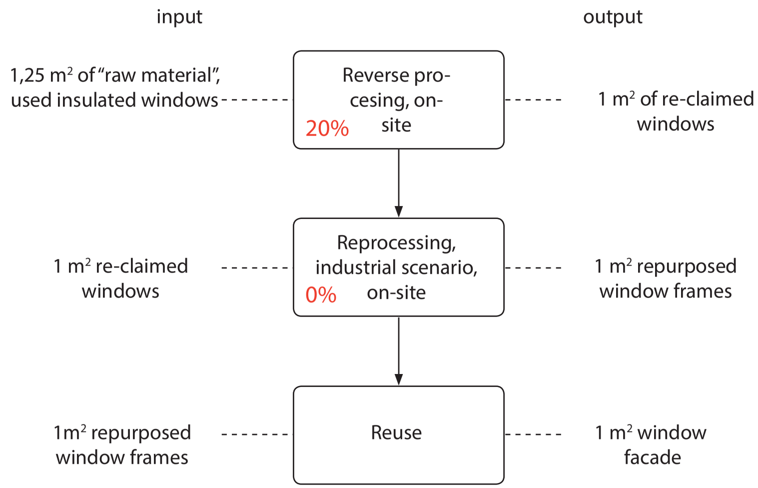
WASTE PRODUCTION

3) We estimate that about 20% (1 out of every 5 windows) are either punctured or the wood is in too bad condition to reprocess.

TOTAL WORKING HOURS INCLUDED IN PRODUCTION OF 1 M^2

49 minutes of efficient production time + 8 minutes of transportation + 20 minutes of mounting = 77 minutes embodied work hours pr. m^2

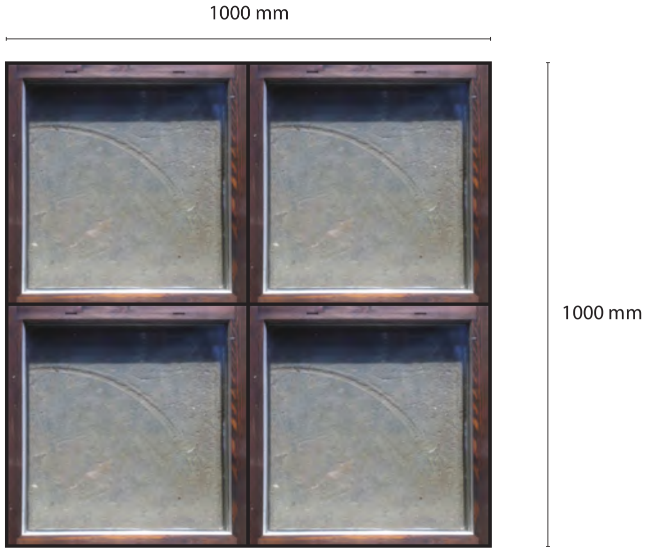
CHART OF PRODUCTION OF COMPONENT FOR 1. GENERATION REUSE



WORKING HOURS

Based on estimates pretty much the same way as with the New Nordic Wall.

Material usage for 1m² of recycled window facade
i.e. 4 re-claimed insulated windows, generic example of setup for calculation purpose, not to be regarded as design proposal



Windows

$= 1m^2$ window facade

Figure 103/Chart of production of component for 1st generation reuse/glazed window facade

Visualization of use of wood wall in context

Figure 104/Visualization of the concept 'New Nordic Wall'

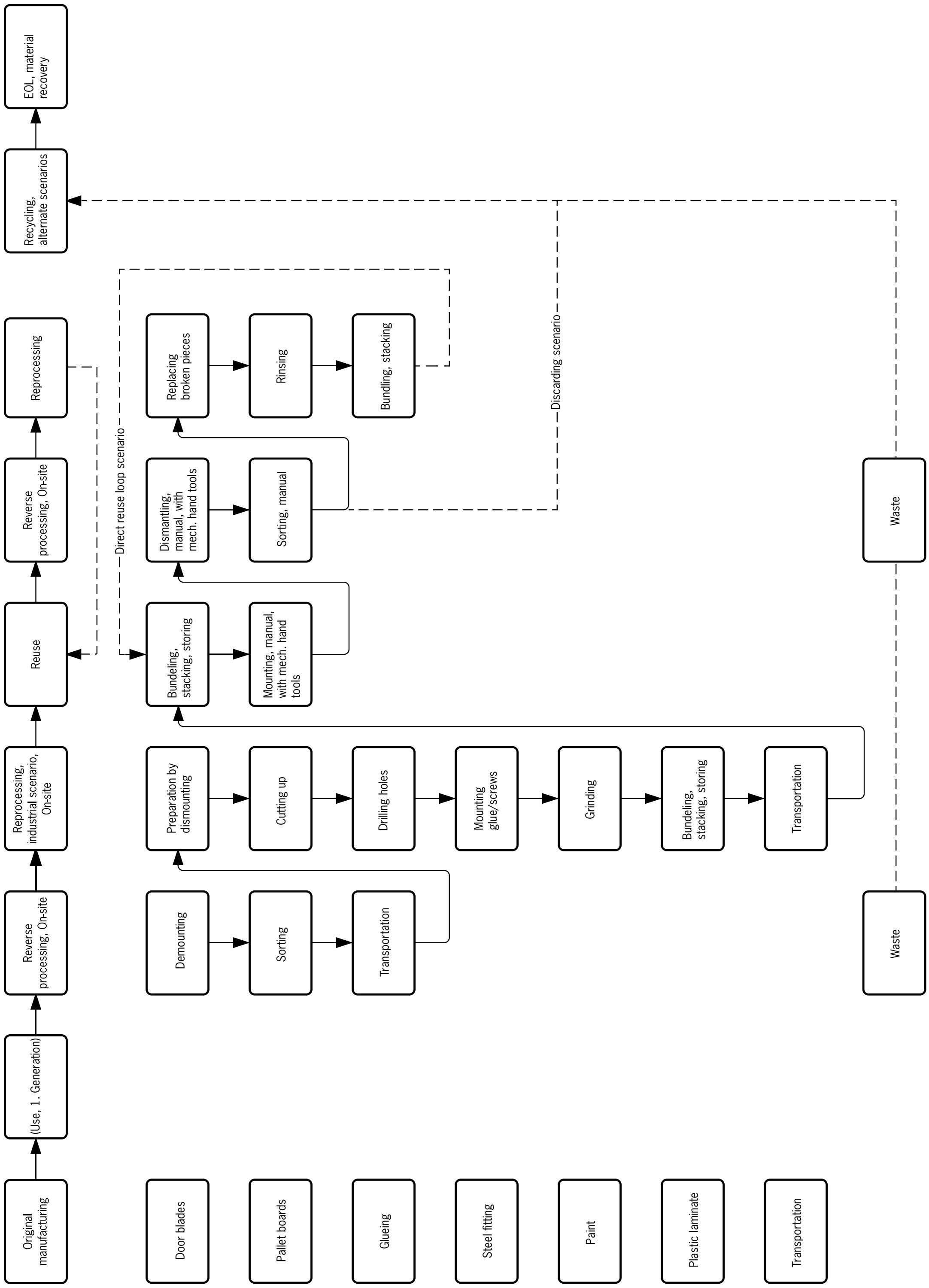


Figure 105/Flowchart for the prototype Indoor wall made from used interior wood

Figure 106/Indoor wall made from used interior wood

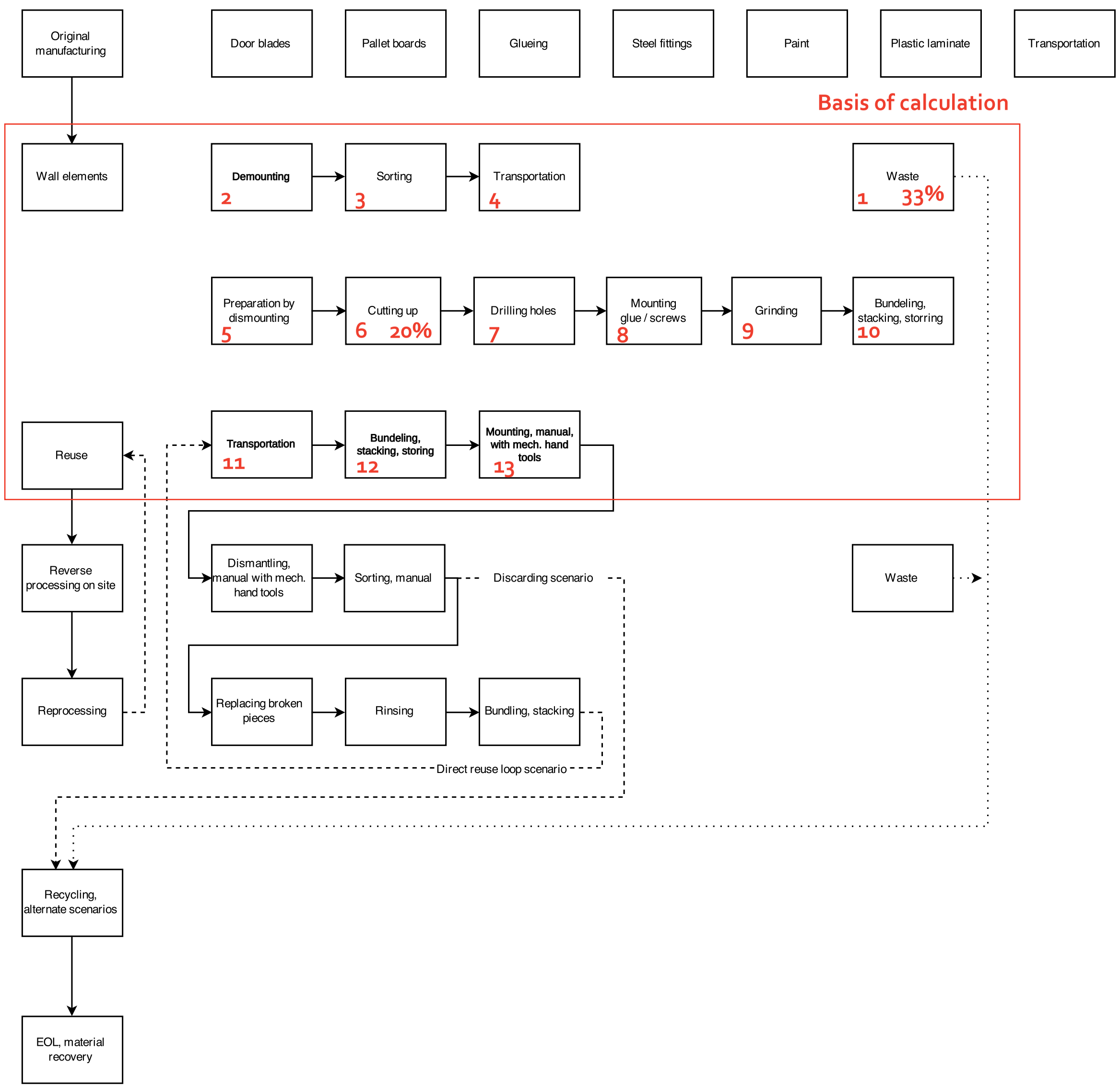


Figure 107 / Complete chart of material lifecycle / Wall element of old doors / the 'New Nordic Wall'

INDSATSFAKTA

The input data has been standarized (all 4 prototypes) for certain process steps i.e. transportation, same car, driving distance, units etc.

2) Demounting wooden floor boards, wooden doors, panels etc. - 5 minutes
An estimate for removal of a

3) Sorting and handling - 2 minutes
Loading truck

4) Transportation - 2 minutes
fx. 25 km by lorry, Mercedes Sprinter 316 CDI 163 HK (typical in Cph)
Max. load 1.400 kg
Own weight: 2214 kg
Diesel consumption when emtpy: 12,6 km/l, when fully loaded, maybe 8 km/l
Energyclass F

5) Preparation by dismounting (Produktionsforberedelse) - 2 minutes
Unloading truck, setting up machines for cutting

6) Cutting up - 12 minutes
Table saw is:
Paoloni P45
Main Motor Power: 5,5 kWh
12 minutes of cutting = 1,1 kW

7) Drilling holes - 2 minutes

8) Mounting glue / screws - 10 minutes

9) Grinding & surface treatment - 5 + 2 minutes

10) Bundeling/stacking/storing - 1 minute
In workshop and storage, off-site

11) Transportation - 2 minutes

12) Bundeling/stacking/storing - 2 minutes
Unloading truck, storing on-site

13) Mounting, manual - 20 minutes pr. 1m2 of installing the wall.
Work time estimate is an average value of: lifting, mounting elements together (which is done really fast), adjusting to door frames, ceiling, outer walls etc.

WASTE PRODUCTION
1) The New Nordic Wall can consist of recycled parts from most wood-based products. The aim is to gather up and reuse all the odd bits and in this way the aim is to create a new aesthic from all scratch.

Since the source of this material could come from any wood related product, as well as given the natural state of the material, we will estimate that 33% of the collected wood will go to cut-offs and/or deteriorated waste (rot and damage)

TOTAL WORKING HOURS INCLUDED IN PRODUCTION OF 1 M^2

43 minutes of efficient production time + 4 minutes of transportation + 20 minutes of mounting = 67 minutes embodied work hours pr. m^2

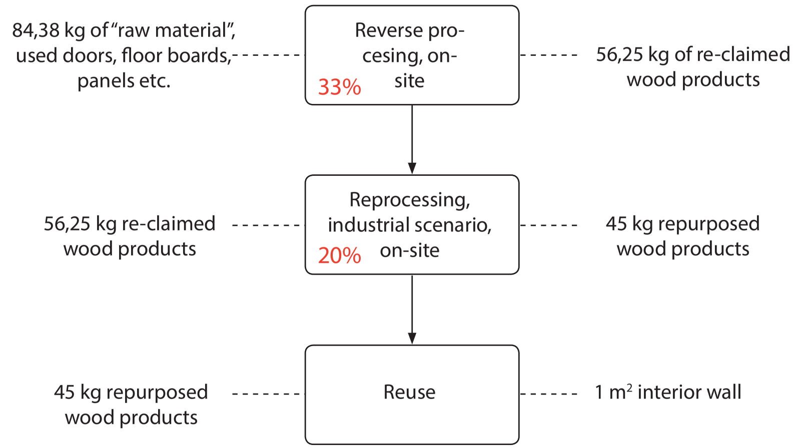
WORKING HOURS

Time usage in minutes is estimated for production of 1 m2 of New Nordic interior wall made from various sources of scrap wood. There are many variables in the sources, where were does the doors/floors come from, what is the condition (is there a lot of waste initially in the harvesting process?) what are the quantities? This will vary each time you harvest. Maybe in particular when it comes to wood, since it's a

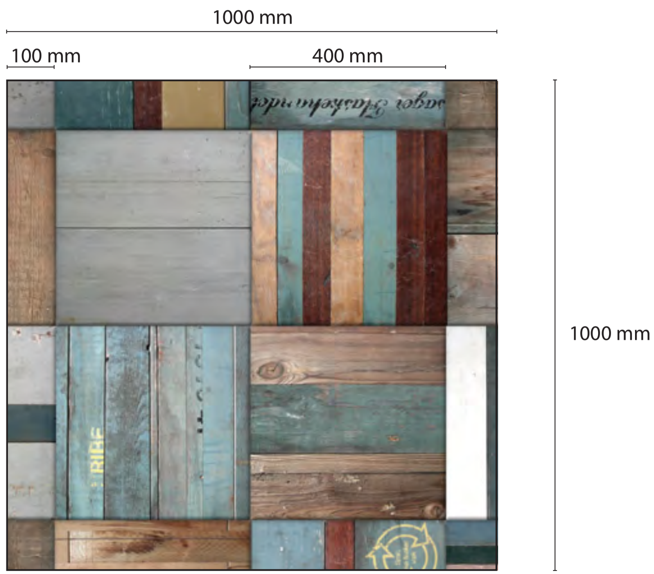
We have discussed the parametres and made assumptions about quantities as well as general steady work flow in wood woorking. Time consumption may be drastically reduced when harvesting is better organised, transportation and storing is coordinated and handled on a larger scale and so on.

We have described the following production as a general estimated access to the materials.

CHART OF PRODUCTION OF COMPONENT FOR 1. GENERATION REUSE



Material usage for 1m² of recycled interior wall



New Nordic Wall - elements

about 6 blocks

= 1m² interior wall

weighing (about) 45 kg

Figure 108/Chart of production of component for 1st generation reuse/ Indoor wall made from used interior wood

Illustrations of facade cladding made from rolled ventilation ducts ⁄ Visualization of use in context
Figure 109⁄Visualization by students Lena Fedders, Amalie Brandt Opstrup og Line Tebering.

Figure 110⁄Visualization of concept illustrated as the facade of an old Vandkunsten project

Figure 111⁄Visualization of concept illustrated as the facade of an old Vandkunsten project

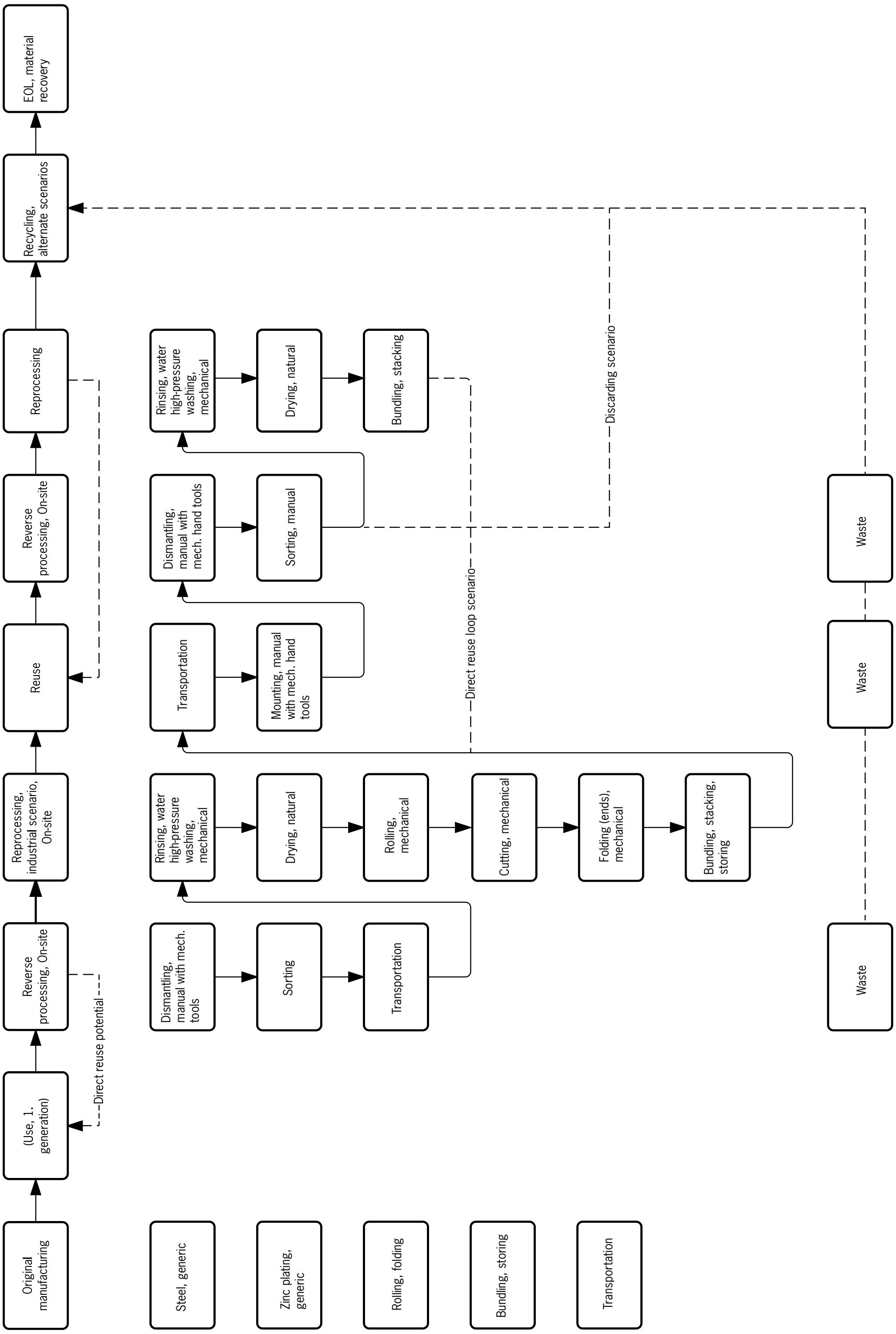
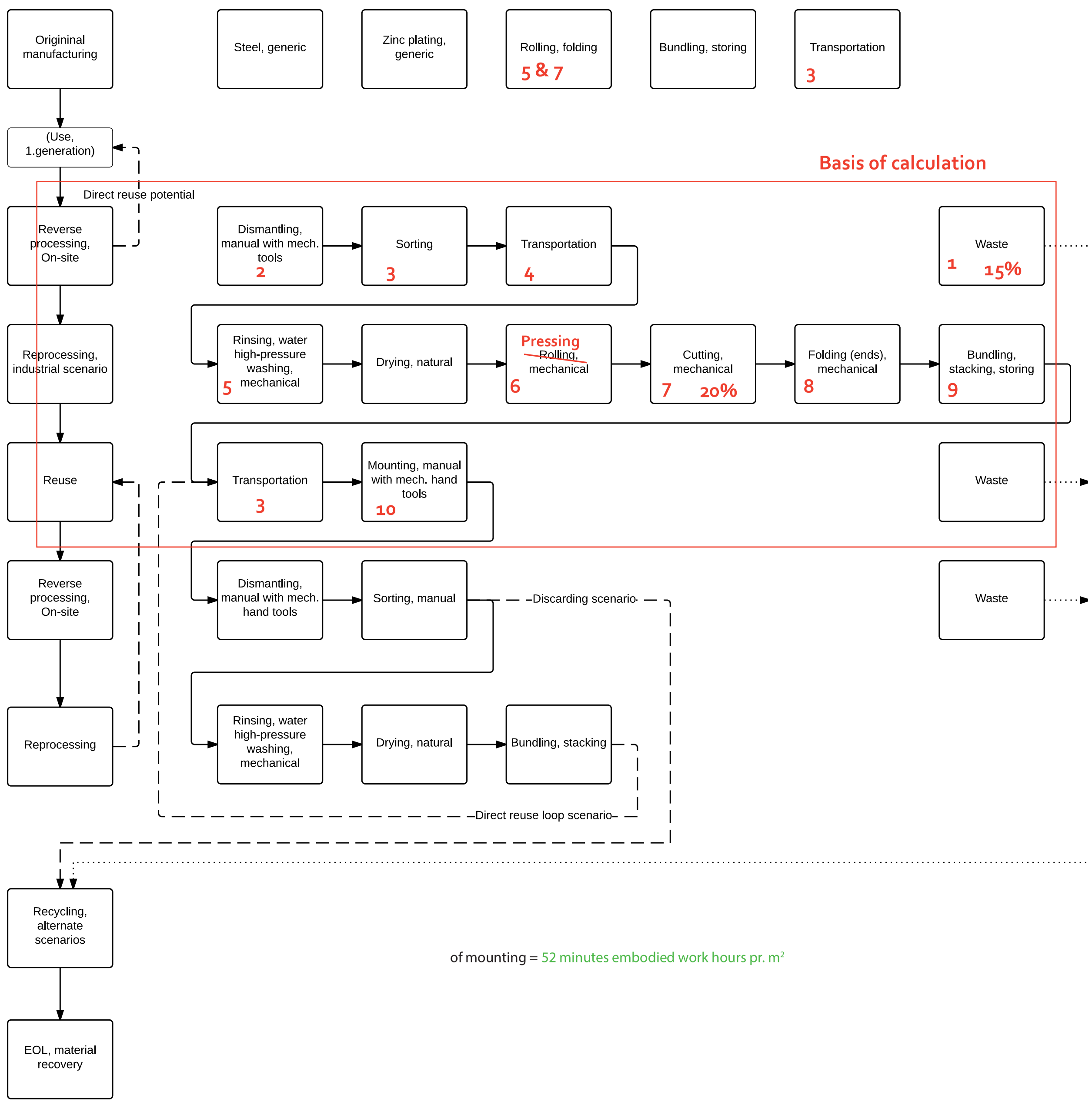


Figure 112/Flowchart for the prototype Facade cladding made from rolled ventilation ducts

Figure 113/Facade cladding made from rolled ventilation ducts



INDSATSFAKTA

Estimate of 5 x 1040 cm Spiro duct (needed for 1m2 facade) Various diameters

WEIGHT/LENGHT RATIO
Fx Duct diameter: 12,5 cm weight pr 100 cm: 1857,14 gram

2) Dismantling/mounting by mech. tools - 10 minutes
2x2 sec. unfastening of screws,
DeWalt machine 14,4 V
250 Watt

3) Sorting is done by manual labor - 2 minutes
no energy consumption
when taken done, a lot of the remaining particles in the duct will/can be shed
maybe obsoleting the rinsing process?

4) Transportation - 2 minutes
fx. 25 km by lorry, Mercedes Sprinter 316 CDI 163 HK (typical in Cph)
Max. load 1.400 kg
Own weight: 2214 kg
Diesel consumption when emtpy: 12,6 km/l, when fully loaded, maybe 8 km/l Energyclass F

5) Not sure whether this procedure is nescessary, but info is: - 5 minutes
data from http://clena.dk/ks-station%C3%A6r

5 sec. high pressure rinsing
5,5 kWh
3x400 V
50 hz

if chemical is needed, then this could do perhaps:
http://www.rkimiljo.dk/media/files/Datablad_NY/UDEN/816001%20-%20280311.pdf

6) Pressing/flattening - info from danvals.dk - 5 minutes
Done by hydralic press
10 tons press,
30 sec. press
1,5 kWh

7) Cutting to standardized dimensions - 2 minutes
Done by steel sheet shearing machine/cutter
5 sec.
1,5 kWh
Cut-offs will be about 20%

8) Folding (ends) - 8 minutes
Done by Hydraulic bending machine or press brakes
20 sec. each end of each duct.
3 kWh

9) Bundeling/stacking/storing - 1 minute
In workshop and storage, off-site

10) Mounting manual with mech. hand tools - 15 minutes
In workshop and storage, off-site

WASTE PRODUCTION

1) We estimate 40% waste in the initial reclaiming process (tear from aging and bended ducts, corners etc.)

TOTAL WORKING HOURS INCLUDED IN PRODUCTION OF 1 M²

33 minutes of efficient production time + 4 minutes of transportation + 15 minutes

Figure 114/Overview of material life cycle for Facade cladding made from rolled ventilation ducts

WORKING HOURS

We have discussed and estimated the amount of minutes of labor for each step of production.

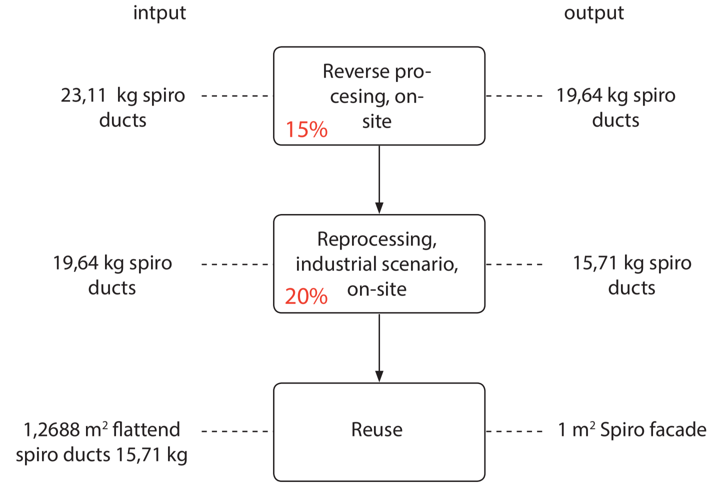
The estimate is based on average values between info from a Danish manufactor of sheet metal products and a estimate of increased production efficiency by an upscaled production flow when the reclaiming strategies are realised.

Example:
7) Folding (ends) -
Done by Hydraulic bending machine or press brakes
20 sec. for each end of each duct = 360 sec.
3 kWh

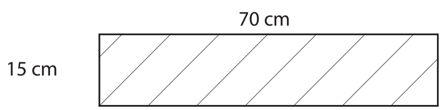
1 person working 8 minutes handling 9 ducts (1m²), operating the machine and packing them on a pallet or similar steps.

The estimate is still rather pessimistic about time consumption to keep it realistic.

CHART OF PRODUCTION OF COMPONENT FOR 1. GENERATION REUSE

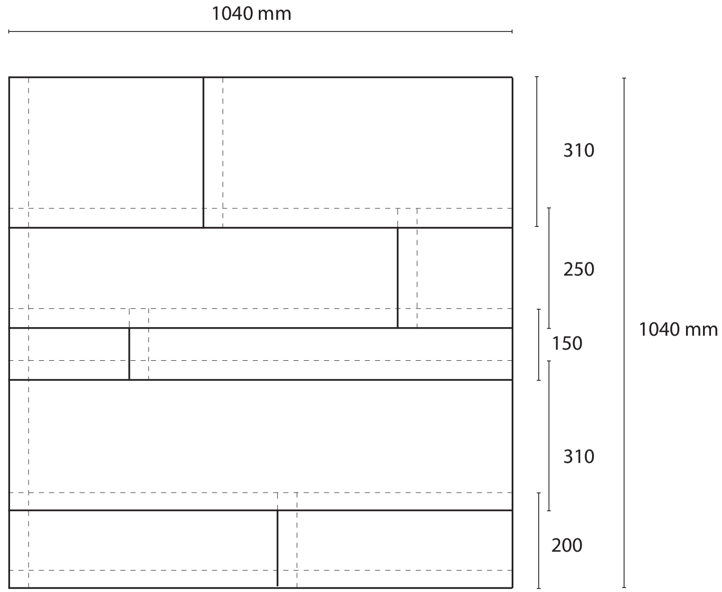


Material usge for 1m² of Spiro duct facade cladding
Calculated based on a 'facadeudsnit' as this:



0,105 m² flattend duct weighing 1300 g

overlapping 40 mm



= 1,2688 m² flattend ducts covering m² facade

weighing 15,71 kg

Org. duct dimension:	Width, flattend duct:
Ø 125 mm	150 mm
Ø 160 mm	200 mm
Ø 200 mm	250 mm
Ø 250 mm	310 mm

Figure 115 / Facade cladding made from rolled ventilation ducts / Chart of production of component for 1st generation reuse

Visualization of use of roof tile cladding

Figure 116/Visualization by students Lena Fedders, Amalie Brandt Opstrup and Line Tebering.

Figure 117/Visualization of a version of the concept

Prototype 5 - Vingetegl

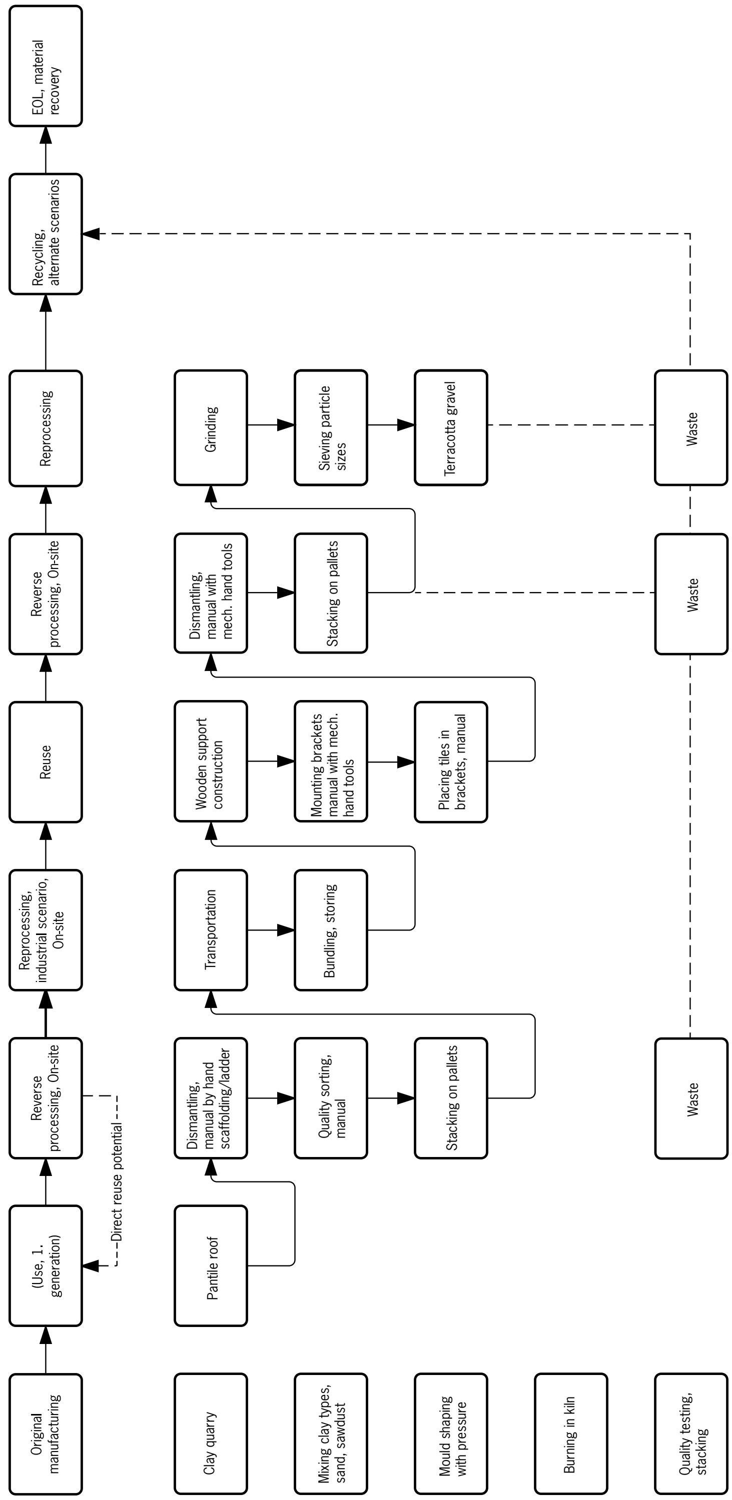
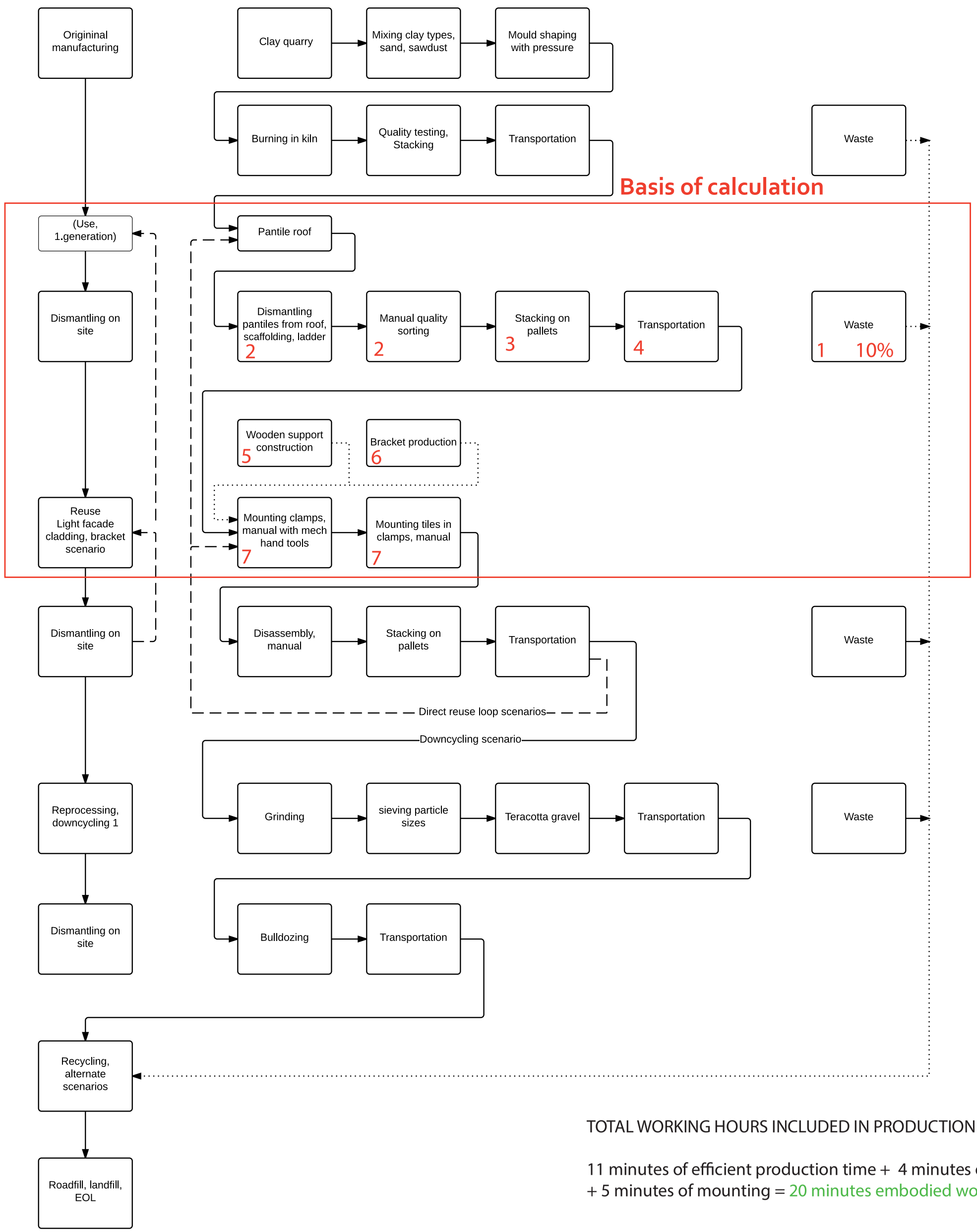


Figure 118/Flowchart for the prototype Facade cladding made from roof tiles

Figure 119/Facade cladding made from roof tiles



TOTAL WORKING HOURS INCLUDED IN PRODUCTION OF 1 M²

11 minutes of efficient production time + 4 minutes of transportation
+ 5 minutes of mounting = 20 minutes embodied work hours pr. m²

INDSATSFAKTA

LCA-data is calculated for 1 m2 of roof tiles repurposed as cladding for exterior walls, garden walls, fencing and other such surfaces. The concept is for at easy-to mount, fairly cheap, aesthetically 'dense' wall cladding which seals off most rain and wind if not all.

2) Dismantling pantiles from roof- 5 minutes
Work is done manually - it's quite easy actually. The tiles are mostly laid out on roof battens with few fastening points/screws.

We estimate that quality sorting could be done right at the point when dismantling the tiles.
A pallet is placed for the whole tiles, and a piping + container at ground level (or something like this) is set up for the broken ones (about 10%)

3) Stacking on pallets - 1 minutes
The tiles are already neatly/optimal placed in pallets during dismounting.
We estimated a small amount of time goes into handling the pallets on-site.

4) Transportation (back and forth) - 2 x 2 minutes = 4 minutes
fx. 25 km by lorry, Mercedes Sprinter 316 CDI 163 HK (typical in Cph)
Max. load 1.400 kg
Own weight: 2214 kg
Diesel consumption when emtpy: 12,6 km/l, when fully loaded, maybe 8 km/l Energyclass F

5) Wooden support construction - 5 minutes
For mounting the tiles we expect 2 rows of battens pr. row of tiles for hanging the tiles from, i.e. 10 pieces of horisontal battens (100 cm) pr. 1m2. Time includes cutting battens to lenght.

5x2 sec. fastening screws pr. batten x 10 battens pr. m2,
DeWalt machine 14,4 V
250 Watt
Energy consumption: 6,9 Watt pr. m2

6) Bracket production - no estimate for work
Is energy going into production of brackets a generic value?
Number of brackets (stainless steel 80x15x1,5 mm): 36 brackets/m2
Brackets weigh about 25 gram = 900 g stainless steel/m2

7) Mounting - 5 minutes
2x2 sec. fastening screws pr. tile x 18 tiles pr m2,
DeWalt machine 14,4 V
250 Watt
Energy consumption: 5 Watt pr. m2

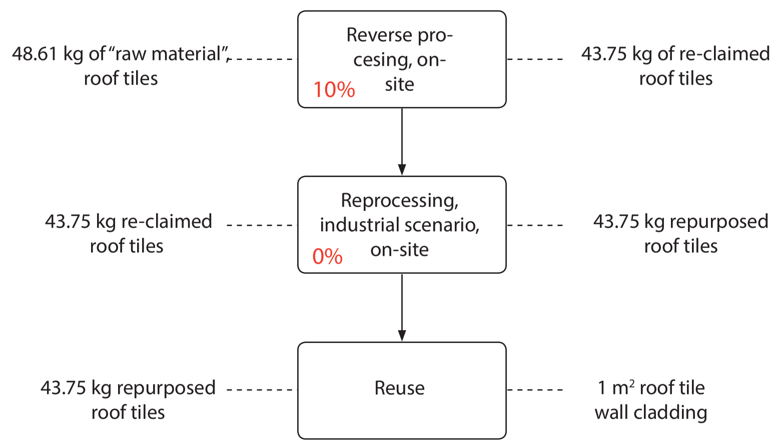
WASTE PRODUCTION
1) Re-claiming stage - 50%
10% waste is the estimate that the roof tiles will be un-reclaimable becuase of natural wear and tear, irreparable damages to corners etc. when dismantled, transported and so on. The concept we propose, however, doesn't need the tiles to be in 100% perfect condition which is why we set a farly low estimate on waste in the initial reclaiming scenario.

Figure 120 / Overview of material life cycle for Facade cladding made from roof tiles

WORKING HOURS

Same mehod of calculation as above mentioned

CHART OF PRODUCTION OF COMPONENT FOR 1. GENERATION REUSE



1m² of recycled roof tile wall
Calculated based on a 'facadeudsnit' as this:

1000 mm

1000 mm

Material usage roof tile wall
5 rows of 3.5 tiles = 17.5 tiles

each tile weighing about 2500 g

= 1 m² roof tile wall cladding

weighing **43.75 kg**

Figure 121/Chart of production of component for 1st generation reuse/ Facade cladding made from roof tiles

Figure 122/ NBCR at LevVel exhibition DogA, Oslo November 2014. See the further list of dissemination on the following page.

Industry experts/ Dates for first round of interviews

- Tscherning A/S: Demolition contractor. Peter Hansen, Head of Department. 14.08.2014
- RGS 90 A/S: Waste handling and recycling company. Michael Christiansen, Sales Manager. 21.08.2014
- Genbyg A/S: Reseller of reused building materials and components. Jesper Holmberg, co-owner and not part of the project. 18.05.15
- HJ Hansen: Scrap Dealer, Morten Widtfeldt, Manager.28/04/2015
- Glasfakta: Expertise and counselling on glass. www.glasfakta.dk. Carl Axel Lorentzen, Engineer and co-owner.17/04/2015
- Glarmester Aage Larsen. www.danmarkssydligsteglarmester.dk Morten Larsen, Owner 15/06/2015
- Diatool Aps Diamantværktøj. www.diatool.dk Kaj Andersen, Owner, Structural Engineer. June 2015
- Danish Waste Solutions. www.danws.dk/ Ole Hjelmar, Chemical Engineer, Co-owner. June 2015
- RoboCluster Innovationsnetværk, September 1, 2015

Additional valuable feedback has been obtained during dissemination at seminars and conferences.

Dissemination

Visions and results of the project have been exhibited and presented in lectures and magazines on numerous occasions.

Exhibitions

Three prototypes and a number of visualisations were exhibited at the exhibition Lev Vel in Oslo at Dog A, November 2014.

One prototype and a series of posters were exhibited at the Reuse Conference in Skive, Denmark, February 2015.

Prototypes were exhibited at the Trends & Traditions Fair at Lokomotivværkstedet in Copenhagen, March 2015.

Exhibition of mock-ups and lecture presentation at Building Green Fair, Copenhagen October 25-28 2015.

Publications and articles

Kleis, B., "Forskningspraktik i detaljen", BYG – Bæredygtigt Byggeri #2 2016 s26-29 (4pp), 26-29, Arkitektens Forlag, København

Larsen, M.S., "Ny arkitektur af gamle bygningsdele", BYG – Bæredygtigt Byggeri #2 2016 s30-32 (3pp), Arkitektens Forlag, København

Madsen, U.S et al (ed), Idékatalog over nye designstrategier for genanvendelse, KADK/Cinark – Center for Industriel Arkitektur, København, 2016 (40 pp)

Nordby, A.S. and Sørnes, K.; "Fra skrap til skatter". Arkitektur N nr. 2-15

Nordby, A.S.; "Ombruk - et bærekraftig førstevalg?" Byggfakta, September 2016

Asplan Viak's Webzine the customer magazine "Kvartalet": www.asplanviak.no/aktuelt/2016/05/31/ombruk-byggematerialer/ www.asplanviak.no/temaer/kampanjer/kvartalet/kvartalet-nr-2-2016-vugge-til-vugge/baerekraftige-materialer/

Lectures

Project ideas and work-in-progress results were presented at Nordic Built Kick-off meeting in Copenhagen November 20th 2014.

Project ideas and work-in-progress results were presented at research seminar at Royal Danish Academy of Fines Arts, Schools of Architecture, Design, and Conservation (KADK), Copenhagen, November 28th 2014.

Project ideas and work-in-progress results have been presented at internal seminar at Vandkunsten with professor David Leatherbarrow, Pennsylvania University and professor Ali Malkawi, Harvard University, December 1st 2014.

Presentation at Harvard Center for Green Buildings and Cities 2015 Fall Conference 'Sustainability in Scandinavia', Boston, November 3-6 2015.

Presentation at ICSA-conference, Everyday Tectonics Session, Guymaraes Portugal July 27-29 2015.

Project ideas and work-in-progress results were presented in lecture at NTNU in Trondheim, October 2014.

Project ideas and work-in-progress results were presented at the Norwegian building waste seminar in Oslo, January 2016

Project ideas and work-in-progress results were presented in «Pecha Kucha» night at NTNU in Trondheim, March 2016

Project ideas and work-in-progress results were presented at Svartlamon-workshop in Trondheim, September 2016

Project ideas and work-in-progress results were presented in seminar on Circular Economy, arranged by OREEC in Oslo, September 2016.

Literature

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Energistyrelsen/SBi (2015) "Introduktion til LCA på bygninger", Copenhagen.

Guest, G., Bright, R. M., Cherubini, F., & Strømman, A. H. (2013). Consistent quantification of climate impacts due to biogenic carbon storage across a range of bio-product systems9

/echler, O., Popovic, O. & Nielsen, S. (2010). Design for disassembly. C25 proceedings.

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Skive Kommune (2015) Afslutningsrapport Projekt Genbyg Skive. (http://issuu.com/energibyenskive/docs/afslutningsrapport_inklusiv_alle_bi)
http://www.kpmg.com/global/en/issuesandinsights/articlespublications/taxes-and-incentives-for-renewable-energy/pages/denmark.aspx