Sustainable and circular retrofitting facade

A future proof panel for building renovation

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Rafael Núñez Larios

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Author:	Rafael Núñez Larios (5137144)
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Mentors

Dr.ir. Roel Schipper	Faculty of Civil Engineering and Geosciences
Dr.ir. Marc Ottele	Faculty of Civil Engineering and Geosciences
Dr.Ing. Thaleia Konstantinou	Faculty of Architecture and the Built Environment
Prof.dr. Christos Kassapoglou	Faculty of Aerospace Structures & Materials

External Mentors

Arjan de Haan	RC Panels B.V.
Carlos Klein	RC Panels B.V.

Delft University of Technology
Faculty of Civil Engineering and Geosciences

Postbus 5
2600 AA Delft
The Netherlands

RC Panels B.V.

Constructieweg 1
8152 GA Lemelerveld
The Netherlands

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“A point has been reached in history when we must shape our actions throughout the world with a more prudent care for their environmental consequences. Through ignorance or indifference, we can do massive and irreversible harm to the earthly environment on which our life and wellbeing depend. Conversely, through fuller knowledge and wiser action, we can achieve for ourselves and our posterity a better life in an environment more in keeping with human needs and hopes. There are broad vistas for the enhancement of environmental quality and the creation of a good life. What is needed is an enthusiastic but calm state of mind and intense but orderly work. For the purpose of attaining freedom in the world of nature, man must use knowledge to build, in collaboration with nature, a better environment. To defend and improve the human environment for present and future generations has become an imperative goal for mankind-a goal to be pursued together with, and in harmony with, the established and fundamental goals of peace and of worldwide economic and social development.”

Declaration of the United Nations Conference on the Human Environment
Stockholm, Sweden June 1972

Abstract

The Paris agreement's mechanisms for 2050 represent a challenge for the world to achieve Net-zero emission and climate resilience. Retrofitting the existing stock is a critical step in every nation to achieve these goals. The building sector has a significant role in the Net-zero emission transition. The ambitions for retrofitting the Netherlands´ by 2030 and 2050 bring the need to explore new products taking sustainability and circular economy as the basis of design. This research explores the application of a "cradle to cradle" design approach to redesign a sandwich panel currently used as a renovation strategy to wrap existing dwellings in The Netherlands. The research in performed from the perspective of a façade company in the national market.

The current product manufactured by the company is not studied with the end of its service life in mind and is designed mainly with fossil fuels related products. Also, the time component is detached from the product, and scenarios where the materials are "processed and disposed" or "mined and reused" are not considered. The research explores three different façade concepts that contrast with a traditional linear production based mainly on fossil fuels. The analysis brings a set of 24 options, each with three circularity scenarios. The conclusions reveal that the environmental impacts and success of a "cradle to cradle" design strategy has a close relationship with the number of years the existing dwellings will be used. By reusing the existing dwellings for prolonged times (50 and 100 years), the best option for the company is to develop a biobased sandwich panel relying on renewables and materials with low environmental impacts but as an efficient "cradle to grave" strategy. However, for a shorter span of usage in the existing stock (25 years), the best option is a "cradle to cradle" strategy where the resources are taken back to the technical cycle combined with reduced usage of materials for the cladding system.

Some of the technical recommendations suggested are to test the biobased panel for a mechanical test. Afterward, develop the construction details for connections in foundation, windows, and doors to finally build a 1:1 mock-up to be tested for meteorological degradations and durability. Also, further analysis is needed for a financial case for the scenarios where materials are used after a first cycle. Finally, further research is needed to develop fully biobased matrixes to biocomposite fully biodegradable, allowing them to get back into a biological cycle.

Keywords

Retrofitting facades, Sandwich panels, Sustainability, Circular Economy, Existing stock, Life cycle Assessment, Composite structures.

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Preface

This thesis forms part of my 2-years master studies in Civil Engineering with a specialization in Building Engineering at TU Delft.

At first, I thank RC Panels for offering me the opportunity to perform my graduation based in their company. I would like to especially thank Carlos Klein, Arjan de Han, and Stein Bakker. They always guided and helped me finding specific information about their product and suggesting clever ideas for the research. Furthermore, I would like to thank my mentors at the TU Delft. Roel Schipper always had a critical view, and in few minutes of talking with him, new ideas and critical things were pointed out and discussed. Thaleia Konstantino who help me with her expertise in renovations, circular economy and always bringing me back to a methodological and research process. Marc Ottelé who guided me and helped to bring all the LCA simulations in order. Finally, I would like to thank Christos Kassapoglou, without his help, I could not have made the analyses of all the multiple composite structures simultaneously.

I also want to thank all my family for their support, especially my mom Patricia and my dad Rafael who always have unconditional support. Also, I would like to thank my friends who always kept me motivated to continue working despite the difficult times, especially Alex, Ashley, Bastiaan, David A., David P., Daniel, Julio, Karl, Luis, Maita, Marvin, Saša, Shai, Victor, and Xavi. Finally, I thank my wife Adriana, who constantly and unconditionally supported and motivated me during this thesis and to continue our adventure in The Netherlands.

- Lo mejor aún esta por llegar, ¡Gracias a todos!

Rafa
The Netherlands, 2021

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EXECUTIVE SUMMARY

Executive summary

Introduction

The Paris agreement's ambitions and mechanisms for 2050 represent a challenge for the world to achieve Net-zero emission and climate resilience. Strategies for retrofitting existing buildings are critical steps in every nation to achieve these energy and climate goals. The building sector has a significant role in the Net-zero emission transition. The construction and use phases take 36% of the world's energy use and 40% CO2 emissions.

Within the built environment, The Netherlands vision for 2050 includes the adaptation of 7 million homes. In the short term, the Government's primary goal is to renovate 1.5 million existing homes by 2030. This housing transition is achievable; for this, The Netherlands must take a **broader view of sustainability and include a circular economy as an essential component.**

Renovations typically aim to minimize the energy consumption of buildings during their use phase; strategies based only on reducing this aim, can ignore and potentially increase the environmental impacts. The designs of retrofitting envelope that promote a circular economy, have sufficient thermal insulation values, and use materials that have a low environmental impact are considered essential strategies to be implemented (Shadram et al., 2020)

The present thesis project is done together with RC Panels, and the case of study is based on their primary product developed and manufactured in the Netherlands. RC Panels successfully developed a solid shaped sandwich panel that retrofits the existing dutch stock by incorporating prefabrication and automation with efficiency in material use, living comfort improvement, and optimal insulation values. The current design consists of a multi glued layered sandwich panel mainly manufactured with different fossil fuel-related products.

Problem Statement

The current RC Panel is not designed and studied with the end of its service life in mind. Right now, the resources, materials, and energy involved to produce the panel for the first time are lost at the end of life (EoL). The life cycle ignores and detaches the time component completely by not including scenarios where the materials are "processed and disposed" or "mined and reused".

The present research aims to find a new design for RC Panels. The thesis focuses on finding circular or "cradle to cradle" alternative designs in a sandwich panel framework. A new design that reduces the environmental impacts mitigates fossil fuels' use and incorporates circular economy as an essential design parameter.

Research Question

To what extent can a "cradle to cradle" design strategy contribute to optimizing the circularity and sustainability of RC Panels?

Subquestions

• What do circularity and sustainability mean?

•Which are the promising product design models that incentive a circular economy?

•What are the boundary conditions of the current panel that should prevail in a new "cradle to cradle" design?

•Which state-of-the-art materials can contribute to the circularity and sustainability development of a panel?

•Which are the circularity and EoL scenarios that need to be considered in the analysis?

Research Approach and methodology

This thesis explores different façade concepts that contrast with the traditional linear production based mainly on fossil fuels. Shifting from generating profits from selling efficiency in using materials to developing profits from the flow of resources and products over time. Taking circularity and sustainability as a base for designing a model that creates viable scenarios to reuse goods and materials while building sustainable resources is viable.

The result will be a series of options for a new panel design for developers, housing associations, and tenants in the Dutch Market. The objective is to retain the same concept of a "sandwich panel" and the current boundary condition and properties of RC Panels.

Research methodology

The research methodology followed is:

Literature review

- Investigation of the current state of the art literature
    - o Why?

- Definition of sustainability and circularity

- Investigation of the case of study
    - o Who? & Where?

Exploration phase

- Research by design (Concept and development)
    - o How?

- Assessment for circularity and sustainability
    - o Definition of scope, goal, functional unit, inventory analysis, impacts assessment, and interpretations.

Elaboration phase

- Reporting
    - oDiscussion, findings, and conclusion
    - oRecommendations and future opportunities

An exploration phase is proposed after the literature review and case study. A loop analysis of multiple stages starting with the original RC Panel design. Then, this design is "influenced" by new criteria incorporating circularity and sustainability. As concepts of design, three new options are proposed: (1) a Biobased sandwich panel (2) Double board panel (3) Hybrid frame/sandwich panel.

After concept design, the "Material choice" phase is proposed as a first filter for the materials to be compared. Different products are chosen for the face sheets, board, claddings in this phase. The designs enter a "Design development" phase where the mechanical and physics part is reviewed with the preliminary choice of materials. This ensures that the panel is strong enough and does not represent a pitfall in later analysis stages. Finally, the panel options enter a Life Cycle assessment, where they are compared with the same functional unit of 1 m2 with three different circularity scenarios.

"

Applying sustainable civil engineering practices is not only profitable to the directly involved shareholders but also to society as a whole (Sukhdev 2012).

"

Literature review

Housing Stock in the Netherlands

The vision for 2050 includes the adaptation of **7 million homes.** The Central Bureau of Statistics (CBS) of the Netherlands reports that 64% of the existing stock was built between 1925-1985. The remaining 36% between 1985 and 2021. Also, approximately 5.2 million happen to be already used from 35 to 50+ years. The lowest energy labels are in the dwellings built before 1980. Hence, this group of homes is in significant need of retrofitting strategies before now and 2050.

The core business of RC Panels right now are **terrace homes.** For this reason, this research is based on this type of dwellings, which also happen to be the largest group in the country with **42.5%** out of the 7 million existing homes.

Time is a subjective topic in this matter; it is difficult to predict the trend of 7 million homes; however, this "time component" affects the environmental performance of the panels. For this reason, the research compares the difference between using the existing stock for a long time and using it for reduced periods.

Retrofitting strategy

The research focuses on a "Wrap-it" scenario. In this case, as its name says, the method suggests to 'wrap' the existing buildings. A second layer is installed in front of the existing façade bringing a new thermal line on the exterior. The concept offers reasonable thermal bridging solutions, creates a minor nuisance to the tenants, and reduces materials waste and disposal.

The wrap-it solution analysed in this research is based on structural panels; these are structured composites that typically consist of a solid rigid insulation core in between a sheeting layer, then fixed between two rigid membranes.

Sustainability

The traditional building process can be defined in six distinctive phases, all will include some transportation, labor, equipment, and energy. Also, waste in form of solids, liquids or gasses are emitted to the environment.

With the passage of time and several actions such as chemical accidents, environmental pollution, and the decrease of ecosystems, researchers realized that the "healing and cleaning" capacity also reoffered as (carrying capacity) of nature and ecosystems is limited. When humans exceed this "capacity", natural free and cleaning services are no longer provided by the environment, and they need to be compensated with new technological solutions.

There are different definitions of sustainable development; Brundtland in 1987 defined it as a "development that meets the needs of the present generation without compromising the ability of future generations to meet their needs". Referring to 'needs' as the availability of natural resources is taken by human actions and becomes depleted and 'needs' as healthy living conditions.

Typically, there are different costs involved in the "price" of a product. Here, to afford the design and development of technologies to clean the ecosystems, the so-called 'external costs' exist. This price must include an "environmental cost", in other words, **"the polluter pays".**

Literature review

Circularity

Currently, many corporations extract raw materials, input energy and manpower to create a product and sell it to an end costumer. After the product is used, it is discarded when its requirements are no longer needed or fulfil. According to the Ellen Mcarthur foundation, the circular economy refers to an industrial model restorative by intention, relies on renewables, eliminates the use of toxic chemicals, and eradicates waste through careful design (Macarthur, 2020). A "restorative by intention" means to redefine goods beyond the required "needs" of a product/service.

Slowing, Closing, and narrowing resources loops

Bocken and others proposed the definitions of slowing, closing, and narrowing resource loops. This was to mark the difference between linear and circular models clearly, and it is done by the systems in which the materials flow through their life cycle. A difference between "cradle-to-grave" and "cradle-to-cradle" cycles needs to be made. The main difference can rely upon the fact that the latter refers to "closed-loop systems" in the use of resources, distinguishing two necessary different types of loops: (1) reuse of resources and (2) recycling of resources (Bocken et al., 2016).

Slowing resources loops means extending the utilization time of a product through the design, and it includes the addition of "service" cycles to enlarge the time the materials are used. Closing means closing the cycle between post-use waste and the production of new materials. Narrowing the use of materials, using as few materials as possible to create a product. This is an eco-efficient cradle-to-grave strategy and is well known in the current economy, and many companies apply the concept of "fewer resources as possible".

Design for dis- and reassembly

Design for dis-and-reassembly facilitates maintenance, repair, a future change and the eventual dismantlement (partially or entirely) to recover systems, components and materials. The main idea is centralized in the recovery of resources, intending to maximize the economic value and minimize environmental through reuse.

There is a limitation in the literature on the end life of sandwich panels in general. Defining scenarios and phases from planning how to disassemble to further treatment (reuse or recycle) of materials. The proposed designs will consider the following criteria and the design for disassembly strategy: (1) When is the EoL decision? (2) Dismantlability from the existing building. (3) Transportation, (4) Sorting, (5) Cleaning (6) Reuse or (6) Disposed.

"

The greenest product is the one that already exists because it doesn't draw on new natural resources to produce (Bocken et al., 2016)

"

RC Panels

RC Panels is a Dutch company located in Lemelerveld in the province of Overijssel in the Netherlands. The central concept is the manufacturing of ready-made facade elements.

The base panel has the following structure from the inside to the outside: (a) 0.70 mm of polyester, (b) 15 mm OSB 3, (c) 200 mm of fireproof EPS100, (d) 0.70 mm of fireproof polyester and (e) façade decorative finish. The panel is provided with (f) polyurea all around the edges and recesses to completely weathertight.

RC Panels - Life cycle assessment

As part of the Smart Renovation Factory project by INDU-ZERO, a project for the North Sea Region within the European regional development fund, the environmental impact of renovation packages where reviewed. In this study, several authors reviewed the RC Panel's.

The LCA assessment was performed to evaluate the panel's contribution to several environmental aspects. The analysis's goal and scope were to optimize the existing product's environmental impacts, analyzing 60 years period with a functional unit of 1 m2. The cycle phases considered in the study are only the product and use phase. **The End-of-life and reuse phase were excluded from the analysis.**

The data inventory was taken from the Swiss Ecoinvent database. The impact assessment was done following the ReCiPe method. The analysis of 1 m2 of the panel is analyzed is presented in the figure below

The study suggests paying particular attention to different panel layers such as the OSB, the glass fiber polyester and the EPS. Together they represent 75% of the total impact of the panel.

The study suggests paying particular attention to different panel layers such as the **OSB, the glass fiber polyester and the EPS**. Together they represent 7**5% of the total impact of the panel**.

RC Panels - Durability report

In March 2017, SKG IKOB researched the exposure of the RC Panel system under a specific climate load. The research was performed with a 1:1 mock-up of 3.80 m height and 3.0 m length wall. The 1st line of defence was examined with a finish with STO mineral brick strips and an STO plaster layer.

The report conclusion says that the load deterioration load corresponds to a weather load of 20 years. However **after the weather deterioration exposure**, the panel showed **NO damaged.** Therefore, SKG-IKOB expected that a **50-year span in achievable.**

Evaluation Phase

Concept design

Three design concepts are proposed based on the design strategy for both slowing and reducing resources loops.

The conceptualization of a new panel started by taking a small section of the RC panel and looking at the interaction of the different components at a closer view. The process started by decomposing the panel in three main sections. Number ONE the "connection of the existing wall and the retrofit panels". Number TWO the "main thermal panel" as the element that will mainly reduce energy consumption. And number THREE is the "cladding" interface.

Concept 1 – Bio-composite sandwich panel

Concept number two is called a double board panel because it uses two boards instead of only one (RC Panel). During the visits to the factory multiple times, it was mentioned that the joint between the OSB and the interior GFP was one of the connections that presented the highest challenge to detach. It was even commented that only incineration is the only EoL treatment.

Concept 2 – Double board panel

Concept number two is called a double board panel because it uses two boards instead of only one (as the RC Panel). During the visits to the factory, multiple times it was mentioned that the joint between the OSB and the interior GFP was one of the connections that presented the highest challenge to detach. It was even commented that only incineration is the only EoL treatment.

Concept 3 – Hybrid sandwich/framed panel

RC Panels is a composite structures company, and keeping the sandwich panel framework is part of their primary interest. However, considering the advantages of a timber frame, concept three is proposed as a hybrid system. The idea comes from challenges that could have concept 2 where the GFP glued behind the OSB3 is removed and the size of the panel is limited to the supply of the boards.

Evaluation Phase

Materials choice

In this section, different materials are researched and selected for the concept designs. The material follows form by researching the properties of materials and their application. Always keeping in mind the boundary conditions of the RC Panel as an exterior “enclosure” and the pursuit of a circular and sustainable product design.

The final selection for the materials are.

Facesheets:

Multiple biocomposite structure where compare. The final selection is a 2 mm Biocomposite membrane made out of flax fiber and a BioEpoxy

Sheathing board:

Different biobased board where selected to be compared with the current OSB and to be used as facesheets (for concept 2). The comparison includes medium density board, plywood and chipboard. The selection is a Birch or Spruce plywood

Cores:

Since the idea with RC Panels started with pursuing a biobased core for the panel, in this section, four materials are selected and input to the structural design: (1) Expanded cork, (2) Hemp mycelium panels (3) Wood fibre (4) PLA Foam.

Cladding:

Different biobased ventilated façade cladding compares such as an actual thin brick, a fibre cement tile and a recycled plastic tile. The selected material was the real brick attached to an aluminium frame

Design Development

The structural design of the present research was done following the classical laminated plate theory (CLPT).

A composite plate model is constructed in a simplistic way, whereby, at the beginning, no account is taken of local stress concentrations due cut-outs due to windows or doors. The deformations in the façade are calculate assuming superposition of the “self-weight” of the panel, “wind load”, and “hoisting mechanishm”.

The materials selection gives the input for the structural analysis. The ranking in the previous chapter provides the starting point for this process. The selected materials are iterated for the three different design concepts. As mentioned before, each concept has two cladding systems and four insulation cores. The total of options analyzed in this chapter are **twenty-four new designs.**

The starting thickness of the cores is calculated with the general formula of the thermal resistance (thickness divided by thermal conductivity). The thermal resistance is the same as the Original RC Panel, 7 m2/(m.K).

Fixing conditions

RC Panels uses multiple anchorage systems, the selection of such depends on the existing conditions of the dwelling in question. For the CLPT the selection of the fixing condition is vertical rails since they could represent a more critical scenario where less bolts are involved.

The summary of the 24 designs presented is in ANNEX XX. Each chart provides the material layer, thickness, and weight per m2. The correct way to read the charts is from left to right. The three concepts are labelled of the far left, then the cladding systems change vertically and the cores horizontally.

Life cycle assessment

To assess the environmental impacts of the new design alternatives, each concept and their variants are assessed with lifecycle assessment methodology. Then, compare each other with the original study performed by TU Gent for the INDU ZERO Project.

The original idea was to make a one-to-one analysis with the same strategy followed for such project. However, due to access limitations to the software SimaPro and the Swiss Ecoinvent database, the original design needs to be assessed again so the comparisons are equal to each other's methodologies and data inventory.

The new simulation tool used is One Click LCA. This was done with a license owned by TU Delft. The license is student permission, and the tool allows different simulations for environmental assessment on an online basis. The software is for construction sector applications, using the EN 15804 standards. After the original design is assessed with the new methodology, a second study of 100 years analysis for the new designs is performed with three circularity scenarios will as a "Cradle to Cradle" strategies.

The three circularity scenarios are:

1) **100 years** with **one terrace home**, including the correct technical cycles for maintenance and replacement of the main components of the panel.

2) **100 years** with **two terrace homes**, after the first retrofitted home is used for 50 years, **a second home** will receive the still **"usable" materials and reuse them for next 50 years.** In between the time spans, the correct maintenance and replacement of the main components will be included.

3) **100 years** with **four terrace homes**, after the first retrofitted home is used for **25 years**, a **second home will receive the still "usable" materials** and reuse them for the following 25 years. The process will **repeat itself until the panel reaches the 4th home** in the 100 years' time frame.

Due to the limitation of data, the environmental impacts of the mycelium hemp panel, and the PLA foam could not be further research in this phase. The remaining twelve out of the twenty-four options with Expanded cork and Wood fiber cores were further analyzed.

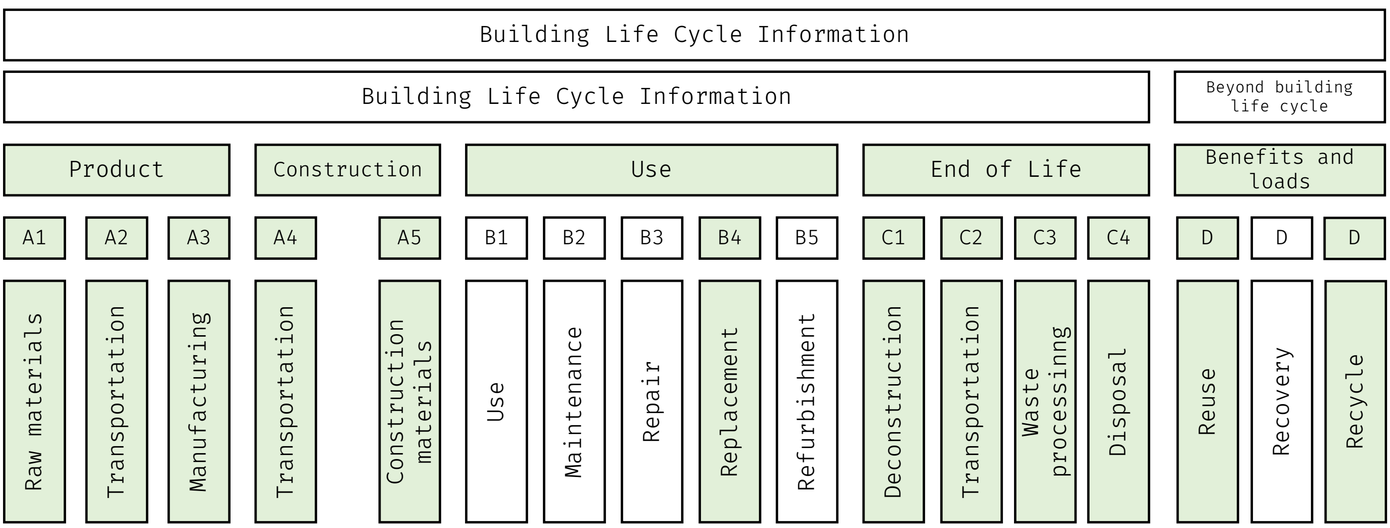

Figure 1 Cradle to Cradle LCA

Evaluation Phase
Life cycle assessment
LCA Results – 1st circularity scenario

The environmental costs index (ECI) of the resources used for each design concept in the first circularity scenario are presented in Figure 2. Two out of the six new design alternatives result in better ECI than the original design. The best design is the “biobased sandwich panels”. C1-Mineral brick scores 24.1%.

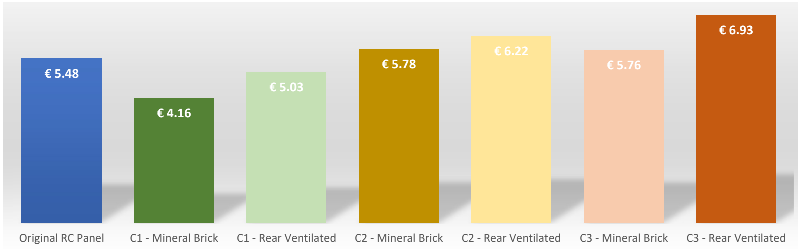

Figure 2 ECI for 1st circularity scenario

LCA Results – 2nd circularity scenario

The environmental costs index (ECI) of the resources used for each design concept in the second circularity scenario are presented in Figure 3. As seen in the graph, three out of the six alternatives generate a better impact than the original design. C1-Mineral brick scores 20.5 % better, C2-Mineral brick scores 15.7 % better, and C3-Mineral brick scores 17.5 % better.

The two biobased sandwich panels have a higher ECI for the 2nd home analysis, and this is mainly because most of the materials in these options and in the original design can not be reuse in a new home; please refer to Figure 4.

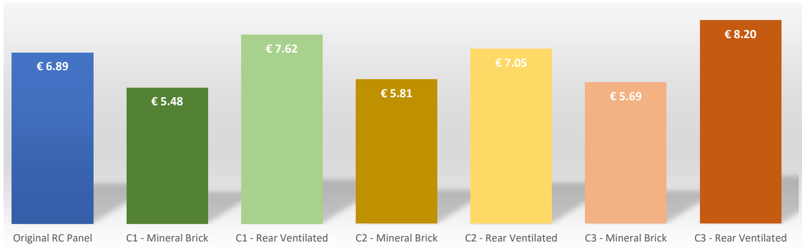

Figure 3 ECI for 2nd circularity scenario

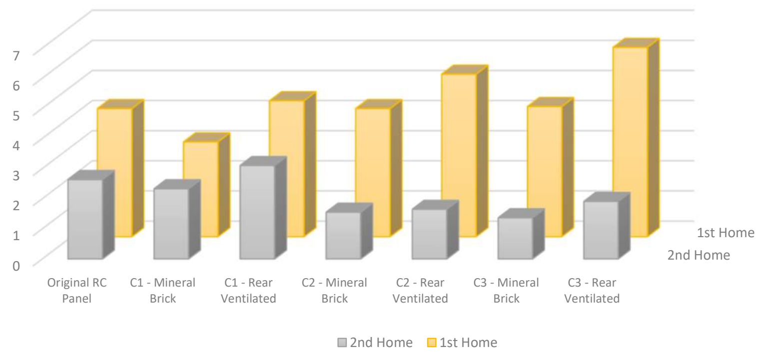

Figure 4 ECI analysis per home - 2nd circularity scenario

LCA Results – 3rd circularity scenario

The environmental costs index (ECI) of the resources used for each design concept in the third circularity scenario are presented in Figure 5. As seen in the graph, now all the six new design alternatives generate a better impact than the original design. C1-Mineral brick scores 13.7%, C1- rear ventilated scores 10.8%, C2-mineral brick scores 21.7%, C2- rear ventilated scores 28.4%, C3-Mineral brick scores 30.1%, C3- rear ventilated scores 25.5%,

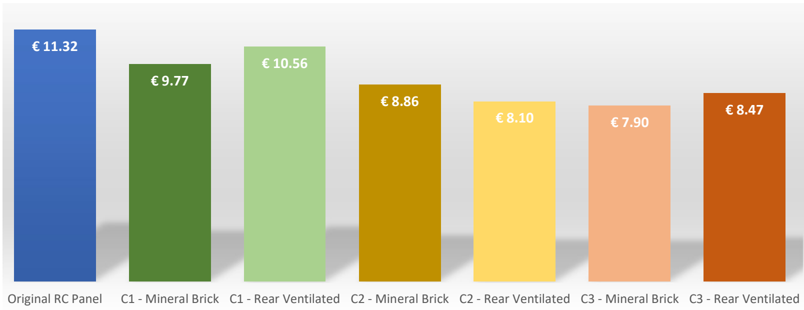

Figure 5 ECI - 3rd circularity scenario

The best design in this scenario is C3-mineral brick; this option is the hybrid frame/sandwich panel with a stucco finish. As seen in Figure 6, the number of outputs due to the resources used for the following homes is considerably less than the rest of the original panel.

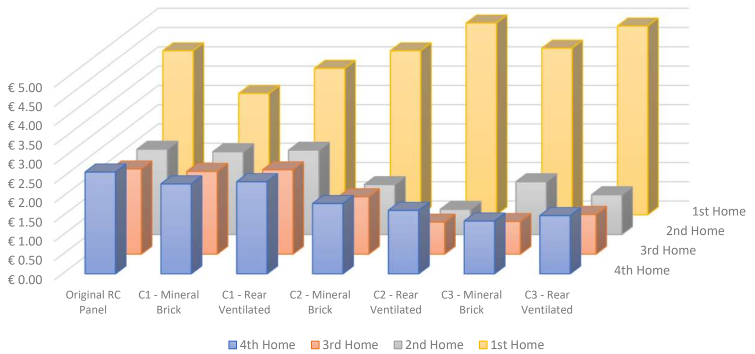

Figure 6 ECI analysis per home - 2nd circularity scenario

Discussion

When using the existing skeleton of the homes for a prolonged time (100 years and 50 years), the best option is to redesign the RC panel as a biobased sandwich panel with a mineral brick cladding system. However, by reducing the time component to a 25-year analysis, the findings suggest that a hybrid frame/sandwich system with a mineral brick will represent considerably lower environmental impacts than the original and the biobased sandwich panels.

These results relate to the circularity literature review with the terminologies of slowing (reusing) and narrowing (reducing) resources loops (Bocken et al., 2016). A "cradle-to-cradle" strategy where the resources are taken back to the technical cycle by extending the utilization time of a product, in this case, are the same strategies that use more materials at the earlier stage of the analysis (product phase). More materials are used to incentivize "assembly and disassembly" panels and in combination with a scenario where they are never going to be reused in a different home, making them not an appropriate strategy to follow because they never balance their ECI in time.

Findings

The findings from the research are offered in comparison with the combination of the life cycle assessments and the circularity scenarios proposed. The four main findings of the research are:

(1) Time component

The findings suggest that the "time component" in terms of the usage of the existing skeletons in combination with scenarios where materials are mined from a first renovated home and reused in a series of subsequent homes, has a close relationship with the environmental impacts of the retrofitting panels.

A "cradle-to-cradle" strategy only succeeds, based on this research results, if the materials are reused in subsequent homes but not if the first renovated home is kept in usage for prolongated time. The main reason is because a "cradle to cradle" design uses more materials at the product phase. The fact that design is incentivized to have "assembly and disassembly" in the internal interfaces of the panels and with a combination with a scenario where they are never reused in a different home, makes them not an appropriate strategy to follow even if the end-of-life is considered in materials coming from fossil fuels such as EPS, Polyester, polyurea, etc.

(2) Residual value

The residual value of the materials is referring as the "beyond the first LCA" benefits and loads of materials. The finding show that reusing makes a big difference in the environmental impacts. Despite the low material usage in the product phase of the original panel and the biobased sandwich panels, the findings suggest that the loads and benefits will likely improve the overall ECI of any design due to correct return to a technical cycles of resources. Hence, an improved functionality of the resources by not having a linear behavior. However, even in combination with four homes with 25 years span, the residual value of a rear ventilated façade compared with the mineral brick slips does not performed with the lowest ECI. Only when combining "reusing" as a cradle-to-cradle design in the main thermal panel and "reducing" as a cradle-to-grave design in the cladding, the product reaches between 30.2 % and 21.3 % lower Environmental Cost Index (depending on the core selection).

(3) Use of bio-based materials

Detaching the sandwich panel from fossil fuels and using biobased materials reduces the ECI of the product in time. The best design strategy for the first and second circularity scenarios is a biobased sandwich panel that relies on renewable materials with low environmental impacts. However, it is essential to investigate and document the modification of natural resources through the manufacturing of the panel. Not all the biobased products can be recycled or can re-enter into a biological cycle because they are not 100% biodegradable. Meaning that the biobased sandwich panel, in this is research, is therefore an efficient “cradle to grave” strategy using renewables as much as possible and narrowing resources loops by using as fewer materials as possible.

(4) Circular principles within sandwich panels framework

One home analysis – 100 years

If the existing stock is used for a prolonged period, like 100 years, the best options for improving RC Panels’ sustainability are the two biobased sandwich panels. Regardless of the two core options (expanded cork or wood fibre), both alternatives will have a better environmental performance than the current product developed by RC Panels and the rest of the new design options.

The best advantage of the current design is its durability and efficiency in the material used. When strategies allowing the reentering of resources to a service cycle are compared with the original design, the environmental impacts in the product phase (A1-A5) of such strategies are considerably higher than the current product.

Two home analysis – 100 years (50 years gap)

Suppose an existing home is used for 50 years, and a second home receives the mined resources from the first home. In that case, the original panel starts to have higher environmental impacts than some of the designs aimed for “detachability”. Three out of the six new design concepts perform better than the original design, and all of them using the current cladding of RC Panels. This starts to tell that the actual mineral brick cladding that brings the 50 years durability span is a significant advantage in combination with a double-board panel and a hybrid sandwich/ frame panel.

Four home analysis – 100 years (25 years gap)

Similarly to the previous analysis, but now with four homes with a 25-year gap in between mining resources from one home to another, the original panel has higher environmental impacts than all the new designs. Six out of the six new concepts have better ECI, and both mineral brick slips and a rear ventilated façade now have a better performance. This process shows how products with an internal and external interface allowing “detachability” will reduce the environmental impacts of retrofitting the existing stock.

The best design in this is now a hybrid sandwich/frame panel with mineral brick. Minimizing the use of materials with a clever design allowing the detachability of resources is proved to lower environmental impact. This design combines the “reduce” use materials of a sandwich panel by using few resources for the cladding and exterior factsheet and the “reuse” of materials of a frame by allowing the separation of resources.

Conclusions

The extent of the application of a “cradle to cradle” design strategy to improve the circularity and sustainability of RC Panels will depend on the time the existing stock to be renovated is used. By means of what is the strategy to renovate and how many years the buildings will still be used and not demolished. Additionally, using renewables materials reduces the environmental impacts of the panels.

To answer the main research question, first, the research sub-questions will be answered:

What do circularity and sustainability mean?

Circularity

Circularity is a model is self-restored by intention; it relies mainly on renewable materials, deletes toxic chemicals by keeping them out of the system, and avoids material waste through the life cycle with a mindful design.

Sustainability

Sustainability stands for the sustainable development of products and needs. Acknowledging that the capacity of the environment to heal the pollution is limited and that there is an economic need to develop technologies to solve pollution caused by human action.

Which are the promising product design models that incentivize a circular economy?

Reusing (slowing loops) resources as much as possible is probably the best model incentivizing a circular economy. As mentioned before, a product that already exists will not take natural resources. However, these strategies have different design solutions such as “design for dis and re assembly” or “creating long-life products”. In both, the product design should facilitate and controls maintenance and repair. The extent of the time used in applying a renovation highly affects the results of these strategies.

What are the boundary conditions of the current panel that should prevail in a new “cradle to cradle” design?

The current RC Panel offers multiple conditions that need to be considered when a new design is pursed.
• The first one is its thermal resistance, currently the company offers an R-value of 7.0 (m2·K/W)
• A second condition is the possibility to detach the panel from the dwellings by not gluing insulation to the existing façade.
• A third boundary is to support the same loads the current panel withstands. These are the self-weight and the wind load for a terrace homes height.
• A fourth condition is to offer an aesthetic al view for the audience in the Netherlands. It is known by RC Panels that clients have a strong alike for bricks.

Which are the state-of-the-art materials for the components of a new panel that can contribute to the circularity and sustainability of the panel?

There are different materials for the different layers of the new panels.

(1) Facesheets: the current research suggests that using a biocomposite reduces the environmental effects caused by the current Glass fiber polyester (GFP).

(2) Wood boards: Changing the OSB3 panel for plywood also reduces the total environmental effects. However, due to the reduction of the environmental impacts of the biocomposite instead of GFP, and the expanded cork (or Wood fiber) instead of EPS, the percentage of the contribution of wood board as increases from 13% with the OSB3 to 23% with plywood.

(3) Cores: There are two new core options suggested by this study: Expanded Cork and high-density wood fiber. The sustainability analysis reveals that both have a better performance than EPS, scoring better the expanded cork option..

(4) Cladding: After reviewing the comparison between a rear ventilated façade and the cladding currently use by the company, it can be seen how mineral brick slips have a significantly better performance than a rear ventilated façade.

Which are circularity scenarios are considered in the analysis?

It is difficult to predict for how the dwellings in the Netherlands will be used, however, this "time component" affects the environmental performance of the panels and for this reason the three scenarios are proposed with a 100 years time span with home interventions in between.

Main research question

To what extent can a cradle-to-cradle design strategy contribute to optimize the circularity and sustainability of RC Panels?

According to the research, a cradle-to-cradle strategy primarily offers the possibility to bring materials back to service cycles. The extent of how much this strategy contributes to improve the sustainability and circularity of the current product will depend on how long the existing stock in question will be used.

Based on the potential of reusing the dwellings between 50 and 100 years, the best option is to use as much as possible biobased materials to reduce the environmental impacts of the retrofitting panel. Even though most resources cannot enter into a service cycle further, if the time expectation is reduced to 25 years, a "cradle to cradle" will be the best option. A strategy relying not only on biobased materials but also in enhancing circularity as an ease of disassembling the resources for a correct re-enter into a service cycle. However, the combination between a "reuse" of the main thermal panel components (Hybrid sandwich/frame panel) and a "reduce" of the cladding system (mineral brick slips) is still the best option for the 25-year analysis.

Recommendations

Technical recommendations

It is suggested to test the biobased panels for both wood fiber and expanded cork.

Mechanical and meteorological testing

The panels are suggested to be analyzed with the proposed dimensions for both cores. This analysis is suggested to be performed with correct loading conditions as a vertical element hanging from anchors or rails and a uniform load acting as the wind. A grid of vertical and horizontal pads is suggested working as a "Whiffletree". Each pad with metal circle or tab of a "known" area and with the surface in contact with the panel coated with a silicon or flexible rubber to avoid failure due to punctual load.

After the mechanical testing, the develop the construction details for the foundation, slabs, windows, and doors for the biobased panel is suggested. Here it important to make sure the biocomposite is not exposed to the environment by protecting it completely it with the STO mineral cladding. After details are developed, perform a durability test like the one performed by SKG-IKOB in 2017. Induced the same meteorological cycles to the biobased panel and observe its degradations and failure.

Environmental recommendations

Future research in biobased matrix with higher biobased content for a biocomposite is suggested. Ideally a full biobased and biodegradable biocomposite could take the biobased sandwich panel closer to a cradle-to-cradle strategy.

Future research the environmental impacts of Mycelium boards with multiple fibers and PLA foams. Also, future research in the reduction of the thickness in the biocomposite to lower the cost and the material usage.

A general research of the availability of biobased materials is important. The environmental impacts of these materials make them an attractive and promising solution to reduce the environmental challenges faced in the world. However, the correct management and availability could be a challenge due to a high demand.

Additional recommendations – Financial and business case

Keep the mind open to strategies with a “reuse” design. As seen in the circularity scenario 1, a biobased sandwich panel with a ventilated cladding scores slightly better than the original panel. This could be seen as an opportunity to manufacture this panel when designers prefer real stone finish.

Have the flexibility to discuss and collaborate with municipalities in the neighborhoods’ planning and offer a multi scenario portfolio that can potentially be freely adjusted. Develop the business model to make sure the resources can be reused needs further development.

The scenarios where the loads a benefit after the first LCA also represent a larger economical investment and they only work if the materials are actually reused. To introduce the time component to their portfolio, the company could ask for an incentive or loan to bring and offer these scenarios where the façades are traced, mined, reused and correctly disposed (if needed). In any case, the collaboration of municipalities with urban designers, architects, and developers to determine what´s the most likely scenario of each neighborhood in the cities is needed. Determining if a “reduced usage of material” is better than a “reuse usage of materials” will depend on these decisions.

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INTRODUCTION

Introduction

Global and national perspective

The Paris agreement's ambitions and mechanisms for 2050 represent a challenge for the world to achieve Net-zero emission and climate resilience. Strategies for retrofitting existing buildings are critical steps in every nation to achieve these energy and climate goals. The European Union energy performance of buildings directive has specific plans for full decarbonization of the existing building stock. Besides reducing the existing buildings' energy consumption, retrofitting strategies aim to reduce emissions, energy and waste generated by demolition, new construction activities, and materials manufacturing.

The building sector has a significant role in the Net-zero emission transition. The construction and use phases take 36% of the world's energy use and 40% of the CO2 emissions. In the Netherlands, the climate agreement is part of the Dutch climate policy. There are different specific sectors commitments: "Built environment", "Mobility", "Industry", "Agriculture and land use", and "Electricity".

Within the built environment, The Netherlands vision for 2050 includes the adaptation of 7 million homes. In the short term, the Government's primary goal is to reduce CO2 emissions by 49% in 2030 compared with 1990. Approximately 1.5 million existing homes will have to be renovated, almost 140,000 per year in 2019-2030. This housing transition is achievable; for this, The Netherlands must take a broader view of sustainability and include a circular economy as an essential component. It is a social challenge where all the parties involved must work together to shape the process correctly (Ministry of Economic Affairs and Climate Policy, 2019)

Renovating The Netherlands

In the Netherlands' vision for 2050, the total number of dwellings that need to be renovated already exceeds the need for new constructions (Ministry of Economic Affairs and Climate Policy, 2019). A renovation strategy includes different building components, which means that it is an integrated refurbishment process (Konstantinou, 2014). One of the key components for fully integrated renovations aiming to improve energy performance is elements where heat losses/gains increase/reduce the energy demand. These are the non-transparent areas (external walls), transparent areas (windows and openings), balconies, roof, and surfaces in contact with the ground. All the before mentioned components comprehending the exterior building enclosure.

Energy efficiency in buildings has forced researchers and the construction industry to resolve the thermal challenges in dwellings, raising the advent of revolutionary systems that could decrease the energy use phase and offer indoor comfort. However, most of these solutions depend on or barely remain within limits imposed by protecting and preserving the planet's resources (Shadram et al., 2020). Retrofitting strategies for envelopes with designs that incentivize circularity, bring proper thermal insulation values, and use materials with low environmental impacts and emissions are believed to be the most effective strategies to be embraced. (Shadram et al., 2020)

Even though a building façade plays an essential role in a sustainable, comfortable and desirable living environment, the existing building stock often lacks performance (Konstantinou, 2014). In dwellings where the heat losses are not correctly addressed, and therefore the energy demand is high, the enclosure contributes an essential part to the energy consumption and, thus, the environmental impacts and emissions of such buildings. Different parameters can contribute to the lack of performances of the facades, and this can be due to the lack (or no need) of regulations and codes in the time of construction, deficiencies in the labor skills or building techniques during the construction time or building materials in their end of the life.
Many of the comfort, technical and physical problems of buildings are connected with the facade. The main structural skeleton of a building is known to have the most extensive lifetime, while the rest are

likely to have shorter timing. Some authors mentioned that facades are likely to lack performance after 20 years while the building's structural integrity can remain for a substantially longer time (Brand, 1990). Therefore, there is no doubt why state-of-the-art solutions should be researched and developed for façade renovations. All in all is an effort including all the scales of intervention from the tenants, homeowners, and housing associations to product manufacturers, suppliers, builders, construction companies and designers.

Renovations typically aim to minimize the energy consumption of buildings during their use phase; strategies based only on reducing this aim, can ignore and potentially increase the environmental impacts. The designs of retrofitting envelope that promote a circular economy, have sufficient thermal insulation values, and use materials that have a low environmental impact are considered essential strategies to be implemented (Shadram et al., 2020)

Circular Economy

Besides addressing the buildings' primary energy demand, the energy performance policies are looking for environmentally friendly properties in the building materials. The design of retrofitting envelopes that promote a circular economy, have sufficient thermal insulation values, and use materials that have a low environmental impact are considered essential strategies to be implemented (Shadram et al., 2020)

The circular economy has been discussed as a promising strategy to reduce the built environment's environmental impacts. The Ellen MacArthur Foundation widely promotes and educate people about circularity in businesses. Different commissions take a circular economy and combine it with recycling and avoiding the loss of valuable materials, moving to a zero-waste economy, reducing CO2 emissions and environmental impacts by creating a mutually beneficial synergy between the stakeholders of the economy (Bocken et al., 2016).. The importance of closing "technical" and "biological" loops in a circular or "Cradle to cradle" instead of a linear or "cradle to grave" economy is mentioned by The Ellen MacArthur foundation. Besides, it promotes that operating toward efficiency alone (reducing resources and consumed energy) is not the solution since only delays the planet's finite nature. "A change of the entire operating systems seems necessary" (Macarthur, 2020)

The present thesis project is done together with RC Panels, and the case of study is based in their main product developed and manufactured in the Netherlands. Therefore, the research will focus specifically on exterior interventions wrapping existing dwellings.

RC Panels

RC Panels successfully developed a solid shaped sandwich panel that retrofits the existing Dutch stock by incorporating prefabrication and automation with efficiency in material use, living comfort improvement, minimal maintenance, lightness, affordable cost, and optimal insulation values. The current design consists of a multi glued layered sandwich panel that is mainly manufactured with different fossil fuel-related products.
The basic panel has the following structure from the interior to the exterior: (a) 0.70 mm of polyester, (b) 15 mm OSB 3, (c) 200 mm of fireproof EPS100, (d) 0.70 mm of fireproof polyester and (e) waterproof mortar with a decorative brick strip. In between each layers (with exception of layer "e") the panel is sprayed with a 3-component polyurethane adhesive.

RC Panels is a member of the "Interreg – North Sea Region - INDU ZERO" Project as part of the European Regional Development Fund. For this project, RC Panels performed a Life cycle assessment (LCA) of their current product in August 2019.

The LCA was performed together with TU Ghent and Kamp C in Belgium, where they evaluated the contribution of the 1 m2 as functional unit (FU) of the RC panel to several environmental aspects based on a specific inventory of inputs and outputs in 60 years(Decorte et al., 2020). The report concludes that the glass fibre polyester, OSB and EPS have the highest environmental impacts in 1 m2 of the panel. Their contributions are 32%, 24% and 19 % respectively. Meaning that these 3 materials contribute 75% of the environmental impacts of 1 m2 from the production to use phase.

To define a Life expectation period of the RC Panel, the company performed a durability test with SKG-IKOB in March 2017. A prototype of 2.7 m height and 3.0 m long was built on a scale 1:1. The tests performed on the panel were: (1) Hygrothermal test, Freeze-thaw test, Wind and water resistance, and bond strength after freeze-thaw test. The report concludes that SKG IKOB could not give a judgment about the functioning of the system in 50 years period. However, after 20 years weather test, the panel showed no damage at all. Therefore, the company expects a lifespan of 50 years achievable.

Problem statement

The current RC Panel is not designed and studied with the end of its service life in mind. Right now, the resources, materials, and energy involved to produce the panel for the first time are lost at the end of life (EoL). The life cycle ignores and detaches the time component completely by not including scenarios where the materials are “processed and disposed” or “mined and reused”.

The durability of 50 years is mainly achieved due to the chemical bonding between the mineral brick cladding + polyester + polyurethane layers. However, what makes the panel so durable could be represented as a problem at its end of life, bringing a challenge to reincorporate the different resources into the nutrient’s cycles (technical and biological).

The present research aims to find a new design for RC Panels. The thesis focuses on finding circular or “cradle to cradle” alternatives designs in a sandwich panel framework. Thus, a new design that reduces the environmental impacts mitigates fossil fuel-related products and incorporates the circular economy as an essential design parameter.

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Research question

To what extent can a “cradle to cradle” design strategy contribute to optimizing the circularity and sustainability of RC Panels?

Sub-questions

• What do circularity and sustainability mean?

• Which are the promising product design models that incentive a circular economy?

• What are the boundary conditions of the current panel that should prevail in a new “cradle to cradle” design?

• Which state-of-the-art materials can contribute to the circularity and sustainability development of a panel?

• Which are the circularity and End-of-life scenarios that need to be considered in the analysis?

RC Panel
Picture by the actor in RC Panels factory

Research approach

This research aims to design a “cradle to cradle” retrofitting panel that incorporates circularity and sustainability as a basis of design. The selection of RC Panels with an exterior façade retrofit strategy as cased of study is further explored because of its advantages in bringing thermal comfort, solving thermal bridges, and the importance and impact of the existing building stock.

The aim is to explore different façade concepts that contrast with the traditional linear model of production of “take-make-use-dispose” and a system mostly dependent on fossil fuels, shifting from generating profits from selling efficiency use of materials to generating profits from the flow of materials and products over time. A circular design model that allows for affordable and viable ways to reuse goods and materials while using sustainable resources where possible.

The end result will be a series of options for a new panel design that could be offered to suppliers, manufacturers, developers, owners, housing associations, and tenants. This objective by retaining the same concept of a “sandwich panel” and the current boundary condition and properties the current product of RC Panels offers.

To support the design, a vast amount of information needs to be researched, such as:

• Investigation of the case of study together with RC Panel

• Definition of “circular Economy” including promising design and business models applications.

• Definition of multiple EoL scenarios.

• Definition of sustainability and how this concept will be quantified.

• In-depth research into state-of-the-art facade materials. A cradle-to-grave analysis of each of the components, applying resulting possibilities and restrictions.

• Review of the production and manufacturing methods and the environmental impacts involved.

This report will represent the design parameter for a technical designing: products specifications, documentation of materials and methods for deconstruction, and in-depth systems descriptions. More than one concept based on the restrictions will be developed. The original design will be compared in terms of accessibility for dismantling, inventory analysis (used of materials), and the full life cycle impact assessment.

Research methodology

Investigation of the current state of the art literature
- **Why?**

Definition of sustainability and circularity requirements

Investigation of the case of study
- **Who? & Where?**

Research by design (Concept, development, and technical drawings)
- **How?**

Assessment for circularity and sustainability
- Scope, goal, functional unit, inventory analysis, impacts assessment, and interpretations.

As shown in Figure 8, the exploration phase is a loop analysis of multiple stages. It all starts with the original RC Panel design influenced by a “new design criteria” incorporating circularity and sustainability. As concepts of design, three new designs are proposed. These concepts are explained further in the “concept design” part, and they were mainly develop based on the two reports given by TU Ghent 2019 and SKG-IKOB 2017.

A “Material choice” phase is proposed as a first filter for the materials to be compared. Different products are chosen for the face sheets, core, board, adhesives, and claddings for the new designs in this phase. A preliminary choice is given based on specific boundary conditions such as “Embodied CO2”, “sequestrated CO2” (if applicable), recyclability, reaction to fire (if tested), density, thermal conductivity, and different mechanical properties such as Young modulus, Shear modulus, and strengths (tensile, compressive and shear).

With the preliminary choice of materials, the designs enter a “Design development” phase where the mechanical and physics part is reviewed. This is done to ensure that the panel is strong enough and does not represent a hazard for thermal and moisture control. After this stage, the panel options enter a Life Cycle assessment, where they are compared with the same functional unit of 1 m2 to the original RC Panel. Ideally, in the end, at least one option can perform better than the RC Panel. This is labelled as “optimal design(s)”

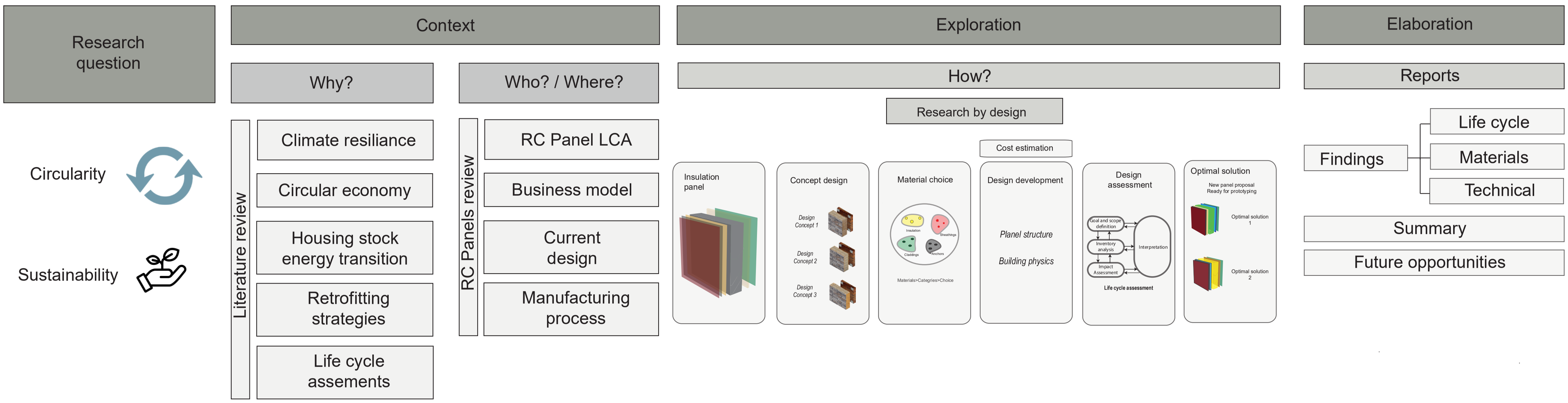


Figure 7 Research Methodology

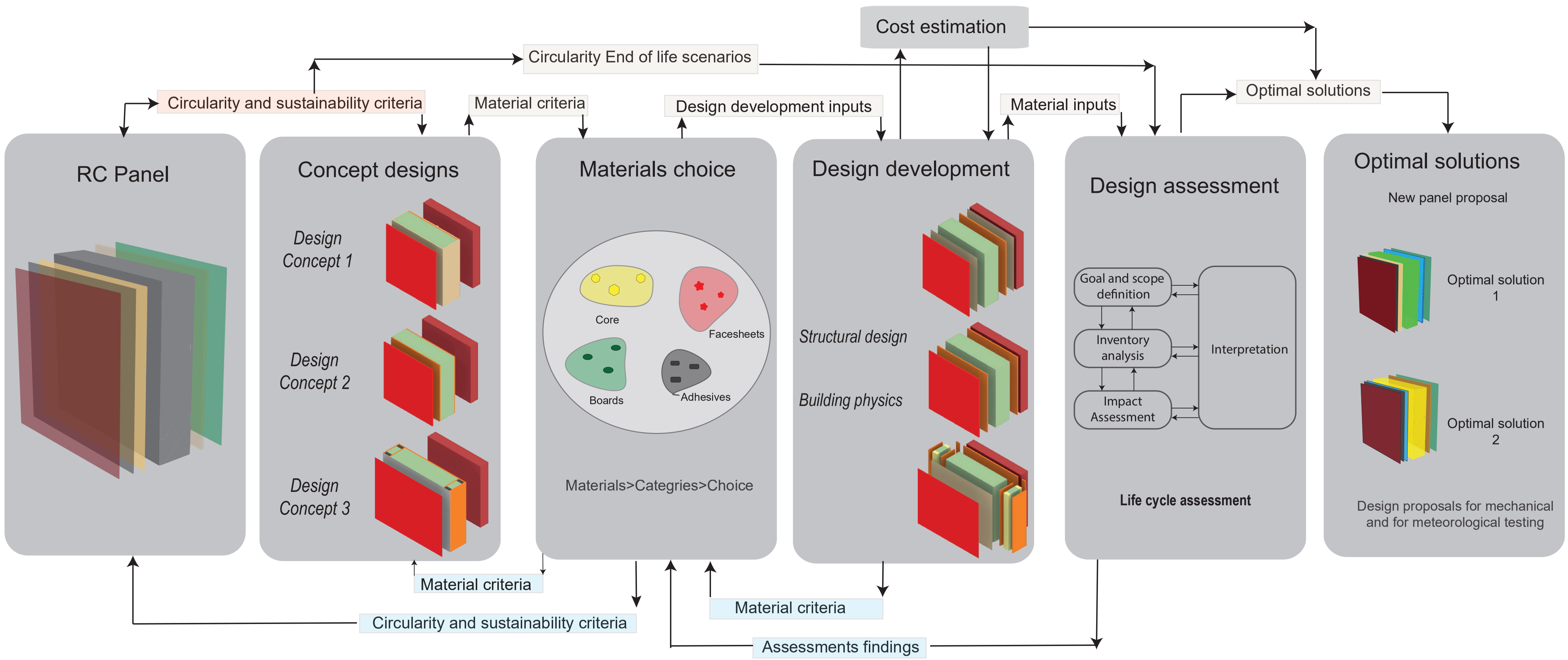


Figure 8 Research methodology - Exploration phase

LITERATURE REVIEW

The Netherlands housing stock

In the Netherlands, the climate agreement is part of the Dutch climate policy. In the built environment, The Netherlands vision for 2050 includes the adaptation of 7 million homes. In the short term, th Government's primary goal is to reduce CO2 emissions by 49% in 2030 compared with 1990. Nearly 1.5 million existing dwellings need to be retroffiting, almost 140,000 per year in 2019-2030.

The Central Bureau of Statistics (CBS) in the Netherlands reported on the 2nd of April 2021 that the country has 7,891,796 existing homes. Out of which 49% is in West Netherlands (North-Holland, South Holland, Utrecht and Zeeland), 21% in South Netherlands (North Brabant and Limburg), 20% in East Netherlands (Gelderland, Overijssel, and Flevoland) and 10% in Northern Netherlands (Drenthe, Friesland and Groningen), please refer to Figure 10 and Figure 11.

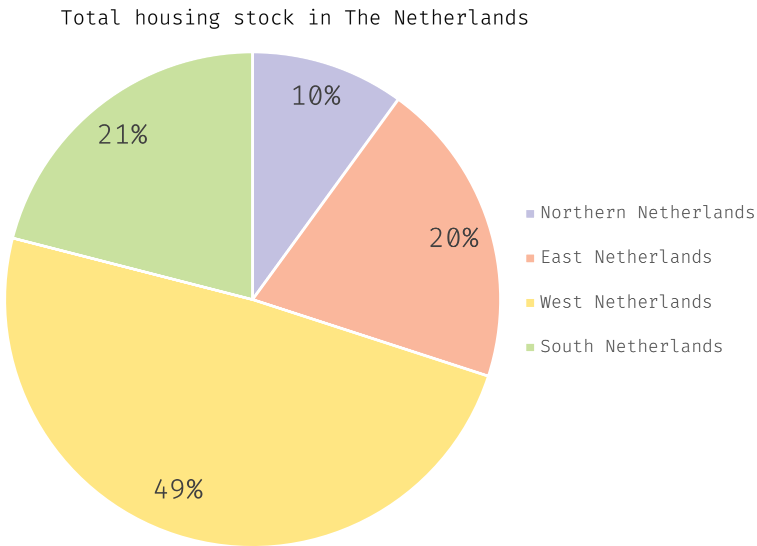
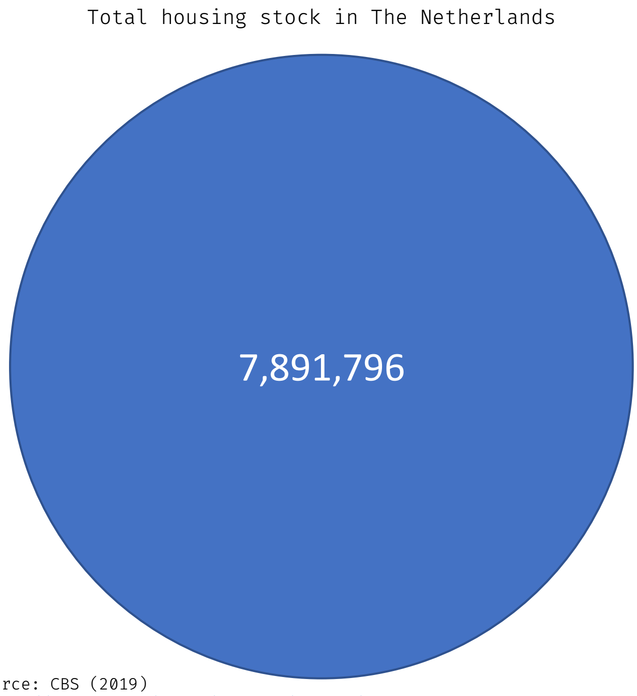


Figure 10 Percentage of total homes per area



Source: CBS (2019)
https://www.cbs.nl/nl-nl/cijfers/detail/82550NED?q=nederland

Figure 9 Total existing homes in The Netherlands

Figure 11 Map of the Netherlands

The year of construction of these dwellings is essential since this can help deduce the homes' energy label . In addition, by reviewing the construction code, one could determine the regulations using specific materials and insulation values for facades.

The CBS also reports that 10% of the existing stock was built before 1925, 23% was built between 1925 and 1965, 31% was built between 1965 and 1985 and the remaining 36% was built between 1985 and 2021. These numbers mean that 2.76 million homes have been used for more than 50 years and 5.2 million happen to be already used between 35 – 50+ years (Figure 12).

By looking at the energy label of the dwellings, it can be seen in Figure 13 that the lowest energy label represent the homes built before 1980, which are a number between 2.76 and 5.2 million homes. Hence, this group is in significant need of retrofitting strategies before now and 2050.

The CBS categorizes homes into four types (please refer to Figure 14). The type of dwellings are (1) detached homes with 23%, (2) Semi-detached homes with 19.6%, (3) terrace homes/corner houses with 42.5% and (4) apartments with a 15%. The core business of RC Panels right now is terrace homes. That's how and why the company started. For this reason, the research is based in these types of homes which also happen to be the largest group in the country.

The Dutch climate agreement said that in the Netherlands, the total number of dwellings that need to be renovated already exceeds the need for new constructions (Ministry of Economic Affairs and Climate Policy, 2019). A renovation strategy includes different building components. (Konstantinou, 2014). The key components for fully integrated renovations aiming to improve energy performance are the elements where heat losses/gains increase/reduce the energy demand. These are the non-transparent areas (external walls), transparent areas (windows and openings), balconies, roof, and surfaces in contact with the ground. All the before mentioned components comprehending the exterior building enclosure.

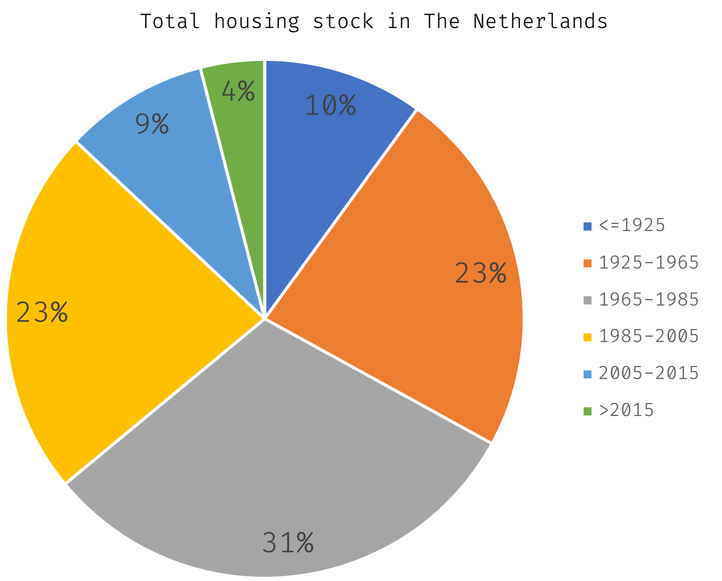
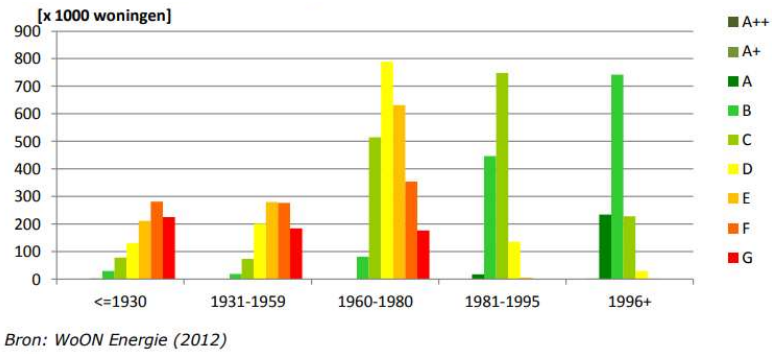


Figure 12 Construction year of existing homes



Source: Energy - Central Government
rijksoverheid.nl ›documents› reports ›2013/04/11

Figure 13 Energy labels for building built before 1966.

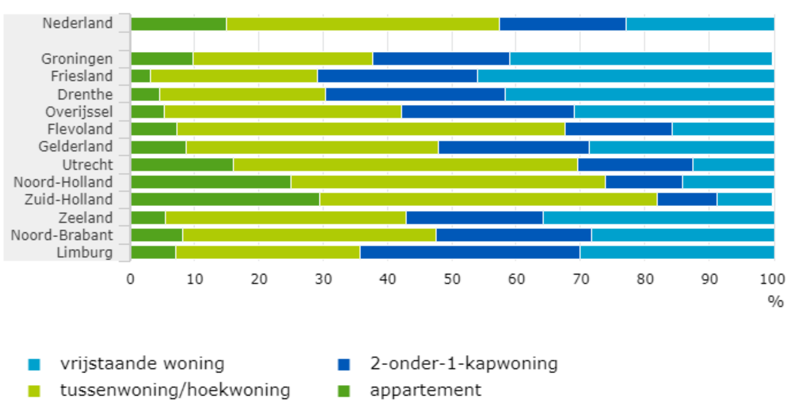


Figure 14 Numer of homes (%) per type in the Netherlands

Renovation strategy choice

The present thesis will focus on the “rap-it” scenario. In this case, as its name says, the method suggests to ‘wrap’ the building. A second layer is installed in front of the existing façade bringing a new thermal line on the exterior. Depending on the amount, quality, and reliability of the existing building information, some restrictions may emerge, and the designer will need to prove the building’s structural stability. The concept includes different components from non-transparent and insulated areas, new windows, doors, and new cladding. It should also address all the elements and forces of an envelope design such as structural integrity, weather tightness, thermal comfort, movements, light transmission, acoustics, and security (Boswell, 2013).

The thermal bridging solution is one of the main advantages of this type of intervention. Many existing dwellings have high thermal losses due to the main structural element’s connection to the outer insulated leaf. Also, it creates less nuisance to the tenants since there is no need to relocate them. Furthermore, the waste and disposal of materials are reduced since the existing building façade is kept on the building. Finally, the rentable interior space is kept the same, the solution does not require to use the interior area to bring a new thermal line.

A wrap-it intervention brings the opportunity to create better-living spaces for the tenants without relocating them to a temporal location. In the Netherlands, 7 million homes are in need to be retrofitted. If all them needed to relocate their users to be refurbished, housing associations could lack space to put people on hold while their home upgraded. In the article “Designing a smart factory for mass retrofit business”, Lange and Kraemer determined and compared generic or starting points for retrofitting a building envelope: frame structured systems and structured/ structural panel systems.

The structured frame approach uses horizontal and vertical elements to provide the primary support of the panel. Typically, they are made from timber, light metals or galvanized steel structures. Together with rigid sheathing, the systems gain strength and get their primary structural support. In between the frame gaps, soft insulation is typically placed, in cases where high insulation values are required, additional rigid insulation is allocated on one side. Later, on top of these, an outer finish cladding is installed (Lange and Kraemer, 2019).

The structured/structural panels are sandwich structured composites which typically consist of a solid rigid insulation core glued on a sheeting layer, then fixed between two rigid membranes. The sheathing and the rigid membranes provide the primary structural support for the panel. The sheathing serves as an attachment to provide fastening. On top of these layers, a finish is installed. Due to the common use of materials and the correct manufacturing techniques, this solution is known as light but with high strength (Lange and Kraemer, 2019).

Oil sands operation in Alberta, Canada (Mining.com, retrivered on july 2021)

"The case for … never demolishing another building" (The guardian, January 2020

Sustainability Research

Nowadays the building processes are leaving behind a linear model (take-make-dispose) and turning into a circular model. The traditional building process can be defined in six distinctive phases, all will include some transportation, labour, equipment, and energy. Also, waste in form of solids, liquids or gasses are emitted to the environment.

Phase I: Raw Materials extraction.

Any new product will require raw materials for its production, and it is known that fossil fuels are generally used for these processes since heavy equipment is involved. One example is timber to produce wood products or carbon and iron to produce steel. This phase is also referred to as the "cradle phase".

Phase II: Manufacturing of (half)products from raw materials.

Raw materials are usually transported from the resources at a specific factory where different techniques and processes are applied to create the "final product". Examples of wood fibre to create insulation or the mix of carbon and iron to create a steel plate

Phase III: Construction and assembly of a product.

Once products are manufactured, they are generally sold to companies like RC Panels. Materials are taken to a different location (as previously), such as factories or construction sites. Products are put together involving manufacturing techniques, the use of equipment, energy, and transportation. This phase is also referred to as "gate phase", from the extraction of raw materials to the construction site is commonly referred as a "cradle to gate" analysis.

Phase IV: Use phase of a product.

In this phase different technical cycles like maintenance and repair actions take place during the service life. Hence, in this phase there is a new requirement of raw materials, energy, transportation, etc.

Phase V: End of life.

When the product its no longer needed or its performance does not comply anymore with the specification, the product is directly disposed. This phase involves deconstruction processes, transportation, waste processing and disposals.

Phase VI: Landfill.

In the traditional construction process, waste materials are taken to landfills, where materials are stored and piled for the rest of their lives. This phase is also referred to as "grave phase" from the extraction of raw materials to landfilling, is commonly referred as a "cradle to grave" analysis.

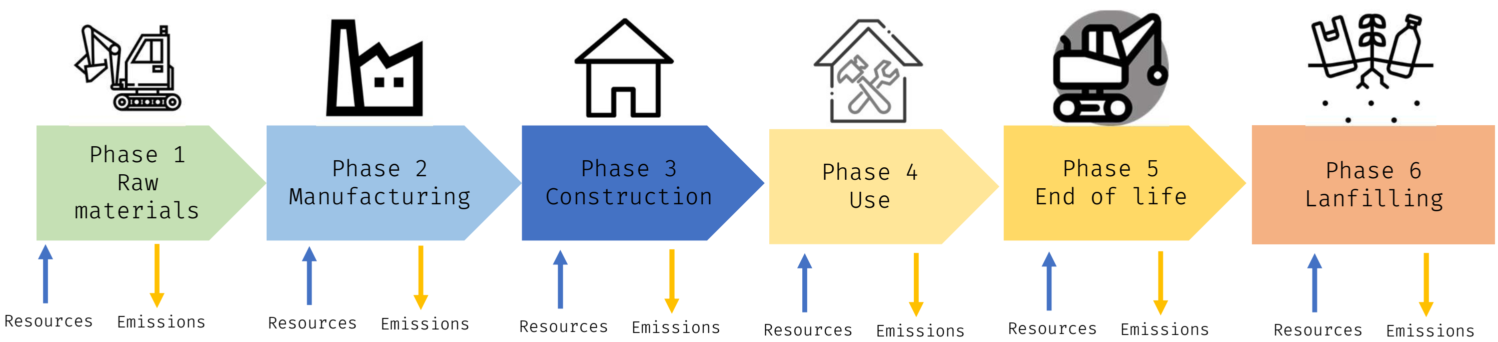


Figure 16 Traditional building cycle

In 1972 the United Nations conference in Stockholm, Sweden, stated that our planet would face massive and irreversible harm if humans do not take the environmental cares of our actions. People realized that resources were finite, and they will become limited at some point.

With the passage of time and several actions such as chemical accidents, environmental pollution, and the decrease of ecosystems; researchers realized that the “healing and cleaning” capacity also reoffered as (carrying capacity) of nature and ecosystems is limited. When humans exceed this “capacity”, natural free and cleaning services are no longer provided by the environment, and they need to be compensated with new technological solutions. To remove pollution and harmful components from different natural resources, technologies need to be researched, developed, and implemented. However, these technologies are often not available, complicated, and costly.

Nowadays, this process is slowly changing towards a more resource-efficient and low-environmental emission model. Technical cycles like recycling and reusing valuable elements lead to a change in the building industry mindset and slowly transforming the traditional linear building process into a resilient, cyclic, and circular process.

Due to the economic need to develop technologies to solve the capacity of the environment to heal the pollution caused by human actions, policy makers introduced specific taxes for the release of harmful compounds and for landfilling waste. This brought efficiency in the building process and in line with a ‘circular economy’, a cyclic building process is targeted and is a main point of interest in modern policies. The Dutch climate agreement issued in 2019 mentions that only by combining sustainability actions with circular economy stability will come to the environmental challenges forecasting the country.

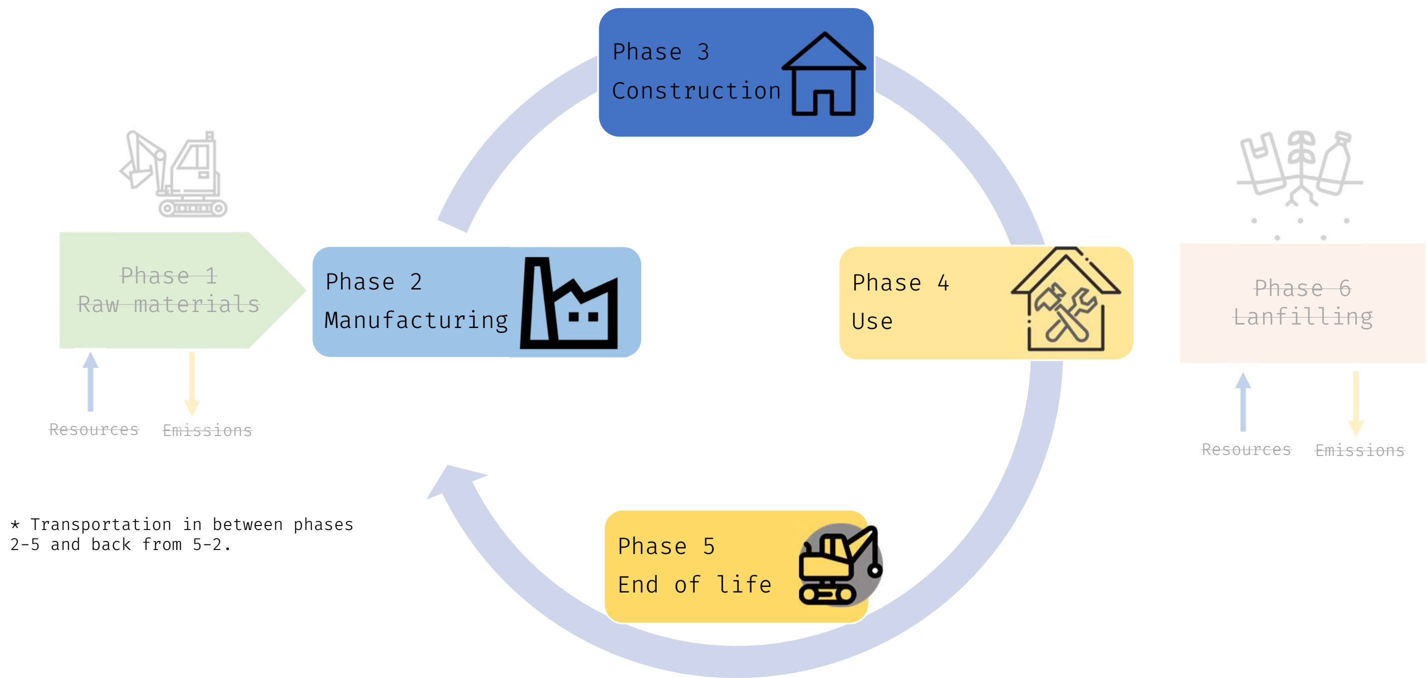


Figure 17 Circular building cycle

Definition of sustainability

Typically, a sustainable product or company looking for sustainable practices is often characterized by a low global warming emission policy (CO2). However, a sustainable practice goes beyond marketing or branding of low CO2 impacts. Companies ignore other environmental categories that can lead to a non-sustainable practice.

There are different definitions of sustainable development, Brundtland in 1987 defined it as a "development that meets the needs of the present generation without compromising the ability of future generations to meet their needs". Referring to 'needs' as the availability of natural resources is taken by human actions and becomes depleted and 'needs' as healthy living conditions. The idea of not compromising by putting a burden in future generations and emitting harmful components into the environment is difficult and/or costly to remove and clean. Also, social balance and economic growth are part of the same definitions.

A year later, in 1988 John Elkingtong explained value can be created by producing and promoting environmental products. He incorporate social, environmental awareness and has 3 main focus points for sustainable development, also known as the "3 P´s": People, Planet and Profit, which can be translated as social fairness (people). Environmental awareness (planet) and economic growth (profit).

The terms Planet and Profit are, to some extent, more relevant for the present research. Perhaps the former can be explained easier; however, "Profit" needs some explanation. Profit refers to "economic growth" for companies to create a social and environmental process when making decisions. This means that producing and marketing both useful and environmental products. Normally, there are different costs involved in the "price" of a product, for example like materials, manufacturing, transportation, etc. In this sense, to pay the burden of extracting materials and to develop technologies to clean the ecosystems the so-called 'external costs' exist, these are costs that companies most 'internalized', meaning that the price must include the "environmental cost", in other words **"the polluter pays".**

Calculating this 'external' costs of a product is not an easy task. Engineers need to become a sort of "detective" or "inspector" to review every single step and process. Also, the investigations might not end only in the product but also in the human effects caused by such pollutions. Diseases might lead to certain health conditions that can affect and entire population. Toxicity and emissions are not crystal clear mainly during long term exposure conditions. Always, preventing the emissions is the best solution however the economy and the needs of the people still need to be satisfied.

There are specific methodologies that address different aspects, these technologies are in constant development and update. One of the most used and common tools is a Life Cycle Assessment (LCA). LCA assess environmental and some of them health problems of a given product in its different life phases. The environmental impacts target depletion resources, emissions, and pollution of natural ecosystems. Some have as a result, a grading of point for resources, environment and health, others convert the emissions and impacts of resource depletion and harmful component to a monetary value, which is commonly referred as Environmental cost Index (ECI). ECI is the "external cost". Companies foreseeing sustainable development calculate all their indirect and direct cost of the production and a specific solution for building the built environment and the end the ECI is added on top.

Circularity Research

The current industrial economy relies mainly upon a linear consumption of the planet's resources, creating the "well-known" 'take-make-dispose' human behavior. Many corporations take r**aw materials, input energy,** and workforce to create a product, and **sell it** to an end customer. After the product is used, it is **discarded** when its requirements are no longer needed or fulfill. Regardless of the efforts made to improve recourses and materials, any model that relies only on consumption detaching the time component at the end of life, disregarding a continuing usage of the resources, avoids the benefits of a residual value the flow of resources.

Efficiency in the use of materials is always desirable, but to address the impacts and use of the resources minimizing materials used must be joined by taking care and improving the way we handle the end-of-life of products (Macarthur, 2020). To ensure that sustained growth produces greater prosperity, it is critical to move from consumption and waste to use and reuse to the highest extent (Macarthur, 2020).

According to the Ellen Mcarthur foundation, a circular economy refers to self restored model, relies on renewables, deletes toxic components, and takes out waste through mindfull design (Macarthur, 2020). A "restorative by intention" means to redefine goods beyond the required "needs" of a product/service. This concept includes the correct management of materials flows, which are defined in two types of nutrients: (1) biological nutrients (resources to re-enter the natural biosphere and rebuild natural resources) and (2) technical nutrients (maximize the life cycles without re-entering the natural biosphere). Please refer to Figure 18 below

Bocken and others proposed the definitions of slowing, closing, and narrowing resource loops. This was to mark the difference between linear and circular models clearly, and it is done by the systems in which the materials flow through their life cycle. A difference between "cradle-to-grave" and "cradle-to-cradle" cycles needs to be made. The main difference can rely upon the fact that the latter refers to "closed-loop systems" in the use of resources, distinguishing two necessary different types of loops: (1) reuse of resources and (2) recycling of resources (Bocken et al., 2016).

Reuse means extending the utilization time of a product through the design, and it includes the addition of "service" cycles to enlarge the time the materials are used. Some examples of these cycles are the complete reuse, maintained, repair and upgrade. This is the first concept Bocken describes as "Slowing resources loops" because it delays the flow from production to recycling and fully incorporates a relation between the product and time. Recycling means closing the cycle between post-use waste and the production of new materials. This is the second concept describe as "closing resources loops". The cycle closes between the post-use and production, bringing a circular flow of materials.

A third concept is conceptualized as "narrowing resources loops", which can be considered as a reduced use of materials, using as fewer materials as possible to create a product. Different authors consider that a desperate resource efficiency to get to the same result is not aimed to improve the life cycle of a product but a strategy to reduce the flow of resources used as an eco-efficient cradle-to-grave strategy. It does not relate to the speed and flow of products and does not involve any service cycle. This strategy is well known in the current economy, and many companies apply the concept of "fewer resources as possible". As this strategy detaches the time component for the cycle of goods by just selling a "resource efficient product", it is proposed to use this approach only if combined with reuse or recycling strategies.

"

The greenest product is the one that already exists because it doesn't draw on new natural resources to produce (Bocken et al., 2016)

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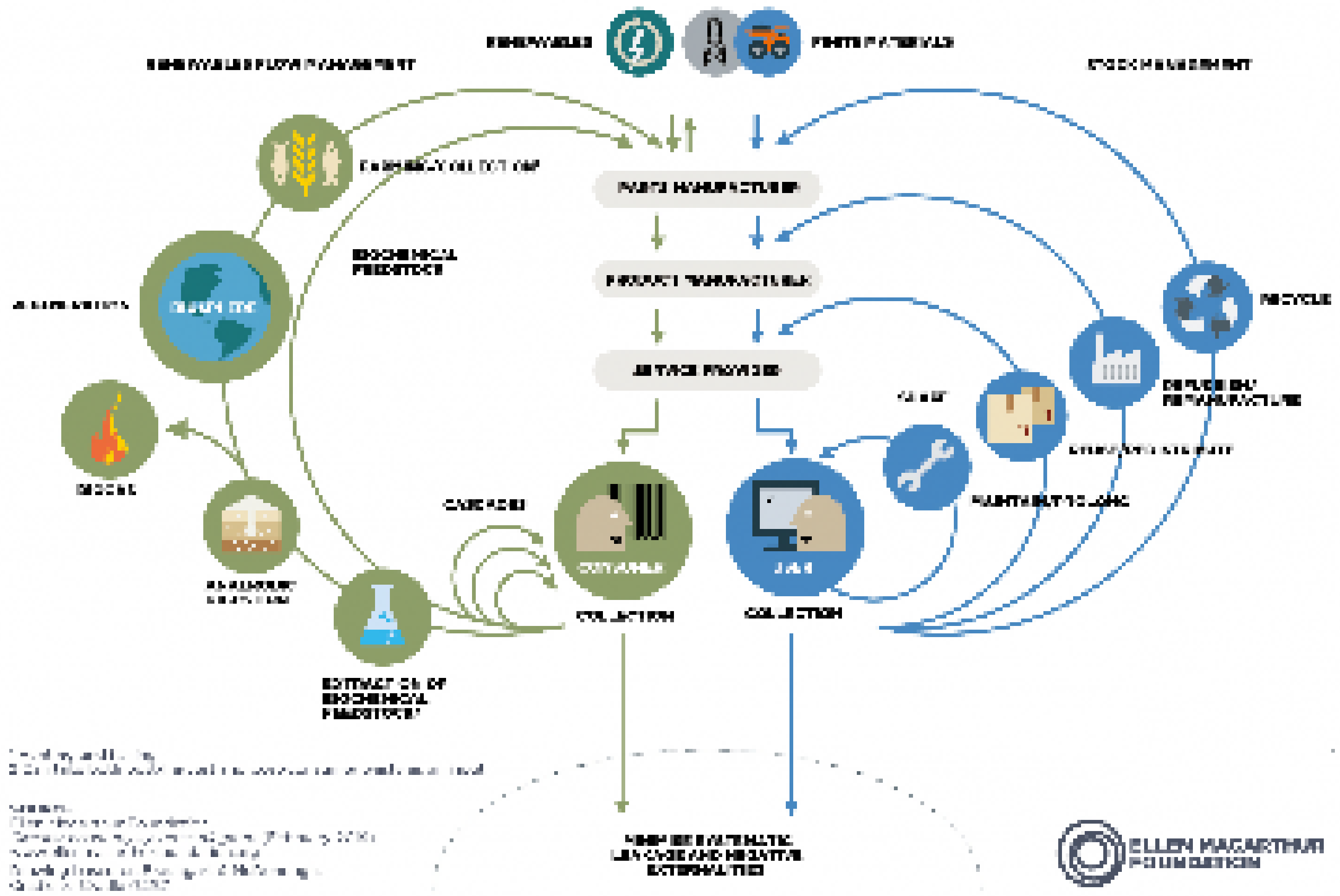

Figure 18 Technical and Biological nutrients flow (Macarthur, 2020)

Circularity – Design strategies

The proper integration of circularity in a product must be at the early stage of design. Once specifications, economic resources, infrastructures, and day-to-day activities are set, it is difficult to make changes. RC Panels is looking at the future, and even though the current panel is already manufactured, new opportunities are always explored, and new ways of working have the doors open.

Product design strategies relevant to slowing and closing loops are described in the following section by summarizing the design strategies used in these two circularity approaches.

Slowing resources loops

There are different design strategies when talking about slowing the resources loop. In the present research, two will be discussed and analyzed: "creating long-life products" and "extending the product's life". Slowing resources loops in the first instance support the design with an attachment to the end-use with reliability and durability. Also, facilities and controls with the design: maintenance and repair; upgrading and upgradability; standardization and compatibility; and dis- and reassembly.

Creating long-life products ensures an extended use of the products; the design strategies are categorized in "Designing for attachment and trust" (products are liked and trusted) and in "design for emotional durability" (long-lasting empathic partnerships between the user and product). Durability, to the extent of the word, as something that will not be broken easily and can be teardown without

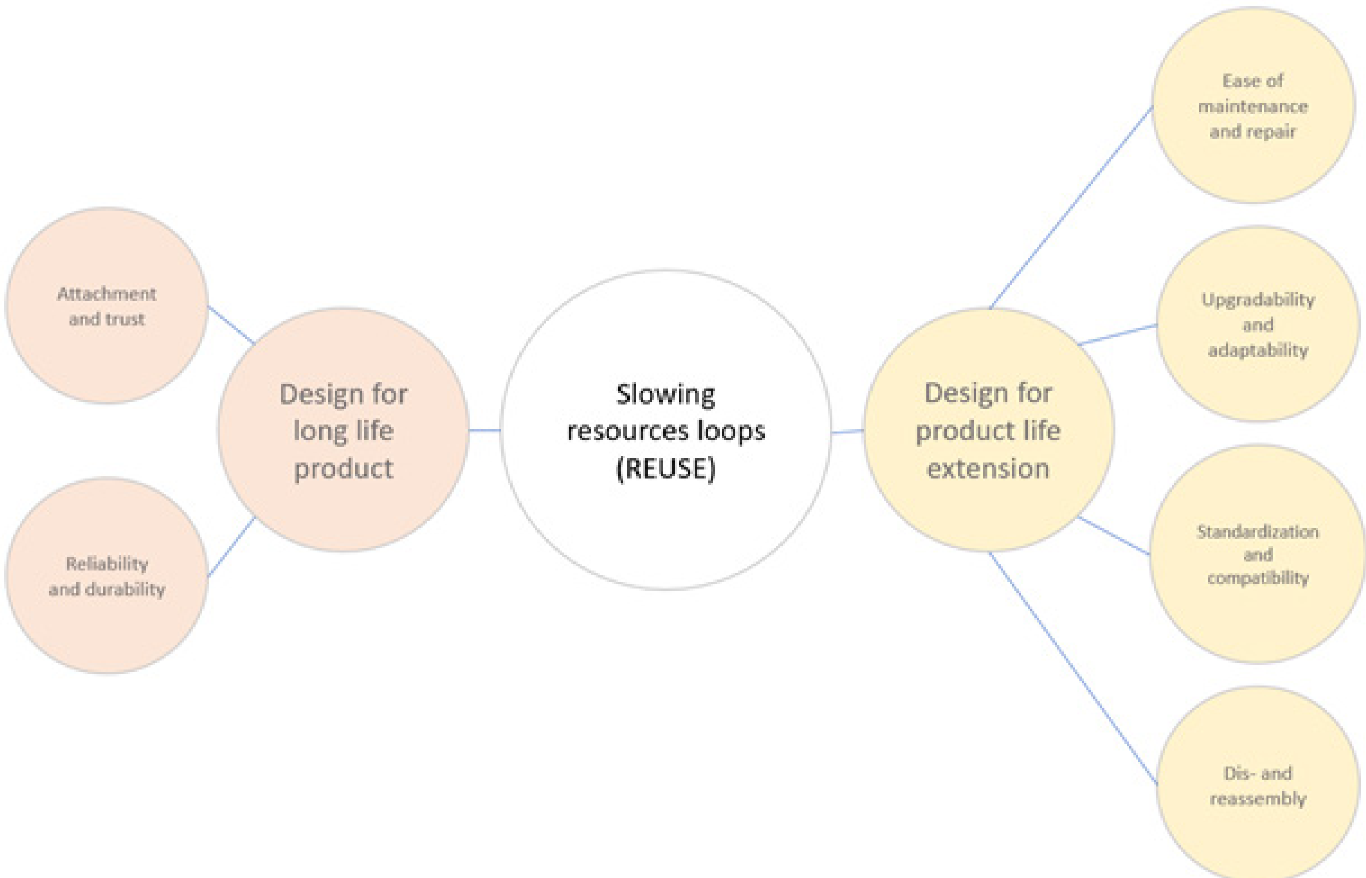

Figure 19 Slowing Resouces loops strategy (Bocken et al., 2016)

any damage. Reliability to the extent of creating something with the correct "maintenance" will prevail with time.

Creating products with a "product-life extension" design approach deals with extending the use phase of a products through technical loops to increase the product life such as maintenance, repair, technical upgrade. The design strategies in this approach are "Design for Maintenance and Repair" (products always will come back to "as new" condition retaining all the functionalities of a product). The next strategy considers a future modification to the product: "design for upgradability and adaptability" (product to be used under changing conditions). Another strategy is "Design for standardization and compatibility" (create 2 or more products that compensate each other). Finally, "Design for dis- and reassembly" is a strategy that induce an ease of disassembling of a product and its internal and external elements. This final strategy is known for its availability for separating materials and allowing them to enter in different nutrients cycles. Below in Figure 19, a summary of the design strategies for slowing loops is shown.

Closing resources loops

For this design strategy is essential to establish a detailed conceptualization of the meaning of "recycling". Hopewell and others classified recycling into four types: (a) primary recycling (closed-loop recycling): here products with comparable properties are created, (b) secondary recycling (downcycling): here products are converted in materials with lower properties than the original, (c) tertiary recycling (chemical or feedstock recycling): here there is a recovery of the chemical constituents of the materials, and (c) quaternary recycling (thermal recycling): here the materials are used to generate energy via incineration, some authors consider this last type as "not recycling" since it does not completely recover the energy of the materials.
Bocken illustrates two strategies for this type of product design: recycle or "dissipative" losses in the "biological cycle" or the "technological cycle." The products that referred to both cycles dissipations are referred to as "hybrids" (Bocken et al., 2016).

"Design for a technological cycle" is suitable for products that provide services and are not only consumed. Within this strategy, materials ("technical nutrients") are correctly recycled into new products. A critical remark is that the "waste" is to be recycled to produce equivalent use and properties to the original product to which the raw materials were used. Here primary and tertiary recycling is desirable since only these forms can regenerate materials with the same properties. "Design for a biological cycle" is widely used in products for consumption (dissipative loss thought the use) This concept incentivize the use of materials that properly reincorporate into the natural systems (biodegraded to restart a cycle).

The strategy "Design for Disassembly and reassembly" is also part of the closing resources loops. Here it can be used for both technical and biological cycles. The idea is to make sure that products and parts can be separated, reassembled, and/or disposed of correctly. Similarly, to the "Slowing resources loops" strategy, this approach is known for its availability for separating materials and allowing the component to enter in different nutrients cycles. Below in Figure 20, a summary of the design strategies for closing loops is shown.

As for both slowing and closing the resources loop, the design strategy for dis-and reassembly is available and, in light of ensuring the correct recovery of components during usage or at the end-of-life of buildings, the present research will continue to adopt such design solutions and compare them with a "reduce resources loop" relying in biobased materials..
There is a limitation in the literature on the end life of sandwich panels in general. Defining scenarios and phases from the planning on how to disassemble to further treatment (reuse or recycle) of materials. The proposed designs will consider the following criteria and the design for disassembly strategy: (1) When is the EoL decision? (2) Dimontability from the existing building. (3) Transportation, (4) Sorting, (5) Cleaning (6) Reuse or recycle (7) Landfill or incineration.

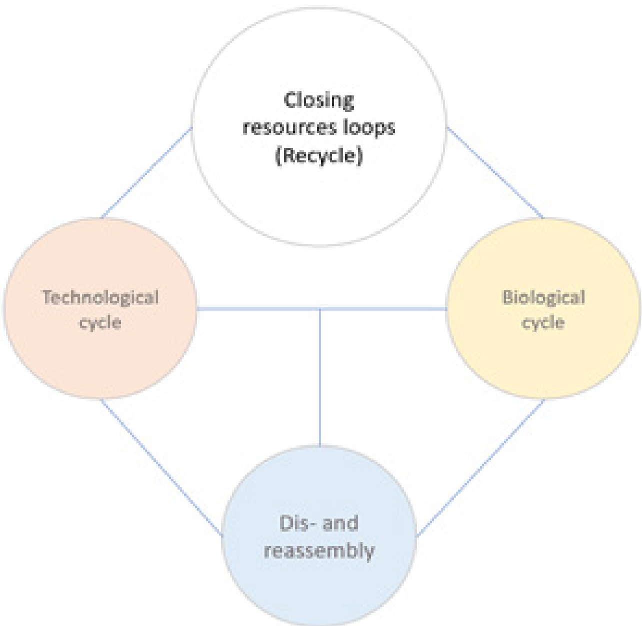

Figure 20 Closing resources loops

Design for dis- and reassembly

Design for dis- and reassembly facilitates maintenance, repair, a future change and the eventual dismantlement (partially or entirely) to recover systems, components and materials. This design strategy comprehends the development of products with materials, construction techniques, and management systems. The main idea is centralized in the recovery of resources, intending to maximize the economic value and minimize environmental through reuse (slowing resources loops) and recycling (closing resources loops). The solution includes a vast range of materials from reusable materials, resources intended as recycling feedstock, and biodegradable natural components.

The design strategy can have multiple purposes, including material recovery, components reuse, material recycling and remanufacture (Akinade et al., 2017). The design process is similar to many other design strategies. It should include a concept design (CD) as an initial abstract formal design, Schematic Design (SD) dimensions selection of structural systems, Design Development (DD) refinement of dimensions, materials, costs-analysis, value-engineering. Finally, Construction Documents (CD) final drawings with specifications and ensure code compliance.

Olugbenga O. and others categorized three broad categories for this strategy be applied successfully: (1) material related factors, (2) design-related factors, and (3) site workers related factors.

As in Figure 21, there are different principles in the design strategy, however for the present research and case of study, the following are propose to be adopted:

(1) Design of accessible connection to ease dismantling, (2) Minimize chemical connections, (3) Incentivize the use of bolted connections, (4) Simplicity of structure, (5) Documentation of materials and methods of deconstruction, (6) Design for worker and labor separation, (7) Modularity and standardization and (8) Safe deconstruction.

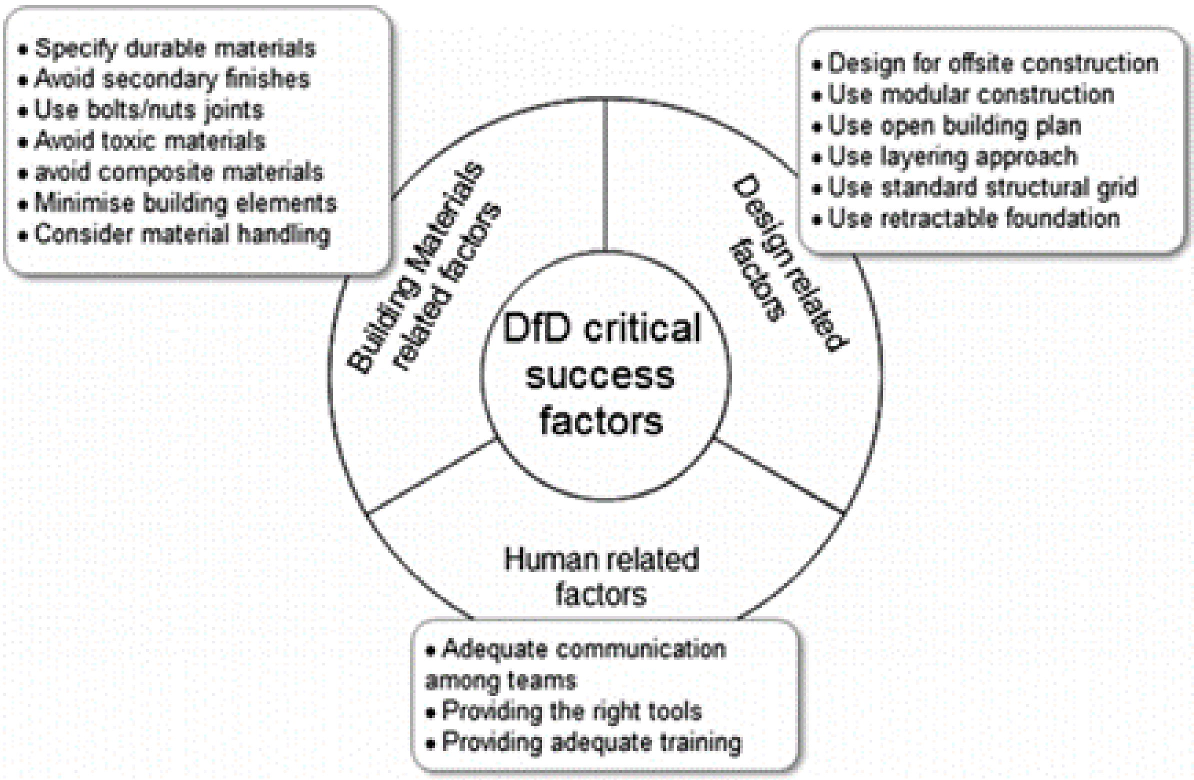

Figure 21 Design for re- and disassembly
(Akinade et al., 2017)

RC PANELS

RC Panels

Description

RC Panels is a Dutch company located in Lemelerveld in the province of Overijssel in the Netherlands. The main concept is the manufacturing of ready-made facade elements. The developed design comprehends a structured sandwich panel applying the wrap-it approach for existing building stock. The process incorporates different manufacturing techniques together with concepts like automation and prefabrication. The company is driven goals are efficiency in material use, scalability, buildings service life extension, living comfort improvement, façade minimal maintenance, lightness, affordable cost, and optimal insulation values.

The base panel (Figure 22) has the following structure from the inside to the outside: (a) 0.70 mm of polyester, (b) 15 mm OSB 3, (c) 200 mm of fireproof EPS100, (d) 0.70 mm of fireproof polyester and (e) façade decorative finish. The panel is provided with (f) polyurea all around the edges and in the recesses to make it completely weathertight.

Panel Manufacturing

The manufacturing process of the panels includes several steps. Each dwelling will have different dimensions and different deformation throughout its lifetime. For this reason, the first step before manufacturing is a Point Cloud Scan to obtain the exact dimensions of the existing building situation. Then, each façade orientation is reviewed in a BIM environment, and each panel is designed individually. There are certain limitations in terms of size; typically, the factory can provide a maximum width of 12.50 m, a maximum height of 3.17 m, and a total thickness (without finish) of 237 mm.

After the BIM design is completed, the details are provided to the factory, and the process starts. First, the two polyesters, the OSB 3, and the EPS100 layers are cut precisely to the panel dimensions, correlating to the point cloud scan. The process starts with a completely horizontal workstation in a line production series, meaning that the panels are always horizontally wise.

The first interior layer of polyester is manually set on the working space, and

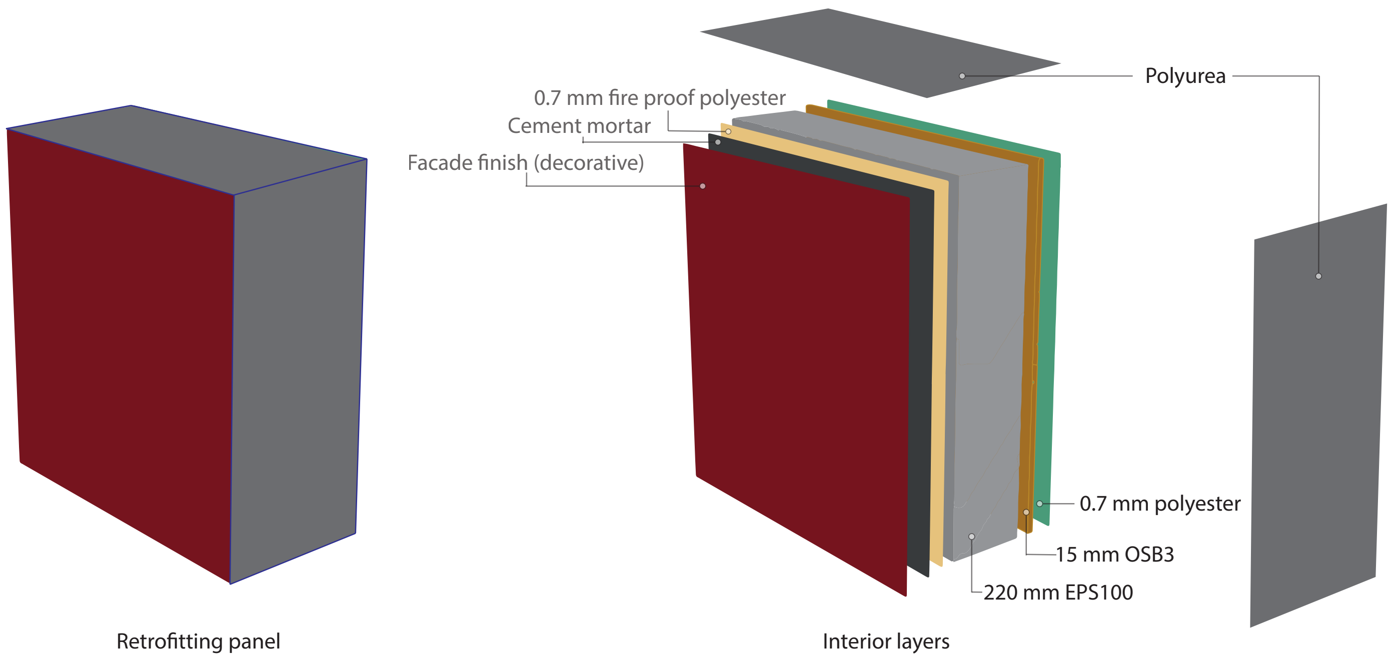

Figure 22 RC Panel

then an automatic nozzle sprays a three-component liquid polystyrene layer. The 15 mm OSB 3 board is set on top, aligned to the polyester's edges, and another layer of polystyrene is sprayed. The EPS100 insulation panel is set on top followed by a final layer of the three-component polystyrene layer. Finally, the fireproof polyester layer is set on top.

The goal of the polystyrene is to glue all the layers together. For this matter, once all the layers are aligned, and on top of each other, the panel is wrapped with an EPMD sheet and vacuumed at 3000 kg/m2. This process ensures the complete adherence of each layer and creates the basic solid-shaped sandwich panel.

Figure 27 shows the main panel manufacturing process; each layer is stacked together and glued together. The result is a ready-made façade element that successfully uses the wrap-it approach to the existing building stock of the Netherlands.

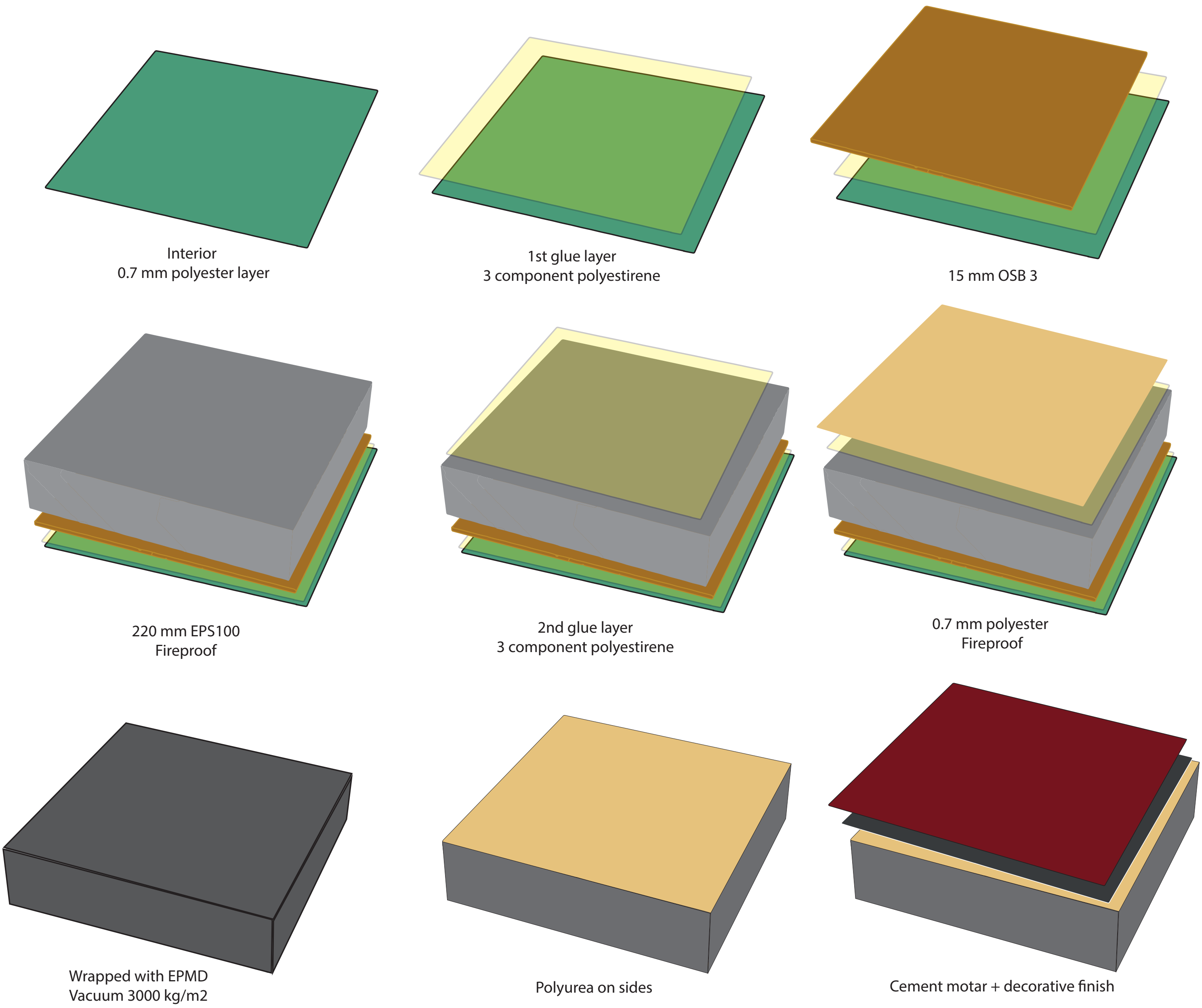

Figure 27 Manufacturing process

Figure 23 RC Panels Factory - Panel manufacturing (picture by the author)

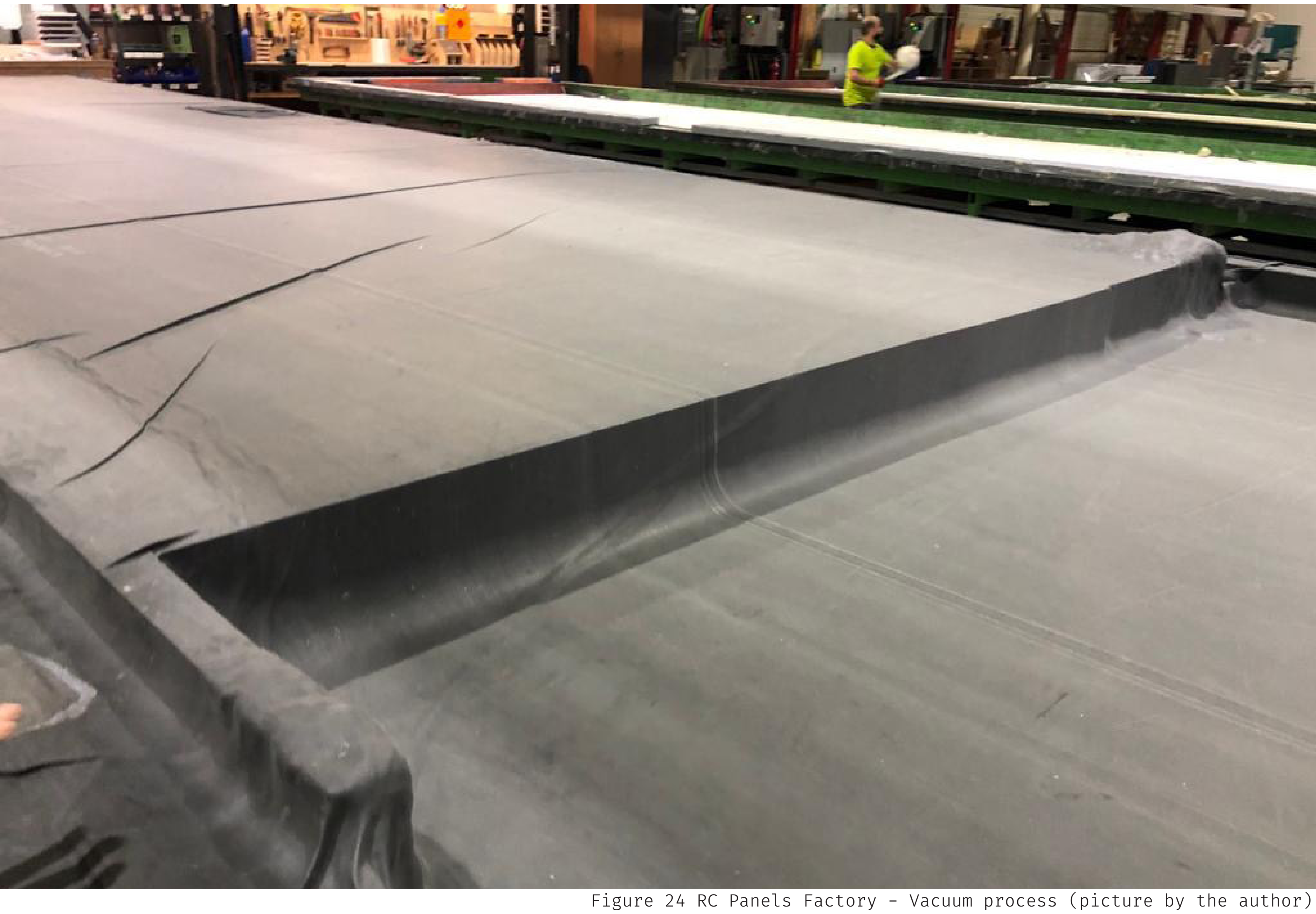

Figure 24 RC Panels Factory - Vacuum process (picture by the author)

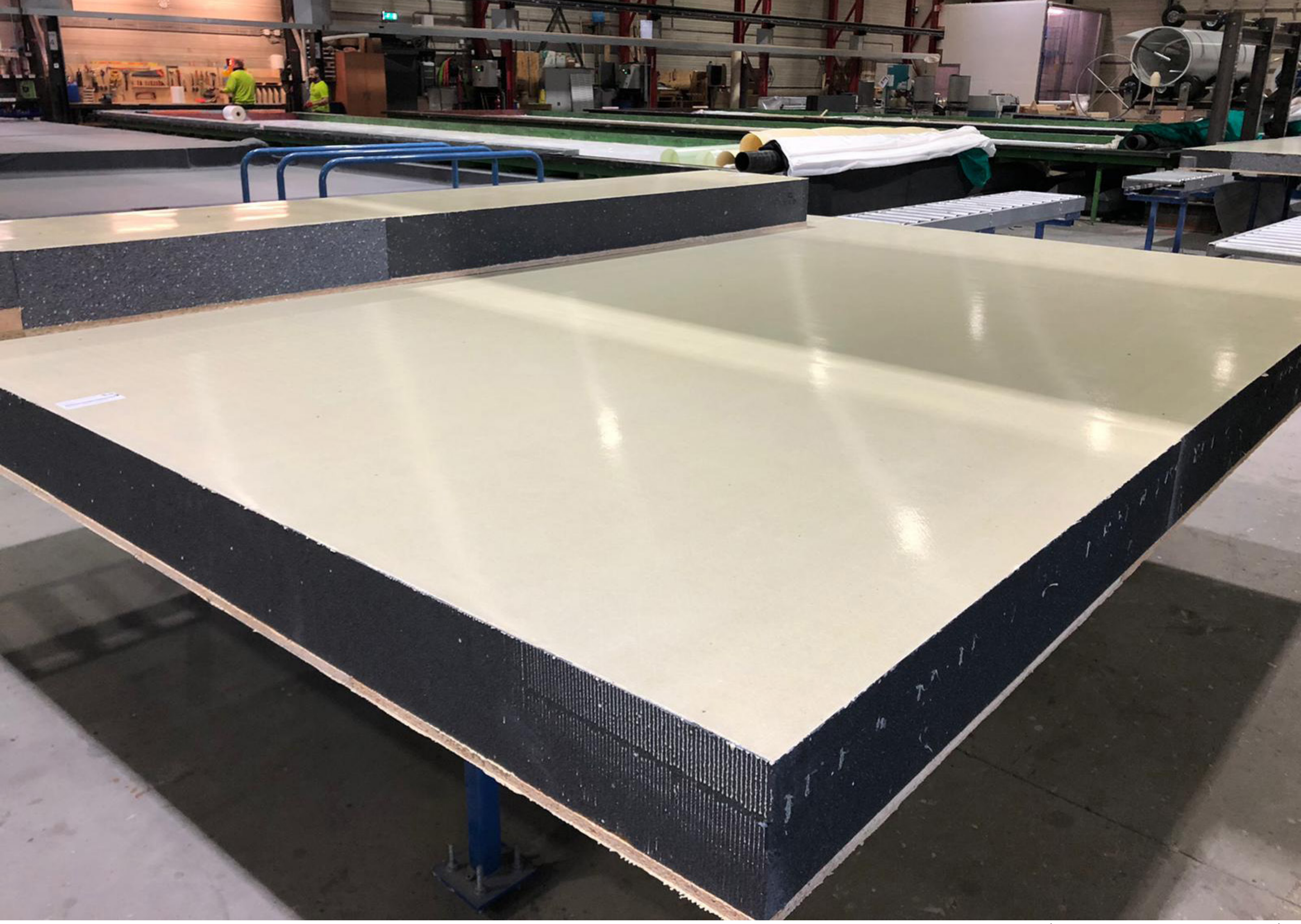

Figure 25 RC Panel without decorative finish (picture by the author)

When the basic panel finished, the panel enters in a CNC machine where the windows and doors openings are cut, leaving a concealed hole between the OSB and the EPS to allow the installation of the windows and door frames. The panel is then sprayed with a polyurea on the sides and openings recesses, making the panel completely watertight. Figure 25 shows the panel after the polyurea spray on the sides.

Once the façade is waterproofed from the sides, it enter into an automated equipment that sprays either a stucco sinish or a mortar to place the mineral brick slips. This equipment is connected to the BIM system that feeds the arm placing the bircks with the location desired by the façade designer. Figure 28 ilustrates this process.

At the end of the factory there is a big gallery where the facades are stored waiting for the transportation to be taken to their final destination. RC Panel per se, does not installed the façade, the company just supplies the product with a manual giving the information on how to “transport it”, “protect it”, “host it”, and “install it”. Figure 26 provides a picture of a façade finished.

Figure 26 Finished facade waiting to be transported to the final destination (picture by the author)

Figure 28 Automated mineral brick installation (picture by rcpanel.nl

RC Panel - Life cycle assessment

As part of the Smart Renovation Factory project by INDU-ZERO, a project for the North Sea Region within the European regional development fund, the environmental impact of renovation packages where reviewed. In this study, several authors reviewed the RC Panel's current design, such as Yanaika Decorte, Marijke Steenman, Anne Goidts and An De Vriednt (Decorte et al., 2020).

The analysis comprehends two parts, the first part as an analysis per element level where the facade panel is evaluated and the second part as a building level where all the renovation materials, including the systems (Heating, Ventilation and Coolings), are included and evaluated. For the present research, only the first part will be analyzed.

The LCA assessment was performed to evaluate the panel's contribution to several environmental aspects based on the inputs and outputs of the life cycle phases. The analysis's goal and scope were to optimize the existing product's environmental impacts, analyzing 60 years period with a functional unit of 1 m2. The cycle phases considered in the study are presented in Figure 29.

The data inventory was taken from the Swiss Ecoinvent database. The impact assessment was done following the ReCiPe method established by the National Institute for Public Health and the Environment in the Netherlands. This method is a harmonized life cycle impact assessment at midpoint and endpoint level (Huijbregts et al., 2016).
The method quantifies the environmental impacts of the complete life cycle of products, where several emissions and resource extractions take place over all the life span of a product. Life cycle impact assessment (LCIA) interprets the study by taking the emissions and extraction to a limited number of environmental scores. This "scoring" is done with the help of "characterization factors" which indicate the impacts per unit of a stressor. The method analyses midpoint impact categories, the damage pathways of said impacts and the endpoint areas of protection that are affected. There are three main areas of protection: human health, ecosystem quality and resource scarcity. An overview of the interconnections between the impacts, pathways and areas of protection is presented (Huijbregts et al., 2016).

First, 1 m2 of the panel is analyzed, including only the internal interfaces, meaning that the exiting wall's connection is excluded from this first analysis. The materials analyzed refer to Figure 27.

Afterwards, for the same 1 m2 of panel analyzed, the interconnection with the existing wall is included. Currently, the panel considers a galvanized steel system placed on both the existing wall and the prefabricated panel. The amounts of galvanized steel considered are: for panel 2.08 kg, for the existing wall 3.26 kg, and the bolts 0.52 kg.

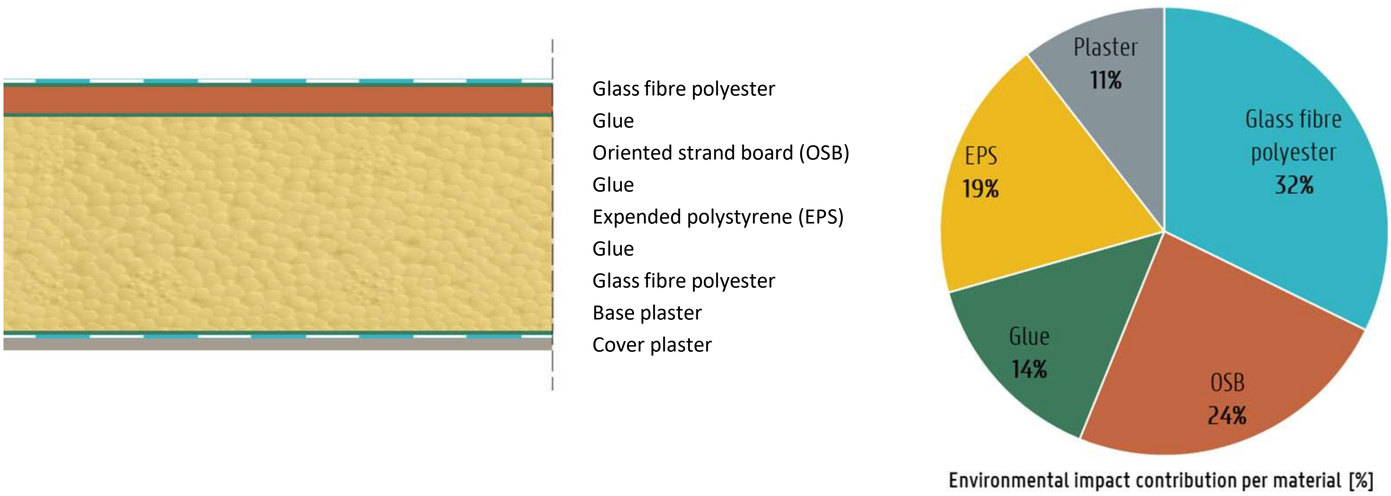

Figure 31 RC Panels - Environmental impact contributions of the RC panel (Decorte et al., 2020)

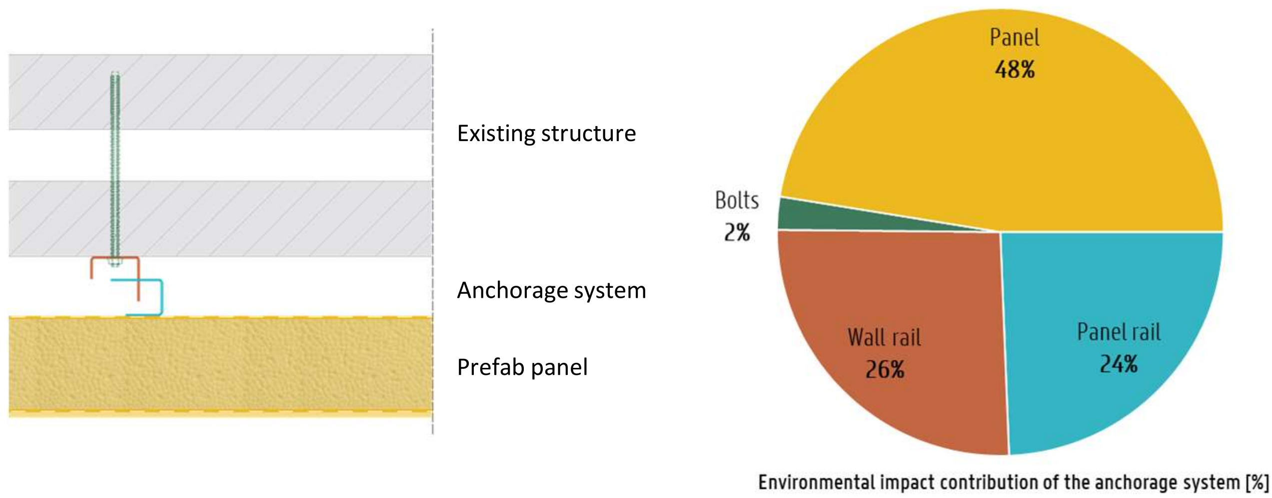

Figure 32 Environmental impact contribution of the Panel + Anchorage system (Decorte et al., 2020)

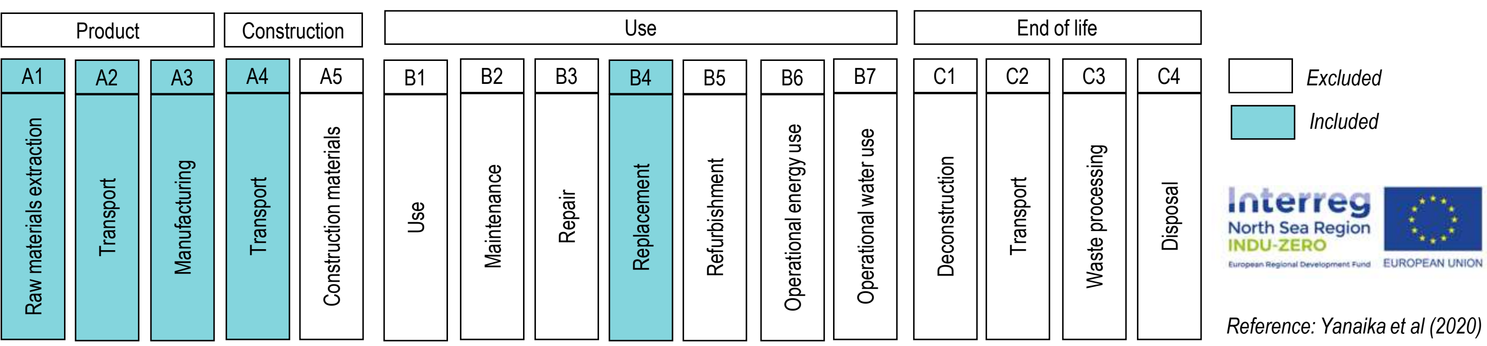

Figure 29 LCA RC Panel - Smart Renovation Factory project (Decorte et al., 2020)

RC Panels LCA Interpretations

As part of the study's interpretations, the authors remark the contribution of both the panel and the anchorage system almost to the same level.

The rails consider 52% of the total impact, while the panel itself 48%. The study suggests paying particular attention to different panel layers such as the OSB, the glass fiber polyester and the EPS. Together they represent 75% of the total impact of the panel.

For the OSB, the suggestion is to omit the material and for the case of the polyester and EPS case, the suggestion is to review the possibility of changing them. In terms of the anchorage, the study reviewed the possibility of changing it to stainless steel; the result was that it would increase the rails' impact up to 71%.

Different proposals to be explored are suggested: an adhesive mortar between the existing wall and the panel, a PVC anchorage system, and galvanized hooks. The selection of the connection system to the existing wall affects the panel's circularity aspect; the option of gluing the panel to the wall is suggested as a negative impact for the detachability of the panel.

After reviewing the study together with its conclusions, different points can be remarked. As seen in Figure 29, the analysis does not include the end-of-life phase of the panel. This means that the impacts of the panel's disposal are not included in this analysis. Likely, the ratio between the panels' impacts and the anchorage changes since the anchorage itself can be demounted and reused easily. Even though the study is performed for 60 years, it detaches the time component from the design by omitting the EoL of the product. Also, the study suggests the deletion of the OSB layer and at the same time recommends an anchorage system change to a PVC or hooks system, even though the main functionality of the OSB in the panel is to be able to attach these kinds of hooks and rails.

Together with the interpretations of this analysis, the present research will propose different alternatives for the current design with the possible EoL scenarios that could occur after the panel is not required in the building or does not fulfil its technicalities. The main design parameters will incentivize circularity as a design that is detachable from the building and between its internal interfaces; as seen in Figure 31, the glue contributes 14% of the environmental impact and affects the reusability and recyclability of the different panel layers

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RC Panel - Durability report

In March 2017 SKG IKOB was asked to conduct research the exposure of the RC Panel system (Figure 22) under a specific climate load.

The research was performed with a 1:1 mock-up of 3.80 m height and 3.0 m length wall, (please refer to Figures 33). The 1st line of defense was examined with a finish with STO mineral stone strips and an STO plaster layer. The mock-up included a frame with window with dimensions 120 x 80 cm has been included in the wall (Hofland, 2017).

The mockup was induced to a 15 to 20-year weather load following different tests such as:

Hygrothermal test following the ETAG 5.1.3.2.1. Where climate loads are carried out: Heat-rain 80 times, Heat-cold 5 times During the test, conditioning process was regularly assessed for flaking and cracking.

At the end of the hydrothermal test a freeze-thaw test followed. This was according to the ETAG 5.1.3.2.2 with 30 cycles of irrigation with cooling.

After the two tests mentioned above a wind and water resistance test was performed following the NEN 2778 marked in the Dutch Building Decree where Wind and water tightness is tested. Also, a bond strength (aging) was carried out to test the adhesive strength of the finishing layer after 7 days of the end of the hygrothermal cycles and freeze-thaw loading.

The report conclusion says “This deterioration load corresponds to a weather load that in practice occurs in 15 to 20 years. **No internal condensation occurred in the wall** during the test. A lifespan of approx. 50 years is nevertheless considered normal for residential construction.” (Hofland, 2017) The author mentions that no judgement can be made with regard of the system to 50 years, however a**fter the weather deterioration exposure of 20 years**, the panel showed **NO damaged**. Therefore, SKG-IKOB expected that a **50-year span in achievable** with the STO mineral brick as 1st line of defense.

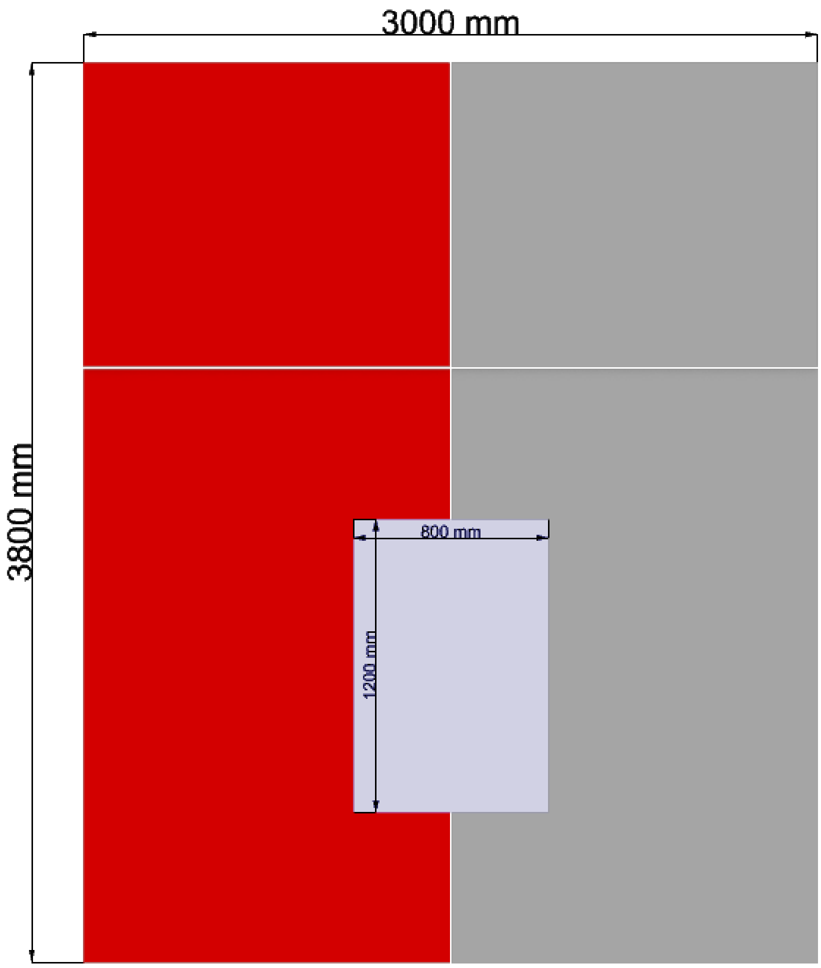

Figure 33 - Rc Panels mock-up model

Interpretations

The RC Panel is an extremely and durable solution, that does not show any deterioration in 20 years, this durability is mainly achieved due to the bonding between the brick slip + mortar + polyester + polyurethane layer.

This line of defence protects any material behind it. What makes the panel so durable is what could represent a problem at its end of life, representing a challenge to reincorporate the different resources to the nutrient's cycles (technical and biological). The "concept" of an extremely durable "line of defence" is ideal when is used with the correct materials behind it.

In the present research this first line of defence will be evaluated and compared with a rear-ventilated façade cladding with 2 lines of defense. A rear ventilated façade is known as a design strategy that allows the reincorporation resources to the technical cycle. Allowing a possible reuse and recycle of materials.

SKG-IKOB
Certificatie

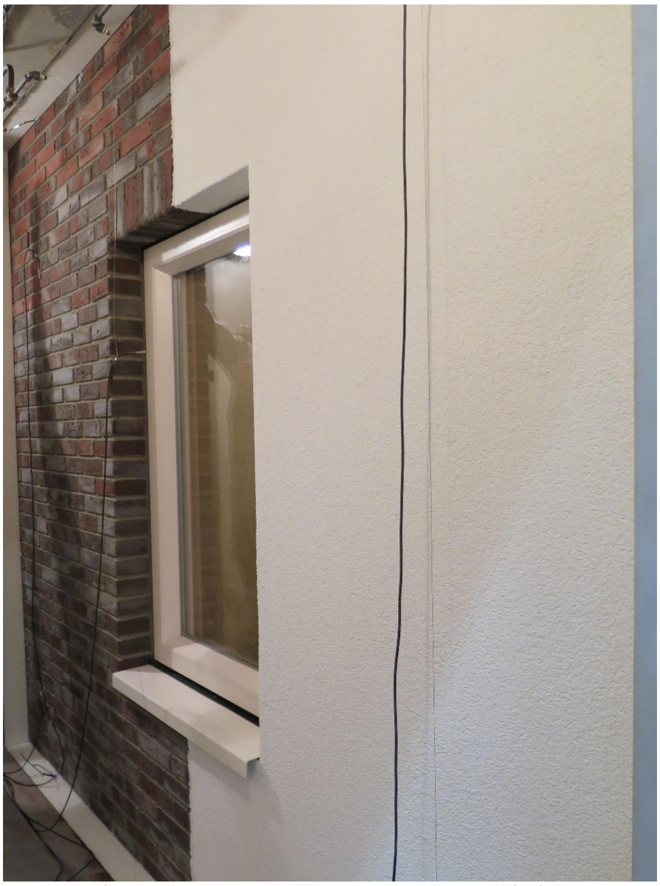

Figure 33 - 1:1 Mock-up for durability test

EVALUATION PHASE

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Concept design

Three design concepts are proposed based on the design strategy of "Design for Disassembly and reassembly" for both slowing and closing resources loops. The idea is to make the panel restorative by intention.

The propose key design components are the following 8:

- Design of accessible connection to ease dismantling.
- Simplicity of structure
- Incentive the use of bolted connections.
- Documentation of materials and methods of deconstruction
- Reduce chemical connections.
- Design for worker and labour separation
- Modularity and standardization

The concept designs development started by looking at the housing stock. There are multiple types of homes in the country; however, this research focuses only on the 42.5% of terrace homes (Figure 35). This type of dwellings are usually 2-3 stories high. Therefore, a maximum of 10 m heigh was established for further analysis.

TThe conceptualization of a new panel started by looking at the interaction in the type of enclosure in question. These interactions were mainly with the facade and the environment around it. As seen in Figure 36, multiple scenarios take place such as: rainwater or any type of precipitation, sun providing UV-radiation and daylight through the windows, wind pressure/suction, and people standing on the outside looking at the appearance or the aesthetics of the façade.

By taking a small section of the RC panel and looking at the interaction of the different components at a closer view, it was easier than looking at the entire facade intervention, always keeping in mind the interaction mentioned in Figure 36. The process started by decomposing the panel in three main sections (please refer to Figure 37) . Number ONE is the interface at the "connection of the existing wall and the retrofit panels". Number TWO is the interface comprehending the "main thermal panel" as the element that will reduce the energy consumption in the building stock. And number THREE is the "cladding" interface, which comprehends the aesthetic view and affects the location of the façade lines of defence.

After developing the interface analysis, the results and conclusions of the LCA performed by TU Ghent and the durability report by SKG-IKOB were considered.

Source: Stitched in color "Expay Chronicles: How Dutch houses are different (retrived on june 2021)

Figure 35 Example of terrace home

The idea is to target the three main components affecting the environmental impacts of the panel, which are the glass fibre polyester (32%), the OSB3 panel (24%), and the EPS (19%). Also, analyzing the 11% contribution of the plaster, which is the smaller contribution of all the panel, and it is what brings the durability of 50 years to the system. However, the same is what could represent a disadvantage of the product when circularity is involved and these products need to be replaced multiple times and the ECI increases.

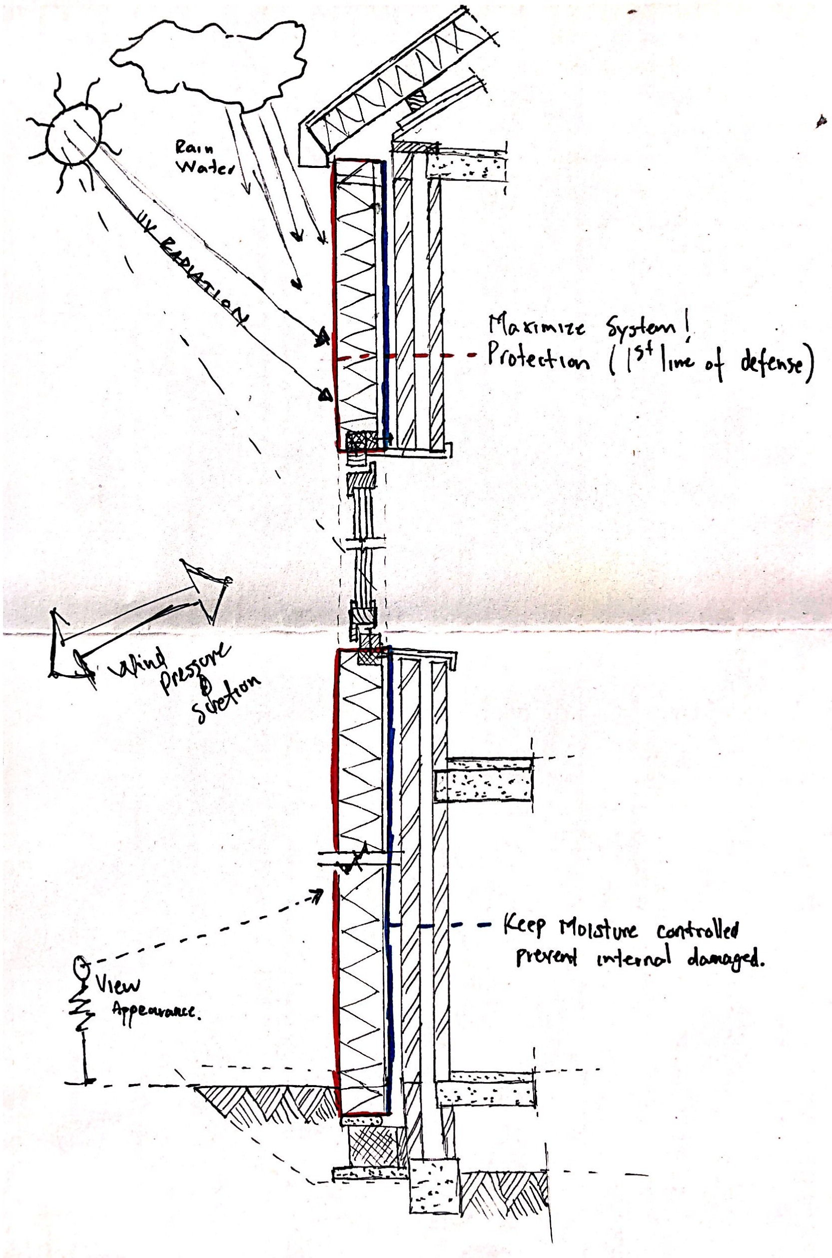


Figure 36 Enclosure interactions

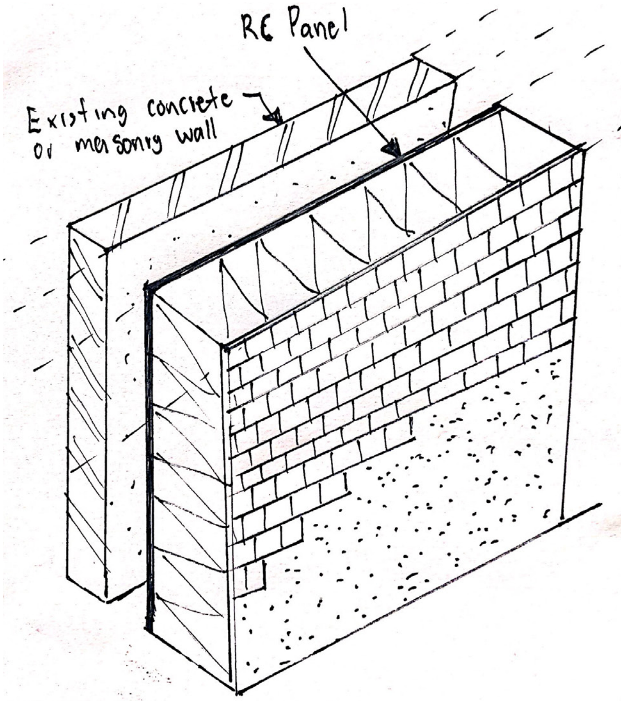


Figure 37 Retrofit panel interactions (1)

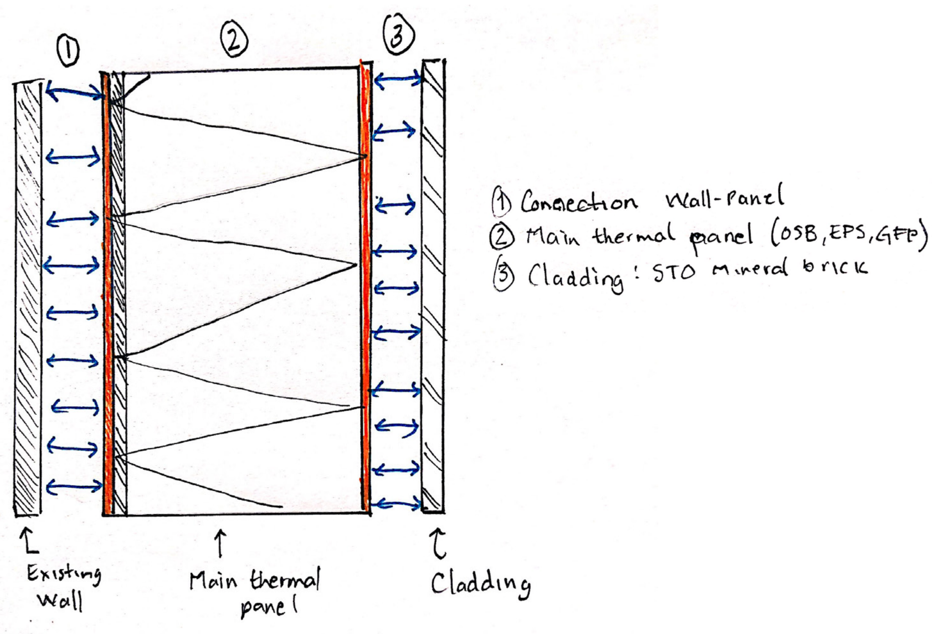


Figure 37 Retrofit panel interactions (2)

Concept 1 – Biobased sandwich panel

Concept 1 aims to use both reuse and recycling at the EoL of the new RC Panel. The idea is to have the flexibility to disassemble the panel to return the different parts to biological and technical cycles. Elaborating in the design key component 1, “Design of accessible connection to ease dismantling,” does not necessarily need to apply to all the panel layers. An example could be a mechanical separation between biodegradable and non-biodegradable materials or a peel membrane easily removed by hand. In this sense, they could each be sent to a different purpose after the first life cycle. This concept will always require keeping a line of separation between nutrients. Figure 40 illustrates a concept sketch of the proposal.

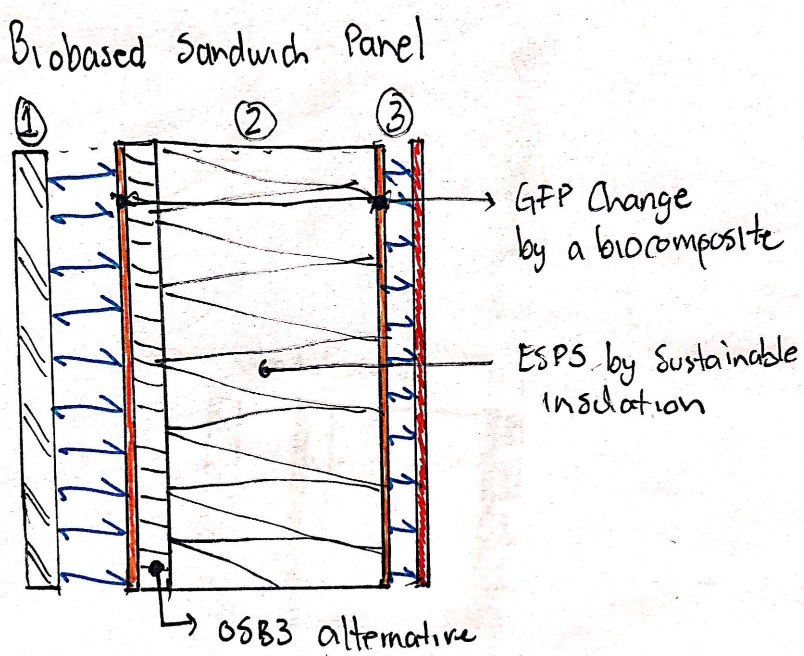
For interface number one, as the connection with the existing wall, the idea is to avoid any chemical connection keeping the same anchors and rail analysis that RC panels currently use. This means that the panel would need to keep the sheathing board on the back of the “main thermal panel”. This is because the board will serve as a line to attach the anchors/ rails and allocate the windows and doors. The LCA reports the OSB3 is the second environmental contributor of the panel; it even suggested deleting it. However, the fact that the board can make the panel detachable and not glued directly to the existing wall, a sustainable alternative to the board, will be explored.

Interface number two, the main thermal panel, maximises the use of renewables, which translates in using biobased materials as much as possible, finding alternatives for the EPS and the glass fibre polyester.

For interface number three (the cladding), the idea is to compare the current cladding with a system that minimizes the chemical connection and incentivises bolts. Therefore, two types of claddings are analyzed, one with the current STO cladding and a second as a rear ventilated façade.

For the **first type of cladding** of the system (top image on Figure 38), only one defence line exists on the exterior part and works as the appearance component. Then a thermal line located at the back of this line of defence protecting the insulation layer.

For the **second type of cladding** system (bottom image on Figure 38), a rear ventilated façade will bring two lines of defence. One at the exterior referred to as a “second line of defense” where most of the water and UV-radiation are diffused and works as the prominent appearance or aesthetic component. Then, behind this 2nd line, a “first line of defence” is located in the cavity. This line will bring the system its life expectancy and allow us to have an airtight and watertight panel.



(1) Connection Wall-Panel
Avoid chemical connection, keep using anchors or rails in the
Keep the sheathing board on the back for anchors and openings

(2) Main thermal panel
Maximize the use of renewables

(3) Cladding
Minimize chemical connection
Incentive use of bolted connections
Design of accessible connection to ease of dismantling

RC Panels has experience with the Dutch market regarding the preference for the appearance of the façade. It is known that people in The Netherlands prefer stone-like finishes for their homes. Also, to preserve the heritage of the bricks that the typical Dutch terrace homes have, the two claddings will keep in line the usage of brick as a finish.

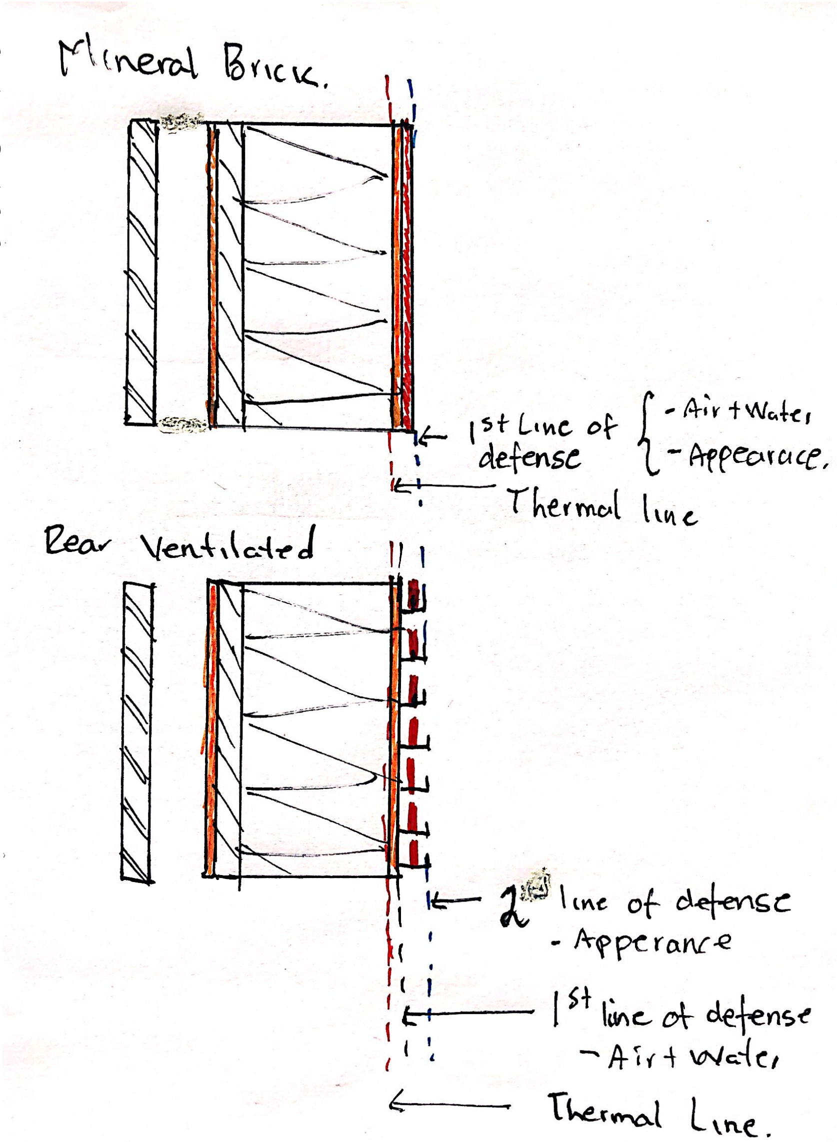


Figure 38 Proposed Cladding analysis

panel

Taking a closer view of a vertical sketch of concept 1 (Figure 39), the proposed replacement for the GFP is a bio-composite membrane for the thermal panel using as much as possible biobased material. This material could allow the company to keep significant facade interventions acting as a membrane holding different divided materials into one panel. This because the insulation and the sheathing boards come in different sizes. This analysis is something that the company is already doing. RC Panels uses glass fibre polyester rolls that are cut precisely to the size of the façade holding the EPS and the OSB together.

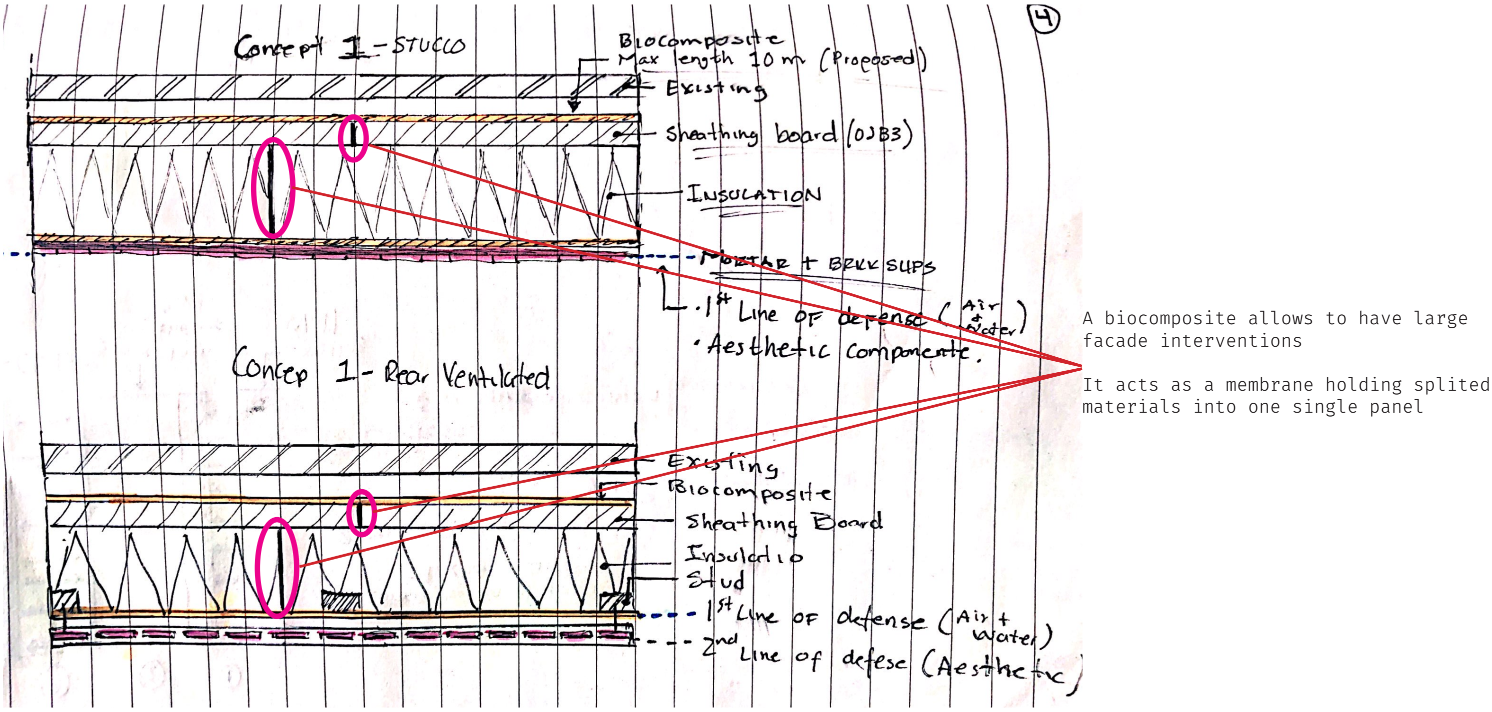


Figure 39 Membrane holding divided materials.

Figure 40 shows concept 1. On the exploded view on the right side, different layers acting on the new façade are shown. From interior to exterior: the existing wall, a first composite membrane, an alternative board, a sustainable insulation material, a second bio composite membrane, and finally, the cladding system.

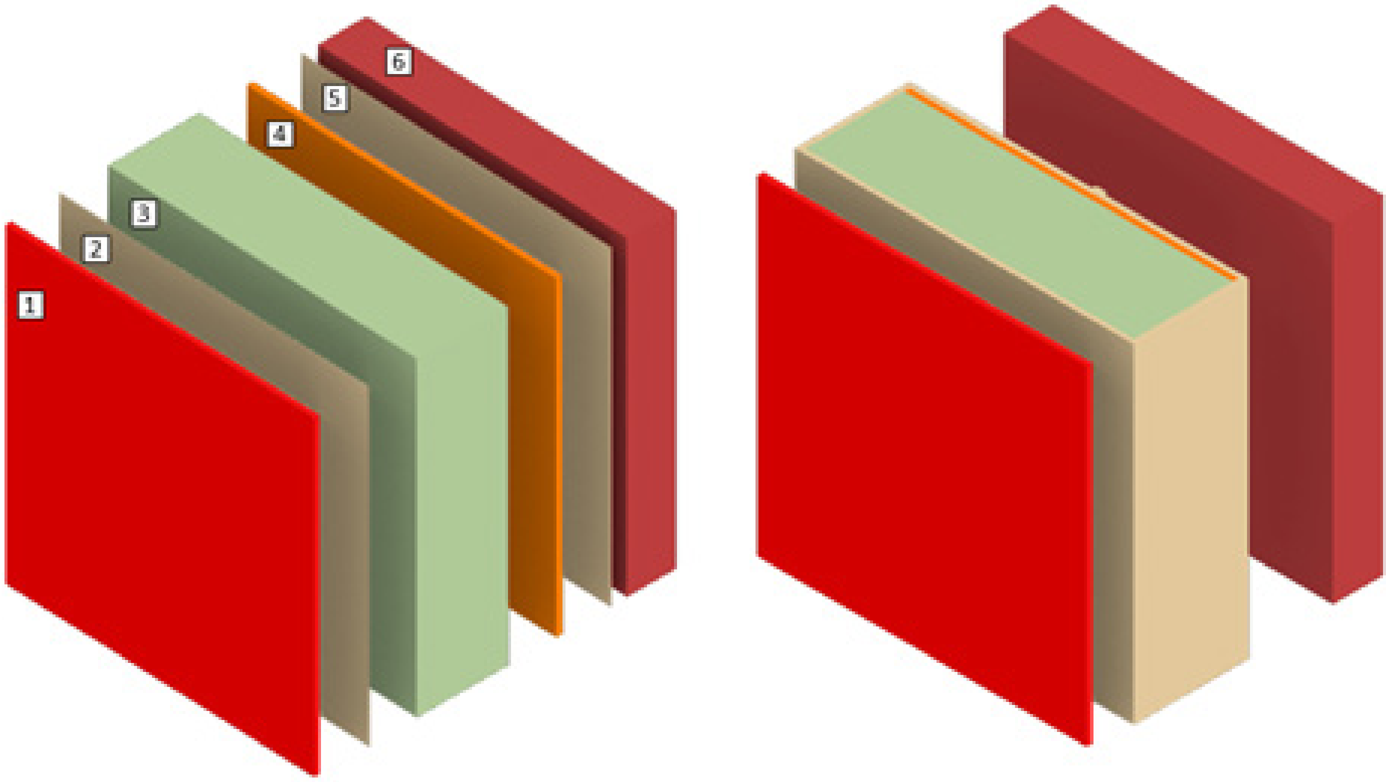


Figure 40 Concept one “Biocomposite panel”. (1) Exterior cladding, (2) Biocomposite membrane, (3) Sustainable insulation, (4) Alternative for OSB board, (5) Biocomposite membrane, and (6) Existing wallW

Concept 2 – Double sheathing panel

Concept number two is called a double sheathing board, and it´s because it uses two boards instead of only one (as the RC Panel). During the visits to the factory multiple times, it was mentioned that the joint between the OSB and the interior GFP was one of the connections that presented the highest challenge to detach. It was even commented that only incineration is the only EoL treatment since the boding caused by the polyurethane made it impossible to recycle either of the materials. Therefore, concept 2 tries to remove this connection and also tries to delete the use of GFP in the product.

Similarly to concept 1, this design is analyzed with the same three interfaces, which are conceptualized as:

Interface number one, having again the minimized connection keeping the same anchors that will be part of them. For concept two, the same applies to the interior sheathing board, and this will serve as the backbone for the “main thermal panel”.

Interface number two, for the “main thermal panel”, two board uses are used with an insulation core in the middle. Not having the GFP on the back allows to easily remove the core from the sheathing board with a thin wire saw and makes the possibility to reuse the different material at the EoL. The LCA done by TU Ghent suggests replacing the GFP; however, we are deleting it in the back part and replacing it with a board on the front.

For interface number three (the cladding), the idea is similar to concept 1, compare the current cladding with a system with a rear ventilated façade. A critical comment here is that a sheathing board are not waterproof, therefore for the rear-ventilated façade its likely to need water proofing membrane.

As in concept 1, **for the first type of cladding the system** (top image on Figure 41), only one defence line exists on the exterior part and works as the appearance component

For the **second type of cladding system** (bottom image on Figure 41), a rear ventilated façade will bring two lines of defence. One at the exterior and one in the interior (“first line of defence”). As the board is unlikely to be waterproof, it is foreseen that a waterproofing membrane will be needed for this cladding system. This membrane will protect the insulation and everything behind it; therefore, its life expectancy will be necessary for the LCA.

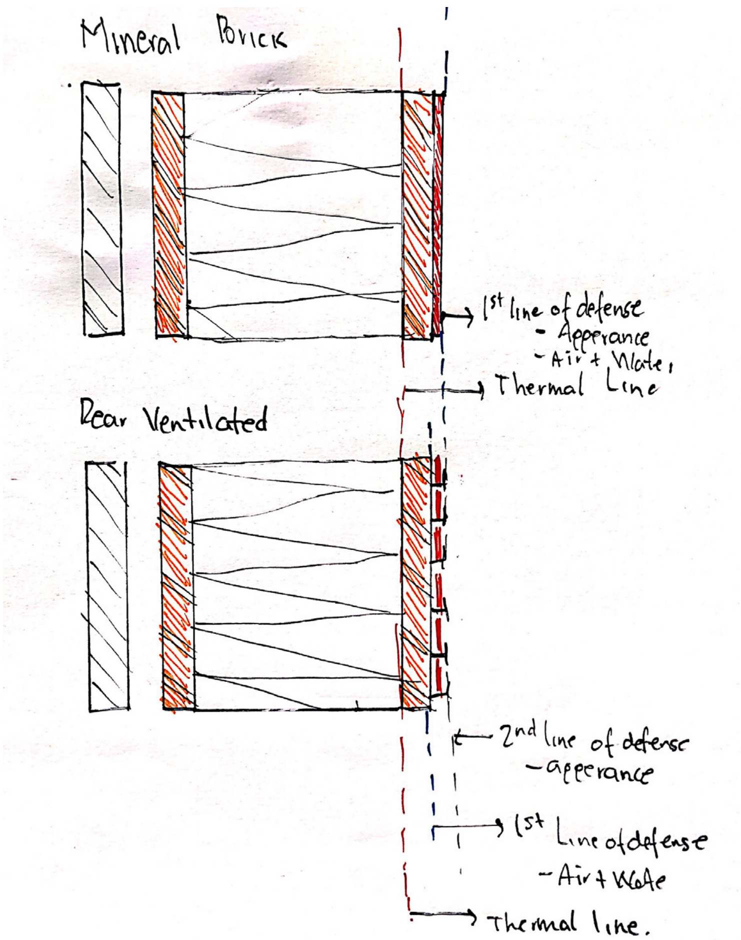


Figure 41 Double sheathing cladding systems

Comparing concept 2 with the original RC Panel, the maximal façade lengths are affected. In the original panel, the glass fibre polyester is what allows lengths up to 12 meters. In this design, the dimensions of the OSB3 are not a problem because they are “joined”. However, in concept 2, the deletion of the glass fiber makes the “factory dimension” of the board an important parameter to consider when modelling the stiffness and the stresses of the panel, please refer to Figure 42. Figure 25 shows concept 2, on the exploded

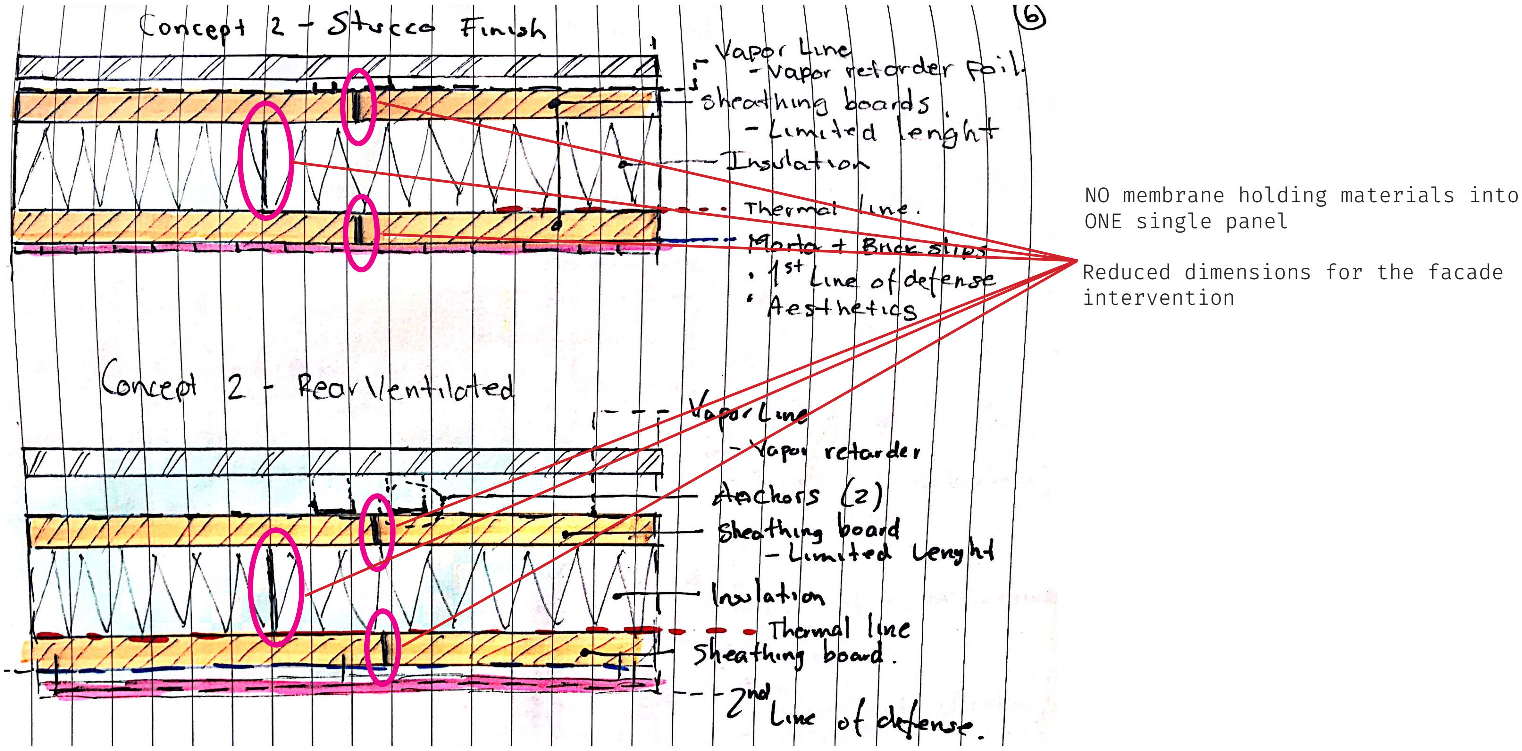


Figure 42 Sheathing board holding divided materials

view on the left side, different layers acting on the new façade are shown. From interior to exterior: the existing wall, a first sheathing board, a sustainable insulation material, a second sheathing, and finally the cladding system.

Figure 43 shows concept 2; on the exploded view on the left side, different layers acting on the new façade are shown. From interior to exterior: the existing wall, a first sheathing board, a sustainable insulation material, a second sheathing, and finally, the cladding system.

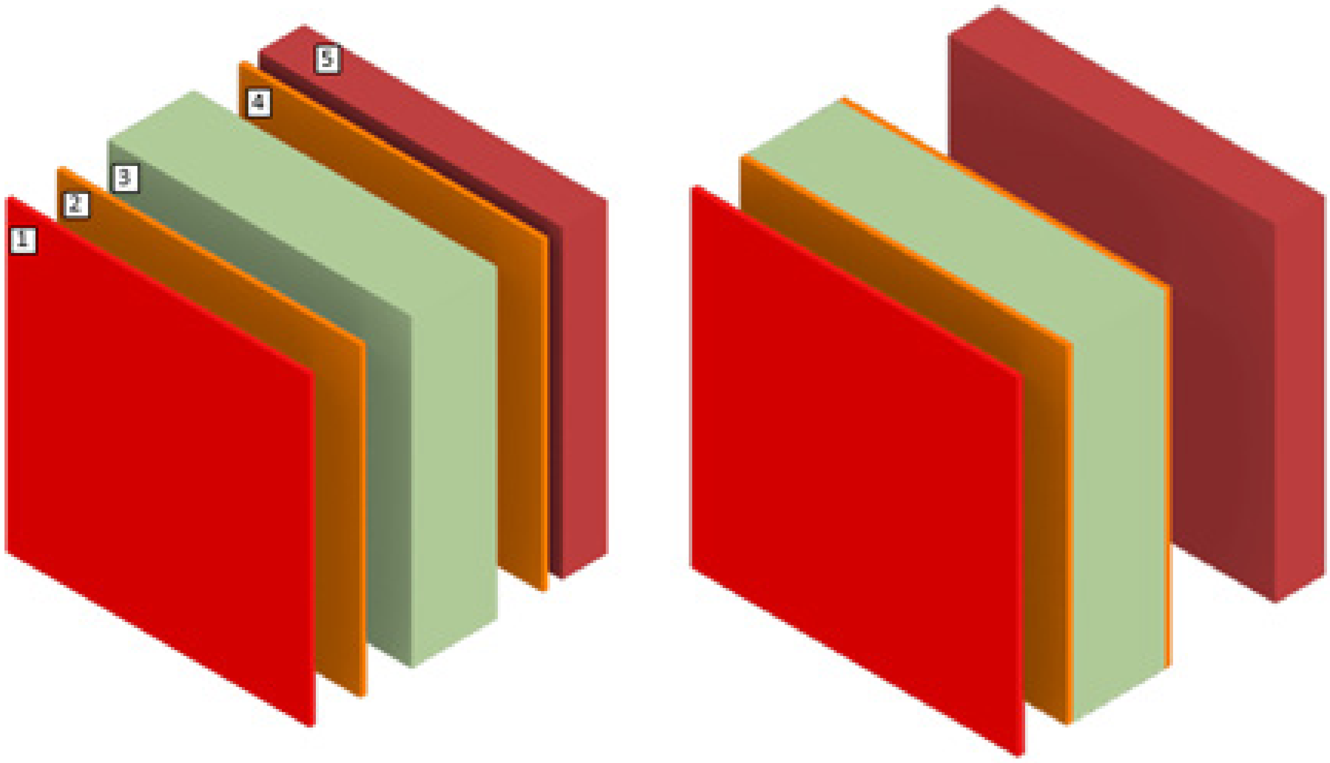


Figure 43 Concept two “Double sheathing board”. (1) Exterior cladding, (2) Sheathing board, (3) Sustainable insulation, (4) Sheathing board, and (5) Existing wall

Concept 3 – Hybrid sandwich/framed panel

Steeman M. and others, in their work “environmental impacts of timber frame walls”, describe multiple advantages of using framed facade system. Their evaluation includes different sheathing boards such as gypsum fiberboard, plywood, OSB, MDF, and chipboards. Different exterior claddings such as masonry, plaster, or wooden claddings. Also, a few insulation materials such as cellulose, glass wool and rock wool (Steeman et al., 2019).

RC Panels is a composite structures company, keeping the sandwich panel framework and considering the advantages of a timber frame; concept 3 is proposed as a hybrid system. The idea comes from challenges that could have concept 2” where the GFP glued behind the OSB3 is removed.

In this case, the GFP is replaced with studs incorporated in the panel’s insulation. This would allow screwing in the back sheathing board to be able to detach it for further use. The sandwich panel concept comes by keeping the exterior composite membrane instead of using another board. Concept 3 also aims to find alternatives for the top 3 materials impacting the LCA of the RC Panel. However, the alternative solutions for the glass polyester are proposed to be changed by studs (as back bone) and a bio-composite membrane (in the front).

Similarly to the two previous concepts, this design is analyzed with the same three interfaces conceptualized as:

Interface number one minimizes connection keeping the same anchors that will be part of all of them.

Interface number two, for the “main thermal panel” use of bio-composite and a sheathing board with an insulation core in the middle. Having the studs in the panel will allow to easily remove the sheathing board, studs, and core bringing the possibility to reuse the different material at the EoL. The bio-composite membrane will work as a peel membrane that could be easily removed.

For **interface number three** (the cladding), the idea is like concept 1 and 3, compare the current cladding with a system with a rear ventilated façade. A critical comment here is that the STO finish will likely stop vapour coming from the interior space. The same could happen with the bio-composite behind the rear ventilated façade. Therefore, for the 2 cladding systems, it is likely that they will need a vapour barrier.

Similarly to concepts 1 and 2, for the first type of cladding system (top image on Figure 45), only one line of defence exists located on the exterior part and also works as the appearance component.

For the second type of cladding system (bottom image on Figure 45), a rear ventilated façade will bring two lines of defence. One at the exterior and one in the interior (“first line of defence”).

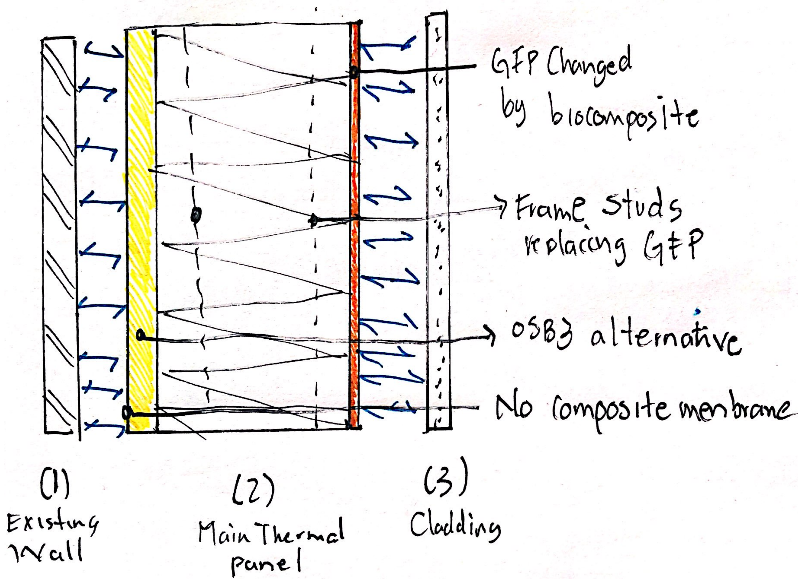


Figure 44 Hybrid system

As mentioned in this concept, a frame allows to have the same facade interventions holding divided materials into one single panel; please refer to Figure 45 for reference in this idea. this idea.

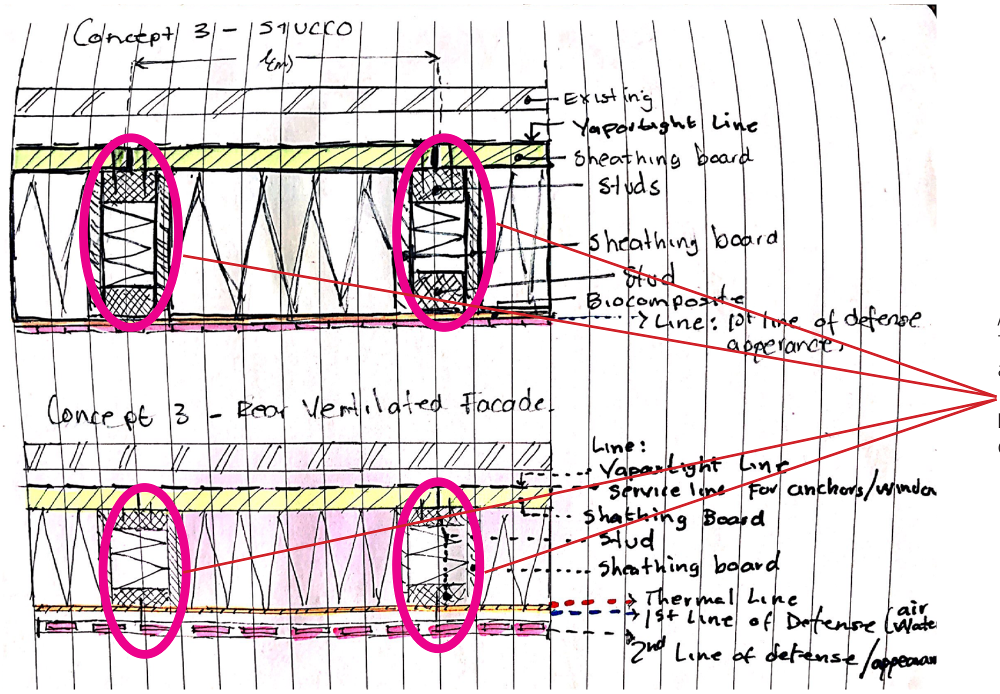


Figure 45 Studs holding back sheathing board

Figure 46 shows concept 3. The exploded view of the left shows the different layers and materials. At the back is the existing wall, then a new board screwed to a set of multiple studs thermally broken by insulation. In between said stud, sustainable insulation is proposed, followed by a bio-composite membrane on top. Finally, the cladding with the two possible options of brick strips and rear ventilated façade.

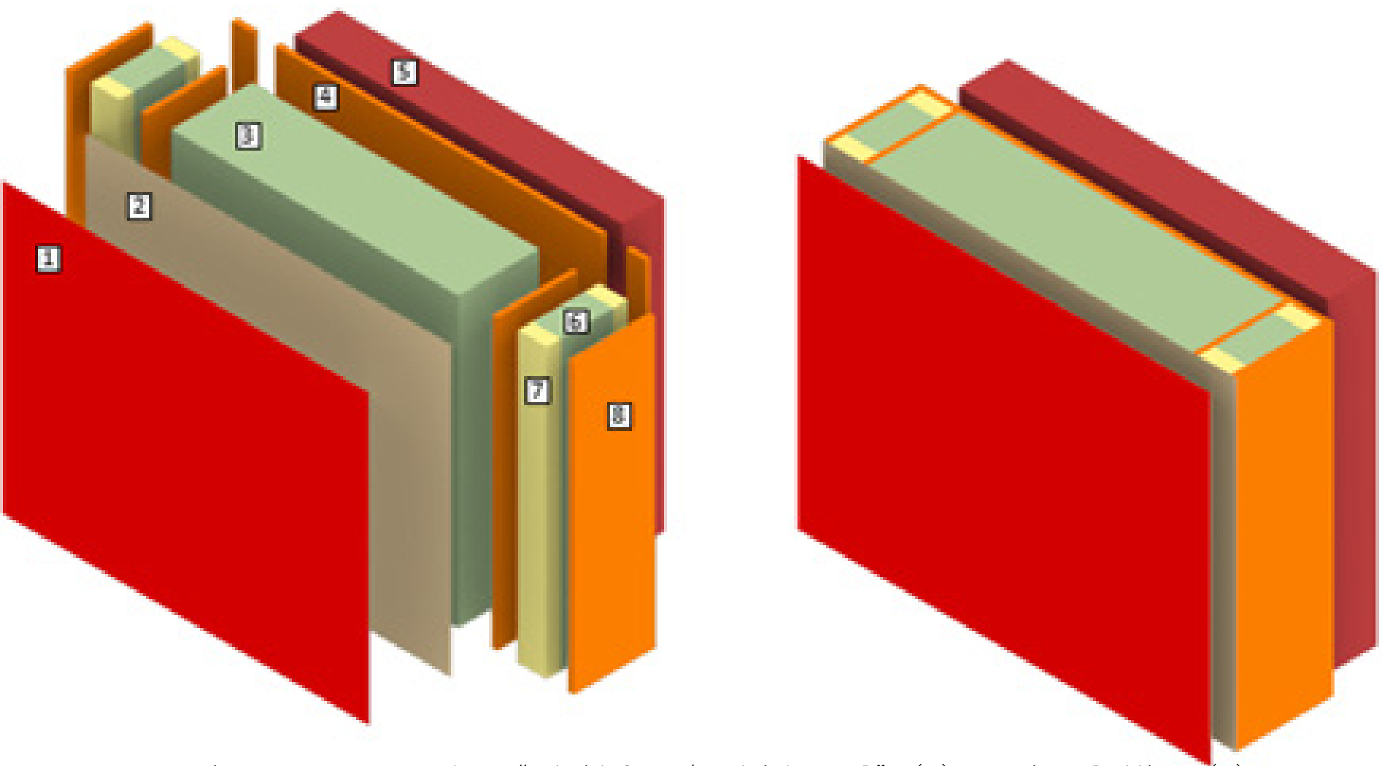


Figure 46 Concept three “Hybrid frame/sandwich panel”. (1) Exterior cladding, (2) Bio-composite, (3) Sustainable insulation, (4) Sheathing board, (5) Existing wall, (6) Thermal break, (7) Stud, and (8) Sheathing board

Materials choice

In this section, different materials are researched and selected for the concept designs. The material follows form by researching the properties of materials and their application and always keeping in mind the boundary conditions of the RC Panel as an exterior “enclosure” and the pursuit of a circular and sustainable product design.

The aim here is to orientate how materials are manufactured, categorized, and available on the market. It is essential to mention that this research is not focused on the development of new materials. To have a filter before the LCA phase, materials will be chosen before analysing their environmental impacts. Only materials with complete development and market availability are included in the comparison and assessment.

The three proposed designs are conceptualized as a composite, which is a structure composed of at least two constituents. Typically, these types of structures are subcategorized in (a) face sheets, (b) adhesives, and (c) cores. However, in this case, the RC Panel is an enclosure and an architectural element. Therefore, at least two or more components can be added, such as (d) sheathing boards (e.g., for the anchorage systems and windows), (e) claddings (e.g., for aesthetic preference) (f) framing studs, or (g) waterproof membranes. At the end of this “Material choice” phase, at least one material will be selected for all the new composite structures subcategories.

Before analysing each new concept material possibilities, a overview of the original RC Panel materials properties and characterisers is presented.

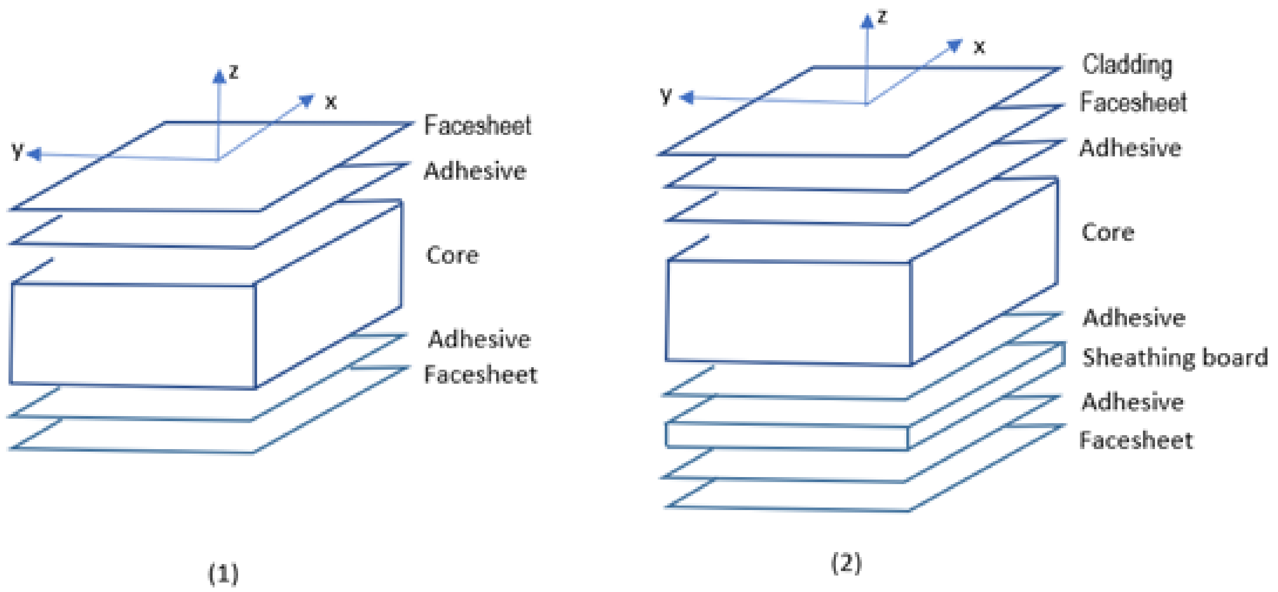


Figure 47 (1) Typical composite structure, (2) Facade composite structure

Original RC Panels Materials

As mentioned before, the RC Panel has different materials involved for face-sheet, adhesive, core, sheathing boards, and claddings. In the following pages, theY will be described for further reference.

Faces sheets

The face sheets of the current panel are composed of glass fibre polyester (GFP) membranes. GFP is a polyester matrix reinforced with glass fibres, as its name suggests. Through specific industrial settings, the material is made by mixing thermosetting polyester resin and glass fibres.

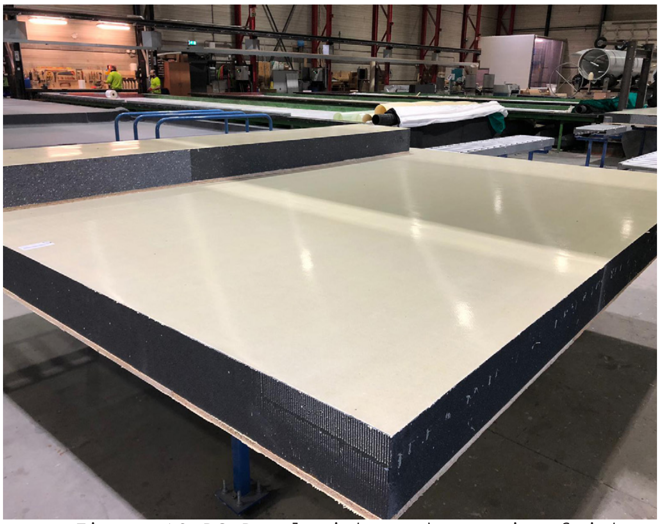


Figure 48 RC Panel without decorative finish

Two membranes are used, (a) one facing the interior and existing wall of the building and (b) another behind the stucco/brick slips cladding. As shown in Figure 48, the GFP behind the cladding is the white top layer in the picture and the GFP facing the building at the bottom of the panel in the picture.

The manufacturer of such membranes or “Woven Fabrics “ is LAMINUX. The interior membrane (facing the existing wall) has 0.7 mm of thickness, and it’s commonly referred to by the company as “natural” GFP. This is because this layer does not have any additives for fire resistance. The membrane behind the stucco, it’s a 1 mm Woven Fabric flame retardant. Both membranes are smooth and soft sanded, present a glass content between 27 and 36% and a density ranging between 1,100 g/m2 for the “natural GFP” and 1,750 g/m2 for the flame retardant GFP.

These membranes act as a holding element for the rest of the materials. Typically, EPS and OSB will come in specific length and width dimensions like 1600×1600 mm for EPS or 1220 x 2440 mm for the OSB. The GFP is manufactured in large rolls of height and length. This allows the company to have large facade interventions. As mentioned in the RC Panels chapter, the company can manufacture facades up to 12.50 m in length and a maximum height of 3.17 m. These “Maximum” dimensions are possible mainly due to the GFP rolls manufactured by LAMINUX. Figure 49 is a picture of the rolls in the factory, the green one is the “natural”, and the yellowish is the fire retardant.


Figure 49 GFP rolls in RC Panels factory

CORE

The core is the RC Panel's thermal component and is made from Expanded Polystyrene (EPS). This layer is manufactured by multiple companies, one of them VBI Weurt B.V in The Netherlands.

EPS is a lightweight, rigid, closed-cell product. It is a "well-known" insulation material and in the market is available with different mechanical strengths to withstand tensile and compressive forces. EPS, as a "closed cell" structure, has low water absorption and low vapour permeability. Also, one of the most significant advantages of the EPS is its density and its low thermal conductivity.

EPS uses as raw material styrene monomer coming from the extraction of ethylene and benzene (oil derivates) and is made using a process that creates transparent spheres of polystyrene of approximately 0.3 mm. Typically, pentane gas is mix with spheres to expand them up to 50 times their original size..At the end of the process, in a cubic meter of EPS approximately 98% is "non-moving" air.

For RC Panels, the possibility to have such a light material for insulation makes the manufacturing process more manageable because the cores can be easily mechanically cut, lifted by hand and placed for the glueing procedure. Figure 50 shows its installation.

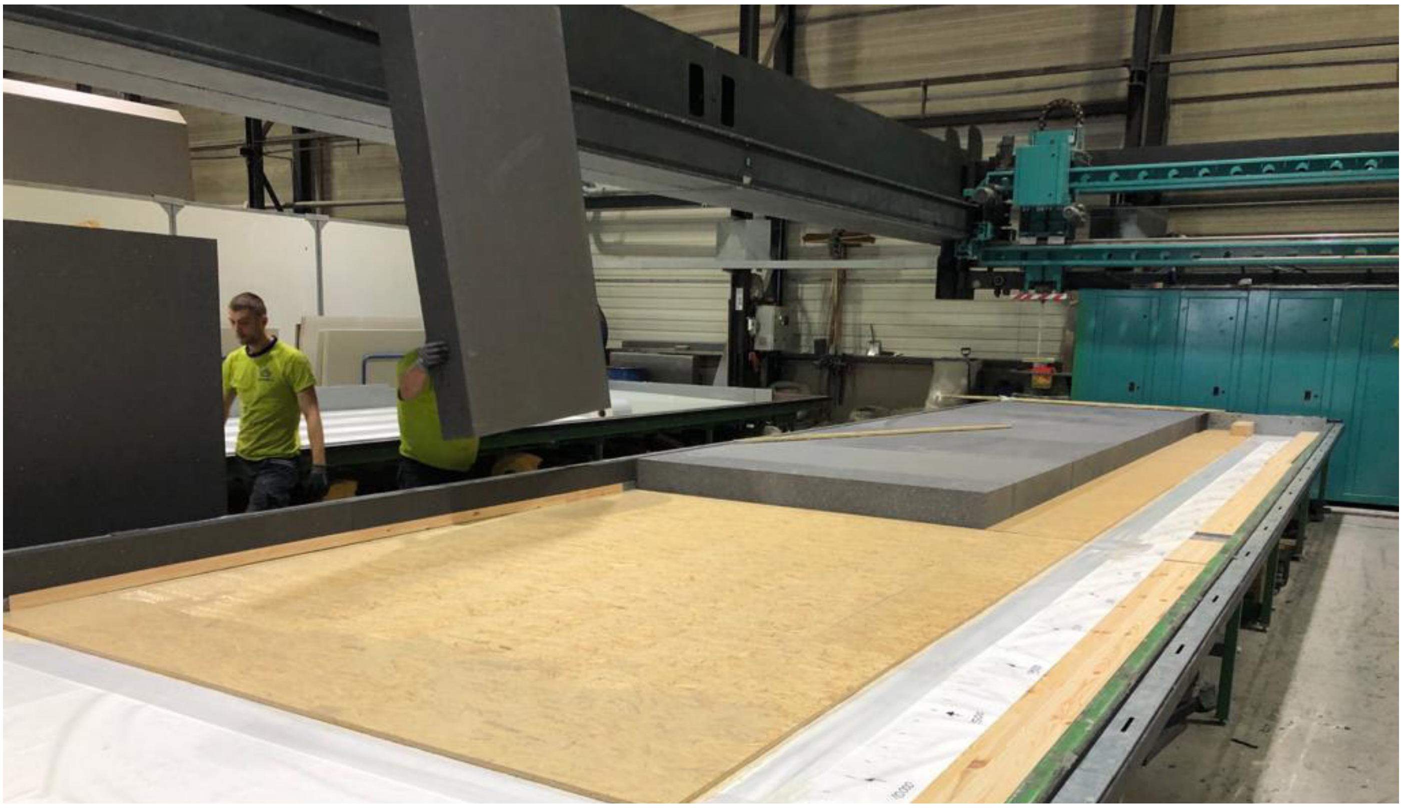


Figure 50 EPS installation

Sheathing board

The RC Panel has an 18 mm Oriented strand board (OSB3) located in the back part between the “natural” GFP and the EPS core. Different companies in the world manufacture this type of products, some examples are Mëtsawood, Smartply, Stora Enso and Kronospan, being the last one the supplier for RC Panels.

OSB is commonly used in the building industry as a structural panel. The board is prudced by heating and curing adhesives and with strands of woo (cross orientated). The mix between wood and adhesive makes high strength and stable wood panel. OSB panels can be considered a light product easily to handle and install depending on their weight. The panel are produced large mats to form a solid panel product avoiding any void or joint.

After visiting the RC Factory, it was concluded that this board works as a service “layer” because its primary function is to attach the anchors for the façade installation and for the windows and doors installation. After the vacuum process, the panel goes into a CNC machine that created the hole for the opening, leaving a recessed edge allowing the installation of timber studs. Also, at the end of the horizontal manufacturing part, the panel is lifted to install the anchors at the back. Figure 51 refers to the opening’s cutout, and it can be noticed that the EPS was cut, leaving the OSB3 on the back to screw in a timber stud. Figure 52 shows an example of one of the types of anchors attached to the OSB panel from the back. These anchors are later connected to a set of plates on the existing building wall.

Figure 51 CNC cuts for openings

Figure 52 Anchors attached to the back of the panel

Adhesive

As adhesive material, a 3-component polyurethane adhesive is used. This layer works as a bonding agent between all the materials besides the finish cladding. The product used is called Maracol 6131A + hardener 4600B manufactured by “Bostik - smart adhesives”. This adhesive is specially designed for different bond constitutions like wood, non-porous synthetics, metals, and stony materials.

In the factory, the different layers are stacked mechanically (with moveable cranes) or manually. Once they are in position, an automatic nozzle sprays the adhesive. Please refer to Figure 53. After the layers are glued, the vacuum process, previously mentioned in the literature review, is done to warranty the complete bonding of the layers.

Figure 53 Polyurethane adhesive installation

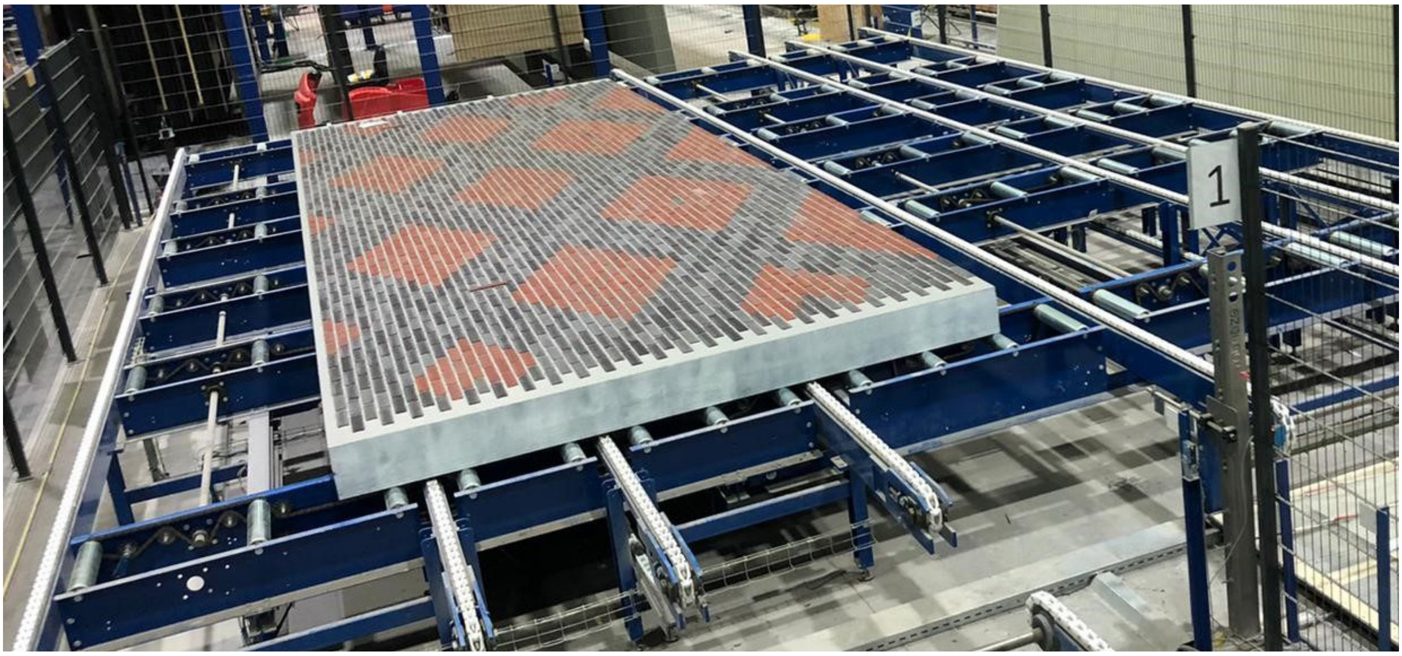
Cladding

The cladding system of the current RC Panels considers two aesthetic options with the same performance and manufacturer. One option is to have a sprayed mortar with mineral brick slips glued or a stucco finish. The company manufacturing this product is STO.

The brick slips are thin, lightweight, and according to SKG-IKOB, extremely durable. The mineral stone strips are much thinner and lighter than the traditional Dutch brick. Its durability and composition, together with the boding mortar, bring the RC Panel a 50-year life span.

This facade cladding is applied directly to the exterior GPF layer (white membrane on Figure 48). This process is done with automated equipment that sprays the mortar on top of the panel and, with air suction arms, takes the brick slips and set them on top. The equipment read the BIM arrangement of the façade design, making it possible to locate the brick slip where the designer indicated.

Together with the rest of the manufacturing of the previously explained materials, this process makes RC Panels a mass production façade factory. The equipment allows the company to create facades (with the maximum dimensions mentioned) in hours, allowing RC Panels to manufacture one terrace home in less than one working day.



Final product on production line (picture by rcpanel.nl

Materials

International system units	RC Panel				
	Facesheet	*Adhesive*	*Board*	*Core*	*Cladding*
References	[4], [45]	[5] [23] [39]	[3] [37] [38]	[1] [2] [45]	[45]
Unit of measure	kg	kg	m3	m3	m2
Material name	**Fiber Glass Polyester**	**Polyurethane - Adhesive**	**OSB**	**EPS**	**STO brick slips**
Biodegradable (Y/N)	N	N	N	N	N
*Embodied carbon - **Production** (kg CO2-eq/Unit)*	3.81	2.86	670.81	60	3.72
Carbon Capture and Storage (kg CO2/Unit)	0	0	-	0	0
Primary Recycling (y/n)	N	N	N	Y	N
Reaction to fire (A-E)	B				
Thermal conductivity W/(m·K)	-	-	0.13	0.031	0.87
Density (kg/m3)	1571-2500	1230.00	600 - 680	30.00	1550.00
Young Modulus E_x (Pa)	7.200E+10	2.100E+06	1.666E+09	7.500E+06	-
Young Modulus E_y (Pa)	8.500E+10	2.100E+06	2.314E+09	7.500E+06	-
Shear Modulus E_xy (Pa)	3.000E+10	7.447E+05	8.960E+08	3.333E+06	-
Shear Strength (Pa)	-	8.060E+07	6.800E+06	9.437E+04	-
Tensile Strength Xt (Pa)	-	8.000E+06	9.000E+06	2.164E+05	-
Compression Strength Xc (Pa)	-	-	1.480E+07	9.139E+04	-
Tensile Strength Yt (Pa)	-	-	6.800E+06	1.08E+05	-
Compression Strength Yc (Pa)	-	-	1.240E+07	4.57E+04	-

Material Matrix for Original RC Panel

Materials selection parameters

After discussing the different materials of the RC Panel for the different sub-categories of a given composite structure, the selection parameters to rank the new concept designs materiality will be discussed. The categories can be summarized to a list of seven parameters: Embodied Carbon, Primary recycling availability, Biodegradability, Reaction to fire, Thermal conductivity, Density and Mechanical properties.

Embodied carbon

Following the strategy to reduce the carbon emissions of the European Union and specifically in The Netherlands, the embodied carbon in the life cycle of a material is an essential parameter for the selection. The embodied carbon can be defined as the CO2 footprint of a material. It expresses the number of greenhouse gases (GHGs) released throughout the life cycle of a product. It can be measured in multiple and different life phases: cradle to gate, cradle to a job site, or cradle to cradle.

A complete LCA includes all the emission of a given product, including its end of life and waste processing. However, in the present research that will be part of the LCA phase, the embodied carbon will be considered the "production phase" of the materials, accounting only for the raw materials extraction and manufacturing process.

Primary recycling

Primary recycling is also referred to as closed-loop recycling. It is the process where a product is disposed and can be recycled into a product that has the same or improves technical properties. The circular economy research based on the Ellen MacArthur foundation remarks that there are "service loops" that allow the re-enter of nutrients to a Technical cycle. In this case, the recycling component will be considered as "positive" if the product can indeed be recycled into the same or better quality. The strategy is to incentive the use of materials that do not delay the end of life of a product by just downcycling processes.

Biobased Materials

To detach the RC Panel from fossil fuel materials and non-renewables (such as EPS, polyurethane, polyester, polyurea), the use of biobased components is done to incentivise the use of renewables. However, biobased materials can consist totally or with a significant part out of organic components. This can be related to both the raw material (source) or the resulting from manufacturing treatment (Mac-Lean, 2017). Also, biobased materials are not entirely biodegradable, and some materials can be non-biodegradable and biobased simultaneously.

Since the phase of the material is before the LCA, in this part, the biodegradability will depend on the presence of materials that can be broken down into simpler substances through the action of enzymes from microorganisms. In other words, if there is a biobased material together with a non-biodegradable component, a percentage of biodegradability will be exposed to rank the materials.

Reaction to fire

The national construction code has minimum performance requirements for materials. Fire performance means that a product needs to reach a certain fire class for a given function. The euro code has seven classes, in descending order of performance, A1, A2, B, C, D, E and F. The classification is based on fire performance tests described in the EN 13501-1. These test results can include mass loss, smoke production, fire growth rate, heat release rate, and flame spread.
For the RC Panel, different tests have been performed in the past; Peutz BV tested the product and classified it as class B-s1, d0. Given the case of study as terrace homes, for now, only individual materials will be compared. At the technical drawings, the fire design will be reviewed, making sure there are no hazard situations with fire spread in exterior and interior cavities. They are also considering whether the case is for a single or multi-family terrace home.

Thermal conductivity

Thermal conductivity, also commonly known as "lamda (λ) value" expresses the heat transfer behaviour. In the international system, its units are W/m•K in. It refers specifically to heat conduction; there are more heat transfer mechanisms such as convection, radiation, and advection. However, the case of the study will be analyzed as a steady flow heat transfer, and only conduction through the composite structure will be reviewed to match the same as the current RC Panel´s R-value.

This parameter is significant for selecting the core because this layer is the main thermal component and thermal conductivity is its main trigger. For RC Panels, the thermal conductivity of EPS is one of the most significant advantages, it brings the possibility to use few resources combined with lightness and affordable prices.

Density

Density is a physical parameter providing the mass of a sample or body divided by its volume, often expressed by the letter "rho(ρ)". This parameter is selected for accounting for the total weight of the materials used.
The impact of the density in a composite structure is mainly lead by the core and sheathing boards. These two sub-categories could be the heaviest in a system, especially the former. The core properties will significantly affect the total weight of a new panel. The relation between the thermal conductivity and density could also be denoted as a lead parameter for most of the engineering part of the façade. The thermal conductivity will directly provide the thickness of the core, and the density will then reflect the total weight. Therefore, this parameter affects the structural components, the manufacturing methods, the environmental impacts, the price, etc.

Mechanical properties:

The fact that the RC Panels is a current product used in the market means any development will need to withstand similar loads to which the current is subjected. Examples of load include the manufacturing process, transportation, hosting, installation, permanents loads (self-weight), and variable loads (wind force). For this, specific mechanical properties need to be considered for the selection of the material. More critical again for the face sheets and cores, these two elements provide the main mechanical component of a composite structure.

The stiffness values will refer to Young's modulus, typically denoted as "E", and shear modulus denoted as "G". There usually are two planes in which the quantity is needed: the transversal and longitudinal directions. So, for example, Ex is Young's modulus of the material in question in the longitudinal direction while Ey in the transverse direction. Strength values will be compared with the stress calculated from the strain's relation with the stiffness. The selection of strengths for the comparison is the compression, tensile and shear strengths.

Facesheets

In a composite structure (more than one constituent), the face sheets are typically composite materials (mix of a fibre and a matrix). The Glass fibre polyester used in the RC Panel is a composite of glass fibers with a polyester matrix. Composites are an exciting and attractive material because they are lightweight, high strength, high modulus of elasticity (stiffness), fireproof (if treated correctly), long lifespans, high chemical resistance, and freedom of forms designs. By picking the suitable correct fibre and matrix (adhesive), the materials can be “tailor-made” for a specific application (Verlinde, 2017).

Typically, in composites, the fibres are orientated differently in each layer, providing strength in traversal and longitudinal directions. For outdoor purposes, the composite is exposed to the sight and the environment; a coating can be added to showcase a desired aesthetic and protection against UV radiation or moisture, deterioration, and fire safety. Conventional composites have a disadvantage at the EoL. The waste treatment is a considerable challenge since the materials commonly used are non-biodegradable and cannot be separated to use further after they are not needed. RC Panels uses glass fibre reinforced composite, but another standard composite is carbon fiber reinforced, widely used in the aerospace industry, automotive sector, and construction because of the strength-weight ratio.

An innovative alternative to these materials is the so-called “biobased composite or biocomposite”. This fibre-reinforced material can be partly or entirely made out of biobased materials. The fibers and matrix can have a natural origin based on renewable resources (Verlinde, 2017).

Biocomposites have the same advantages as non-biobased composites (like glass fibre or carbon fibre based) but made from sustainable, infinite (if professionally manage) natural resources and manufactured with low energy demand.

Fibers

Fibres can be divided into four categories: (1) Inorganic fibres (like glass and carbon), (2) Synthetic fibers (polymers), (3) metal fibres, an (4) natural fibres. Some examples of natural (biobased) fibres are hemp, flax, wood fiber, kenaf, etc. Biobased fiber can be classified accordingly to its origin from plants, animals, or minerals. Some of the critical components of the fibers are the percentage of cellulose, hemicellulose, and lignin

The mixture of a fiber with a matrix (adhesive) results in a configuration that combines the advantages of both materials. Typically, biocomposite use as matrix resins. To some extent, there are some “commercially available” biobased resins with up to a maximum of 75% of biobased content. The matrix used in RC Panels is polyester resins, but there are many conventional matrices such as epoxies, phenol-formaldehyde and polyurethane-based. All these bonding materials are also called polymers and they are divided in: thermoplastics and thermosets.

Thermoplastics are moldable when they are heated to a specific temperature. They can turn solid when cooled down, therefore demoldable. However, they have relatively low strength. Examples include nylon polyethene, polypropylene, polystyrene, polyvinyl chloride, and Teflon. Thermosets have higher strength, longer life span and resist high temperatures. After curing, the material will not behave as thermoplastics. When heated up to a specific temperature, the material becomes permanently solid, making it a not recyclable option.

As for concepts 1 and concept 3 a composite is selected as material to be used, and the idea is to make biobased, only natural fiber are researched. There are multiple types of natural fiber such as plant based, leaf based, fruit based, and animal based. Not all are available in the market and some of them are in pre-research. One of the companies selling these types of products in the Netherlands is SCABRO. In their website multiple fabrics made from natural fiber can be found.

Hemp fiber
(Textile gence,retriverred on july 2021)

Hemp fibres

In the Netherlands, hemp production takes place mainly in the province of Groningen with almost a 70% of the Dutch hemp market. In 2019, the country produced and exported 31,768 MT of hemp seeds (with an approximate value of $53.7 million dollars). There are two main processing facilities one is HempFlax and the other Dun Agro, both areas are located in the village of Oude Pekela in Groningen (M.Selten and C. Riker Report, 2020).

Flax fiber
(Textilespehre, retriverred on july 2021)

Flax fibres

Flax cultivation in The Netherlands, Belgium and France dominates the flax seed market in the world. An approximate of 75,000 hectares are located in these 3 countries. The Netherlands is considered to make up higher-yielding varieties of flax than in the other two (Hoeven, 2013). There are a few companies producing the fiber in the country such as “Van de Bilt zanden en vlas BV” and “Hemp flax”.

Wood fiber
(Miller waste mills, retriverred on july 2021)

Wood fibres

Wood fibre comes from wood chips which at the same time come form natural trunk of wood. Wood chips become wood fibre throught high mechanical pressure with high temperature (RHP, no date). It is estimated that The Netherlands only locally produces about 8% of its wood fiber demand. The Dutch imports more than 95% of its wood related products. Most of these products come from Scandinavian countries like Sweden, Finland, or from Russia. The Dutch government intends bring up the local production from 8% at least 25% in wood fiber by 2025. To do so, approximately 3.9 million m3 would need to be produced each year

Kenaf fiber
(Miller waste mills, retriverred on july 2021)

Kenaf fibres

It is a relatively new fiber with a grow market in USA. Some authors refer as a comparable to conventional fiber composites and promising solution for biobased composites (Akil et al., 2011). The plant comes mainly from countries in Asia and Africa (Verlinde, 2017).

Matrix

Polymers are divided into thermoplastics and thermosets. Since concepts 1 and 3 are using composites materials and the intent is to use a biobased composite. Ideally, the matrix should also be 100% biobased. However, most of the bio polymers available in the market are partially biobased. Some of them go up to 75% of biobased content.

Thermosets can have different advantages and disadvantages when compared with thermoplastics. The basic and main difference is the former gains its strength when heated, and it cannot come back to its original form after cooling. On the other hand, thermoplastics can be re-shaped and heated without damaging the integrity of the material and without any chemical change.

Depending on their source, thermoplastics can be divided into biobased or synthetic. Some examples of synthetic thermoset polymers are epoxies, polyesters, Phenol formaldehyde and Polyurethane. Some advantages of these materials are their low manufacturing cost, less energy requirement, and ease of mix with fibres (no voids creation). However, some of the disadvantages are their long curing time (low production) and their difficulty to recycle.

Biobased thermoset comes mainly from plant oils; they can be produced from different plant species and some vegetable's oils. Examples like soy or cashews can be mentioned. Another example of biobased thermosets is Polyfurfuryl alcohol coming from the sugar in the hemicellulose from biomass. These materials are known to have high chemical resistance and fire retardance. Since there are not 100% biobased thermosets, one extra category can be set as "Synthetic biobased" thermosets, where a mix of these two types of polymers is created.

As one of the design parameters for the new RC Panel is the use of renewables and the aim is to replace the GFP with a biocomposite, it would not be logical to use a thermoset or a 100% thermoplastic. However, Biobased thermoplastics are not yet available in the market and further research needs to be carried to their usage in these types of applications. Therefore, in the present research, thermosets mixing synthetic and biobased chemicals are presented. The matrix selection was also based on data availability for their response when combined with the fibres mentioned in the previous chapter.

Biocomposite selections

The selection of the biocomposite depended on the availability of data for the properties of the mix between fibers and matrix. Since the intent is to use natural fibre and a bio-synthetic resin, different papers and studies were reviewed were coupon testing, fire resistance, and/or weather deterioration of these type of materials together.

Magdalena Węgrzyn and others analyzed biocomposite using hemp fibres and a matrix of a polyethene polymer coming from sugar canes modified with phosphonium. These combinations are commonly known as biopolyethylenes (BioPE). They analyzed the mechanical properties and thermal behaviour in air atmosphere. Samples with and without phosphonium liquid was tested for tensile strength, impact strength, hardness, degradation, and thermal stability. The samples modified improved all the strengths, but their young modulus decreased compared with the non-modified samples. Also, the samples with phosphonium shown better degradation behaviour and better thermal stability. The study does not provide information regarding the durability (Węgrzyn et al., 2021).

Merjin Verlinde tested multiple samples of a 2 mm biocomposite made from 10 layers of flax fibre (natural fiber) and a biobased-epoxy matrix. Together with the flax and the matrix the samples had a 64% of biobased content. In her thesis, the samples were tested for durability and tensile modulus and strength. The tests' goal was to indicate the estimated lifetime of the material and the behavior of biobased composite in different environments. This biocomposite arrangement was tested by

SKG-IKOB, the same company that did the durability report of RC Panels. In this case, a set of 18 samples were tested with different configuration to a set of weather loads. One set of the samples was left without any weather deterioration, and others were induced to climate cycles. The results interpretations are that for a life span of 50 years, the composite needed to have a 13% increase in the bending stiffness (Verlinde, 2017)

Ferran Serra-Parareda and others tested multiple fibres such as abaca strands, spruce fibres, recycled fibers, and barley fibres combined with a biobased polyethylene (BioPE). The reviewed deformations and stiffness under specific loads to obtain Young's modulus of such combinations. They compared their results to conventional composites like carbon and glass fiber. The recycled and barley fibers showed the lower Young modulus, while the Abaca strands and spruce accounted for the highest. Also, the deformations of biocomposites were compared with the glass fibre (GF). They did not show significantly different, though it's remarked that GF provided lower strains than natural fibers (Serra-Parareda et al., 2021). The study does not provide information regarding durability (Węgrzyn et al., 2021).

Materials	*Facesheet*	*Facesheet*	*Facesheet*	*Facesheet*	*Facesheet*
Unit of measure	kg	Kg	Kg	Kg	Kg
Material name	Carbon fiber composite	Biocomposite Hemp fiber and BioPE	Composite: flax + bioepoxy	Biocomposite Spruce fiber and PLA	Biocomposite Kenaf and BioPE
Biodegradable (Y/N)	N	N	Patially	Partially	N
*Embodied carbon - **Production** (kg CO2-eq/Unit)*	5.7	0.76	0.9	-	0.98
Primary Recycling (y/n)	N	N	N	N	N
Density (kg/m3)	1600.00	1350.00	1185.00	1320.00	-
Young Modulus E_x (Pa)	7.00E+10	6.78E+08	1.69E+07	8.00E+06	-
Young Modulus E_y (Pa)	7.00E+10	2.10E+08	5.24E+06	2.50E+06	-
Shear Modulus E_xy (Pa)	1.00E+09	1.039E+08	2.487E+06	-	-
Shear Strenght (Pa)	9.00E+07	-	3.691E+07	-	-
Tensile Strenght Xt (Pa)	6.00E+08	2.30E+07	2.23E+09	5.25E+07	2.80E+07
Compresion Strenght Xc (Pa)	5.70E+08	2.19E+07	2.11E+09	4.99E+07	2.66E+07
Tensile Strenght Yt (Pa)	6.00E+08	2.30E+07	2.23E+09	5.25E+07	2.80E+07
Compresion Strenght Yc (Pa)	5.70E+08	2.19E+07	2.11E+09	4.99E+07	2.66E+07

Table 2 Material Matrix for Facesheets alternatives

Cores

In a composite structure used in a facade, the core plays and important role since its the main thermal component. Depending on the raw materials and manufacturing, insulating materials will have properties that sometimes are not comparable, meaning that a direct comparison might not always be applicable.

When minimizing an envelope's heat fluxes, a low thermal conductivity is undoubtedly the most crucial property of any insulating material. However, different criteria can also be critical when choosing the correct product. These criteria will depend highly on the application, which in this case if for retrofitting envelope strategies. An insulating material assessment should consider the material's behavior when exposed to heat, water, moisture, mechanical, and ecological and environmental impacts. The characteristics can be narrowed to density, thermal conductivity, specific heat capacity, vapor diffusion resistance, constant compressive strength, tensile strength, dynamic stiffness, fire reaction, and embodied carbon and energy (Pfundstein et al., 2008).

Another essential aspect when selecting insulating materials is the forms of supply. Typically, when a material is already commercialized, different market shares will take place. A form of supply classification for organic and inorganic insulation materials can be set as boards, rolls (batts), in situ foams, loose-fill, caulking material, sandwich, and panels.

Conventionally, the classification of insulating materials is mainly done depending on their raw materials. Two classifications can be distinguished as inorganic (mineral) and organic origin of the raw materials. The materials in these two groups are subdivided into natural and synthetic, and this sub-classification depends highly on the processing of the original raw materials. In natural products, the materials are kept unchanged from the primary origin source. In case the mineralogical composition of the raw material is changed due to specific processing techniques, the materials are referred to as synthetic products. (Pfundstein et al., 2008).

Recent researchers have categorized insulation materials into (1) conventional (organic and inorganic) materials which are available and are currently used in buildings, (2) state of the art materials which are insulation products in research and development with limited commercial availability, and (3) Sustainable insulation materials which are material with the lowest impact during the production stage amongst the three insulation types (Kumar et al., 2020).

As part of the feedback from RC Panels during the research development, its known that the company wants to promote a biobased panel with a biobased core. For this reason, the alternatives considered for the analysis are only biobased products with the possibility to have primarily recycling; therefore, they can be categorized as sustainable insulation materials.

Given the criteria of biobased cores, the selection was made in correlation with a circular economy context. The material selection should allow the return of the materials to either a technical or biological cycle. Also, only materials available in the current market were selected. Three types of cores are presented: Expanded cork, Hemp mycelium board, and Wood fiber. During the research, multiple companies were contacted for gathering information about their products, all with presence in the Dutch Market.

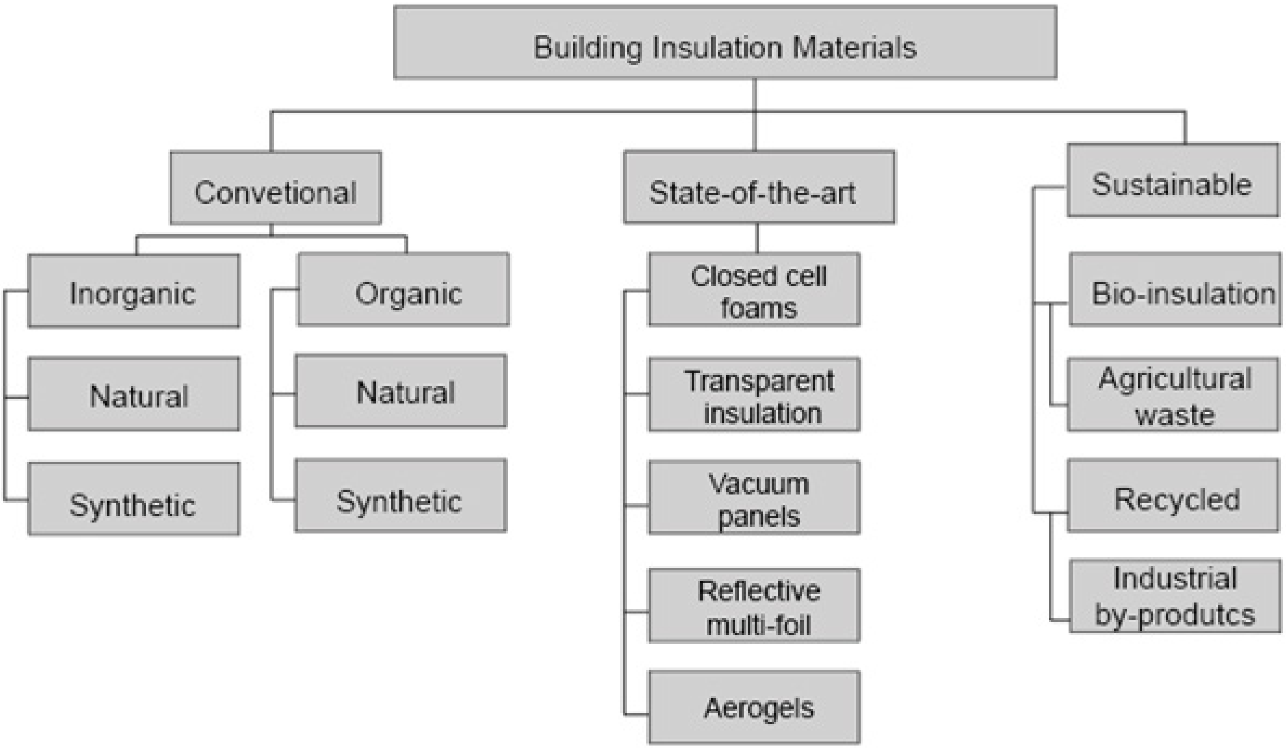


Figure 54 Insulation Materials classification
(Pfundstein et al., 2008; Kumar et al., 2020)

Expanded cork insulating panels
(ARTIMESTIERI, retrivered in july 2021)

Expanded cork

Cork comes from a tree called “cork oak” and is a 100% natural . During the harvest season, the tress are protected and trested correctly to avoid any time of damage. Cork’s secret is in mixing gases, which is similar to the air that fills each cell, and in the percentage of suberin contained in its walls. Suberin is a kind of a natural wax that surrounds every cell’s wall, blocking the air and giving it impermeability (CORKRIBAS, 2020). Portugal is known as the world´s larges cork centre. The country has over 30% of the market share followed by Spain with a 22%. In the present research, different conversation occurred with CORKRIBAS as a manufacturer located in Paio de Oleiros, Portugal.

Mycelium insulation panel

Mycelium composites are a new type of material, taking the attention of multiple authors increasing in research and distribution for construction purposes in Europe and America. This product uses natural fungus cultivation as a renewable and low energy material fabrication alternative. The technique is an “upcycle process” for agricultural waste from industries like straw, flax, and hemp. (Jones et al., 2020). In the Netherlands, a few companies are exploring Mycelium. In the present research, different conversations took place with “Grow Bio” as a manufactured of hemp-mycelium panels located in Heerewaarden in the Province of Gelderland

Hemp fiber mycelium panels
(Flagel J, 2020)

Wood fibres

Wood fiber insulation panels are fabricated out of the waste coming from the manufacturing of wood products. Through a thermal-mechanical manipulation the pieces of wood are shredded into fiber. The boards are dried, trimmed, profiled and stacked for final distribution. Typically its production is of 25 mm, therefore for thicker boards the process requires gluing multi-layered with a natural white casein glue. The Netherlands has a large market presence of wood fiber panel mainly coming from Germany. In the present research different conversations took place with “Gutex” as a manufactured multiple types of wood fiber panel, especially important for this research the high-density panels ranging from 120 – 180 kg/m3.

Wood fiber insulating panels
(Gutex , retrivered in july 2021)

PLA Foam

Polylactic Acid Foams

Polylactic acid foams (PLA) are a well-known and commercial “bio-based plastic”, they offer similar characteristics to EPS and XPS. These types of materials have multiple applications in different industries like packaging, delivery, and construction. In contrast with EPS, PLA foams come from renewable raw materials like corn starch, sugarcane, or tapioca roots. Also, this material offers different EoL treatments like recycling and biodegradability (Morão and de Bie, 2019). As well as the previous cores, the EoL options of this material can contribute to enhance circularity through a correct returning of materials to a technical or biological cycle. biological cycle.

Materials	*Core*	*Core*	*Core*	*Core*
Unit of measure	m3	m3	m3	m3
Material name	Cork panels Corkribas	Mycelium Grow bio	Wood fiber Gutex	PLA Foams
Biodegradable (Y/N)	Y	Y	Y	Y
Embodied carbon - ***Production*** *(kg CO2-eq/Unit)*	75.9	172.25	107	534.45
Carbon Capture and Storage (kg CO2/Unit)	272	397.5	392.69	393
Primary Recycling (y/n)	Y	Y	Y	Y
Reaction to fire (A-E)	E	A	E	E
Thermal conductivity W/(m·K)	0.037	0.04	0.042	0.049
Density (kg/m3)	130	132.5	140	214.5
Young Modulus E_x (Pa)	1.04E+07	1.70E+06	6.00E+05	1.28E+09
Young Modulus E_y (Pa)	9.20E+06	1.28E+06	6.00E+05	1.28E+09
Shear Modulus E_xy (Pa)	1.90E+07	5.39E+06	3.30E+06	1.29E+09
Shear Strenght (Pa)	9.00E+05	3.26E+06	5.40E+04	-
Tensile Strenght Xt (Pa)	1.00E+06	5.00E+09	3.00E+04	4.68E+07
Compresion Strenght Xc (Pa)	7.00E+05	4.60E+04	1.50E+05	1.79E+07
Tensile Strenght Yt (Pa)	5.00E+05	5.00E+09	2.25E+04	4.68E+07
Compresion Strenght Yc (Pa)	6.00E+05	4.60E+04	1.13E+05	1.79E+07

Table 3 Material Matrix for cores alternatives

Sheathing boards

Sheathing boards are a well know product. Typically they are used in wall systems providing a screwing or nailing solid base and sometimes serve as a layer of protection against external conditions. Wall sheathing can be either structural or non-structural. In standard frame systems, structural sheathing ties studs together, avoiding twisting and bending deformation in the walls. Most of these boards lack insulation properties. They have a low contribution to the R-value of a façade. During the present research, several market available sheathing boards were found. The classification of sheathing boards can be summarized in (1) wood-based, (2) Gypsum based, (3) Glass mats, and (4) Cement boards.

Wood-based Boards includes plywood, oriented strand board (OSB), chipboard, and Medium fiber board (MDF). They all rely in the use of biobased materials mixed with a binder that combines the properties of both constituents, similarly as a composite.

Gypsum based boards are a non-combustible product made mainly out of gypsum with a paper layer on the exterior surface (also commonly known as drywall). One of the disadvantages of this product is that gypsum retains moisture and is suggested not be used in exterior systems or wet interior areas. Glass mats are like gypsum-based boards; however, they use fibreglass instead of paper on the exterior faces.

The cement-based board use Portland cement combined with a glass fibre mesh. They are noncombustible and provide a solid base for finishing or claddings. A disadvantage of this board is the cement, this product has high environmental impacts and is known to be one of the highest contributors of the construction industry CO2 emissions.

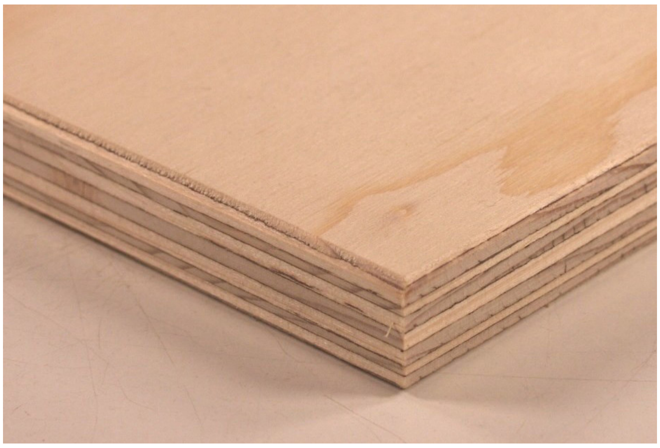
For the selection of the boards, only wood-based panels were considered. The LCA performed by TU Ghent suggested the deletion of the current OSB used in the panel. However, as mentioned before, the OSB works as a backbone. For this reason, alternatives for the OSB explore, ideally a material with a lower environmental impact but also lighter, with a higher modulus of elasticity and higher strength.

The selected materials were Plywood, Medium fibre board (MDF) and Chipboard. All these manufactured by companies with a presence in the Netherlands. Metsawood has all the previously mentioned products in their catalogue, mainly coming from Scandinavian countries. Companies like Smartply and Stora Enso distribute MDF

Materials	*Board*	*Board*	*Board*
Unit of measure	m3	m3	m3
Material name	MDF	Plywood	Chipboard
Biodegradable (Y/N)	N	N	N
*Embodied carbon - **Production** (kg CO2-eq/Unit)*	396.76	756	798.93
Primary Recycling (y/n)	-	-	Y
Reaction to fire (A-E)	B	E1	B
Thermal conductivity W/(m·K)	0.14	0.12	0.14
Density (kg/m3)	540 - 600	400 - 600	620-740
Young Modulus E_x (Pa)	2.800E+06	8.615E+09	1.190E+08
Young Modulus E_y (Pa)	2.800E+06	3.385E+09	1.190E+08
Shear Modulus E_xy (Pa)	-	3.500E+06	2.896E+05
Shear Strenght (Pa)	-	2.070E+06	-
Tensile Strenght Xt (Pa)	5.50E+05	1.18E+07	1.78E+06
Compresion Strenght Xc (Pa)	-	1.97E+07	1.97E+06
Tensile Strenght Yt (Pa)	5.50E+05	6.20E+06	1.78E+06
Compresion Strenght Yc (Pa)	-	1.03E+07	1.97E+06

Table 4 Material Matrix for sheathing boards alternatives

MDF board
(PERI, retrivered on july 2021)



Plywood board
(PERI, retrivered on july 2021)

Chipboard
(Unilingpanels, retrivered on july 2021)

Medium Fiber Board (MDF)

MDF wood-based panel manufactured by shredding softwood into wood fibers. The fibers are combined with a mix of wax and synthetic resins like urea-formaldehyde. The mix forms panels which are subjected to high temperature and pressure. Some manufacturers might add certain additives for specific additional requirements such as moisture control or fire safety. Some authors mention that MDF can be made out of multiple other woods, examples like: recycled paper, carbon fibers and polymers, steel, or glass (G.Kowaluk, 2012).

Plywood

Plywood is manufactured out of complete wood sheets that are cross-laminated. This technique is what gives the boards their characteristic strength and stiffness. Helping to reduce deformations, expansions, and contractions. It´s considered to be up to 20% lighter than OSB. Also, has good moisture resistance and when installed correctly, can be dried quickly. Some of the wood species used in The Netherlands for plywood are pine and birchwood, mainly from Finland.

Chipboard

Chipboard is known to be a non-structural sheathing board. However, Metsawood offers a structural grade chipboard in their catalog. It offers different formats like OSB of 2400×600 mm with thickness of 18 and 22 mm. They are typically manufactured from recovered wood with a 90% post-consumer (Recycled wood) and a 10% from waste flows from manufacturing processes.

Claddings

It is known that in The Netherlands, typically, clients, architects, or investors have a strong preference for stone-like materials such as concrete or brick. Also, a robust system is even sometimes preferred over “low-budget” and non-real materials. The great preference for these intricately links to the availability of raw materials and the type of architecture around the country. End-clients will always be sensitive to this type of subjective/aesthetic impressions.

Now, the cladding system of the RC Panel is made of mineral brick slips that mimic actual clay brick. The present research design involves the application of a circular economy, and this material does not entirely fit since some of the resources are non-renewable and difficult to separate and hence reuse or recycle.

One of the biggest challenges that can be foreseen for RC Panels when dealing with large scale dwellings interventions is the materiality and impression of its cladding system. When architecture firms get involved and the preference for different materiality is desired, the panel´s integrity can be compromised. As mentioned in the literature review, what brings the panel´s longevity is applying this cladding. Therefore, the present research brings the idea of comparing, for each concept design, a rear ventilated façade with the current system.

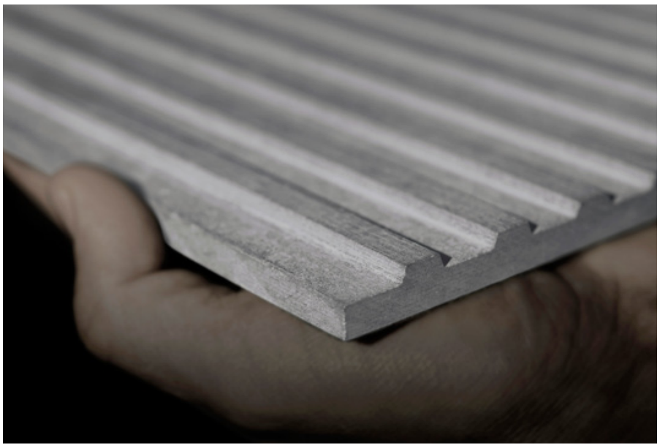
As seen in the LCA performed by TU Ghent, only 11% of the environmental impacts come from the cladding. Using a rear ventilated façade is likely to have higher impacts at the beginning, since more material will be used. However, when the system gets a post used after the EoL of a retrofitted home, the 11% will likely be lost due to the impossibility of separating and a rear ventilated façade would be easily disassembled and reuse.

Three new cladding system are presented, all in the integration of a rear ventilated façade with different designs trying to integrate a stone-like finish. The systems are (1) Pretty plastic, (2) Mechslip and (3) Equitone. All with market presence in the country.

Mechislip - Real thin c lay bricks
(Mechslip, retrivered on july 2021)

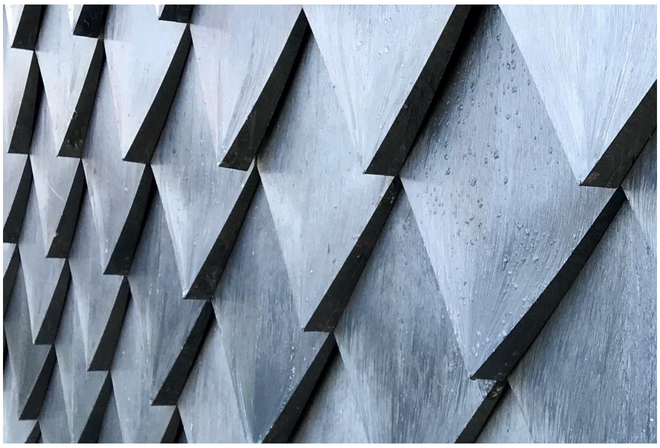
Mechslip - Thin clay brick

Mechslip is real brick with a mechanically fixed system. The bricks are 28mm thick, and are supported by an anodised aluminium support rail. It has an extensive range of colours, textures and brick sizes. The company offer all the shapes needed for enclosure detailing, such as corner bricks, headers, and soldier bricks.


Equitone - Fiber cement
(Equitone, retrivered on july 2021)

Equitone - Fiber cement tiles

Mechslip is real brick with a mechanically fixed system. The bricks are 28mm thick, and are supported by an anodised aluminium support rail. It has an extensive range of colours, textures and brick sizes. The company offer all the shapes needed for enclosure detailing, such as corner bricks, headers, and soldier bricks.


Pretty plastic - Recycled PVC
(Pretty plastic, retrivered on july 2021)

Pretty plastic - Recycled PVC tiles

PPretty plastics is a new company with a presence in The Netherlands. The company up-cycles waste from PVC from the building industry. It has an easy screws-in installation with a frame behind the tiles. A highly circular product where waste does not exist and raw materials are used endless times. A disadvantage of this system is its “only” format, a “diamond shape” of 40cm in height, 30cm in width, and a thickness of 29mm.

Materials	*Cladding*	*Cladding*	*Cladding*
Unit of measure	m2	m2	m2
Material name	Pretty plastic	Mechslip	Equitone Fiber cement
Biodegradable (Y/N)	N	-	-
Real stone material	N	Y	Y
*Embodied carbon - **Production** (kg CO2-eq/Unit)*	Not available	0.453	7.80
Carbon Capture and Storage (kg CO2/Unit)	0	0	0
Primary Recycling (y/n)	Y	Y	N
Reaction to fire (A-E)	Not available	A1	A2
Thermal conductivity W/(m·K)	0.19	0.71	0.6
Density (kg/m3)	827	1500	1230

Design Development

Structural Analysis

A composite material is the mix of 2 or more constituents. 'Composite' means the combinations between fibers and matrix. The building block of composite materials can be defined as a "ply" or "lamina". When laminae are installed on top of each other a laminated plate is then created. Most of the laminae are unidirectional or fabric plies with bidirectional orientations (Kassapoglou, 2013).

The structural design of the present research was done following the classical laminated plate theory (CLPT). In this theory the stresses and deformations are represented by the Hooke's law. The theory uses real material properties obtained by simple coupon tests where properties such as Young's modulus, shear modulus, and Poisson's ratio can be obtained. These material properties are related to the composition and arrangement of a given plate and its deformations at the bottom and top coordinates (referenced from the geometrical center) of each "ply" (Kassapoglou, 2013).

The composite plate model is constructed in a simplistic way, whereby, no account is taken of local stress concentrations due to cutouts due to windows or doors. The deformations in the façade are calculated assuming superposition of the "self-weight" of the panel and the "wind load". Also, the deformations caused by hoisting the panels for their final installation is reviewed and compared.

Panel structures analysed.

TThe materials selection gives the input for the structural analysis. The materials from the previous chapter provide the starting point for this process. In the following pages, the selected materials will be iterated for the three different design concepts. As mentioned before, the mineral brick slips used by RC Panels will be compared with a rear ventilated cladding. This is important to mention because this "change" affects the total weight of the panel, and therefore the deformations and stresses caused by the cladding system.

As one of the main interests for RC Panels is the selection of a biobased core, multiple core options will be integrated in the structural design. The material choice shows that all the cores have different advantages and disadvantages in the framework of insulation. To introduce multiple cores to the structural design, filter the options and check whether one or more will fail or not with the given loading conditions.

The starting thickness of the cores is calculated with the general formula of the thermal resistance (thickness divided by thermal conductivity). The thermal resistance is the same as the Original RC Panel, which is 7 m2/(m.K).

The material selection, for the three design concepts, are the following:

• Facesheets: 3 mm Flax Fiber with bio-epoxy biocomposite membrane.

• Cores: (1) 260 mm Expanded Cork, (2) 345 mm Hemp mycelium board, (3) 294 mm Wood fiber and (4) 345 mm PLA Foam.

• Sheathing boards: 18 mm Birch Plywood

• Claddings: STO Mineral brick slips (current cladding) and Mechslips thin brick (rear ventilated system)

Materials mechanical properties

The mechanical properties assumptions used for this investigation are as follow:

Biocomposite flax and bioepoxy		*Reference*
E_x (MPa)	452	*(Merjin, 2017)*
E_y (MPa)	140	*(Merjin, 2017)*
v_xy	0.45	*(A. Pozzi, 2012)*
G_xy (MPa)	104	*Assumption*
Thickness (m)	0.002	*(Merjin, 2017)*
Density (kg/m3)	1350	

Sheathing *Plywood*		*Reference*
E_x (GPa)	7.18	*Mëtsawood DoP (Retrived: Jul/2021)*
E_y (GPa)	2.82	*Mëtsawood DoP (Retrived: Jul/2021)*
v_xy	0.30	*Akgul ét al (2014)*
G_xy (GPa)	2.30	*Mëtsawood DoP (Retrived: Jul/2021)*
Thickness (m)	0.018	*Mëtsawood DoP (Retrived: Jul/2021)*
Density (kg/m3)	500.00	*Mëtsawood DoP (Retrived: Jul/2021)*

Cores		
Cork panels		*Reference*
E_x (MPa)	8.32	*(Olieviera et al, 2014)*
E_y (MPa)	7.36	*(Olieviera et al, 2014)*
v_xy	0.30	*(Gómez A et al, 2021)*
G_xy (MPa)	15.20	*CoreCork by Amorim Data sheet (2021)*
Thickness (m)	0.259	*Corkribas (2021)*
Density (kg/m3)	130.00	*Corkribas (2021)*

Cores		
Mycelium		*Reference*
E_x (GPa)	1.36	*Grow bio Data Sheet (2021)*
E_y (GPa)	1.02	*Grow bio Data Sheet (2021)*
v_xy	0.30	*Zhaohui (Joey) Yang (2017)*
G_xy (MPa)	4.31	*(Girometta et al, 2019) and J. Fernandez-Cabo (2012)*
Thickness (m)	0.343	*Grow bio Data Sheet (2021)*
Density (kg/m3)	132.50	*Grow bio Data Sheet (2021)*

Cores		
Wood fiber panels		*Reference*
E_x (MPa)	690.00	*(Rocco Larh et al, 2017)*
E_y (MPa)	690.00	*(Rocco Larh et al, 2017)*
v_xy	0.29	*(D Peralta et al. (2013))*
G_xy (Mpa)	3.30	*Gutex Data Sheet (2021)*
Thickness (m)	0.294	*Gutex Data Sheet (2021)*
Density (kg/m3)	140.00	*Gutex Data Sheet (2021)*

Cores		
PLA Foam		*Reference*
E_x (GPa)	1.28	*(Oluwabunmi, 2020)*
E_y (GPa)	1.28	
v_xy	0.35	
G_xy (GPa)	1.29	
Thickness (m)	0.343	
Density (kg/m3)	214.50	

Loading conditions

Two loading conditions are analyzed for the panels:

- The first condition is considering the panels are installed on the walls, the loads are:

o Wind pressure and suction causing deformations in the entire panel, for this in the CLPT the maximum deformations were considered at the corners and center of the panel.
o The total weight of the panel per m2 directly affecting the deformations and stresses concentrations in the anchorage system.

- The second condition is considering the hoisting in the jobsite:

o The total weight of the panel directly affecting the deformations and stresses concentrations in the preparations for hoisting. For these analyses, the practices used by RC Panels were considered. In the following pages this procedure is explained.

For the first loading condition, the combination of the wind load and the self-weight was done, assuming superposition of the strains and stresses. Two separate models were analyzed with the loads, and then just a summation provides the total local stress at the bottom and top coordinates of each layer.

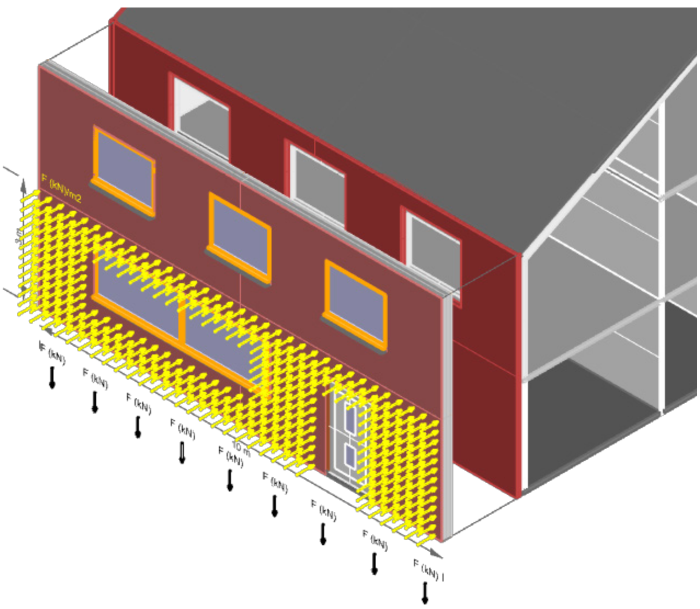


Figure - 1st loading condition

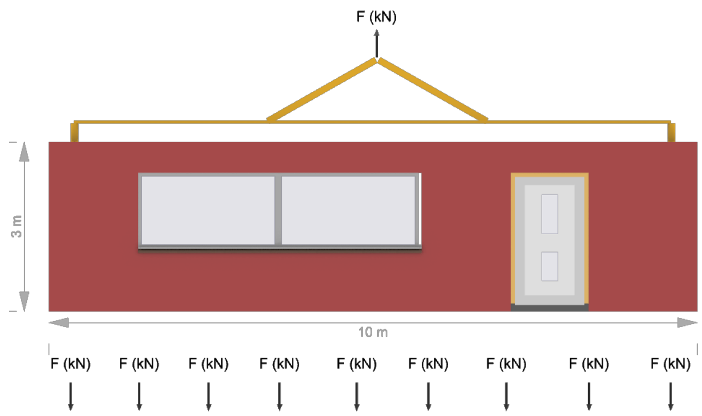
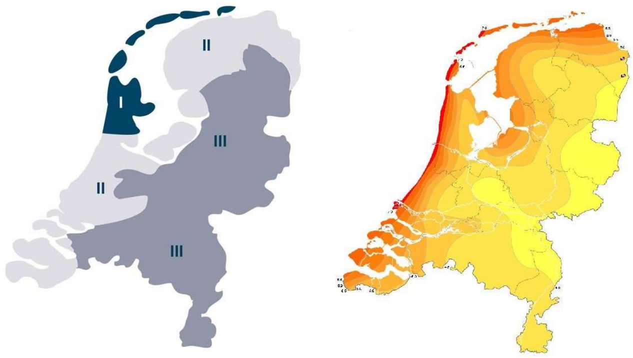


Figure - 2nd loading condition

Wind load

The maximum height for terrace homes is selected as 10 m. Most terraced houses will be below this height. The most critical wind speeds are closer to the coast; therefore the "wind areas" selected are I and II and the "basic wind load" chosen is the most critical between both areas. The value selected for qp,K is 1.02 kN/m2



Basic wind load - $q_{p,K}$ [kN/m2]		
Wind area	**Built**	**Not Built**
I	0.81	1.02
II	0.68	0.85
III	0.56	0.70

The load coefficients for both pressure and suction on facades in terraced houses are divided in the norm "EN1991-1-4:2005+A1". The external pressure coefficients Cpe.10 and Cpe.1 for zone façade zones A, B, C, and E (Figure 37) are defined in Table 6.

Wind suction:
Zone A: over the rst 2m of the panel in a house of 10m deep

Zone B: over the rest of the panel

Wind pressure:
Zone D: for wind pressure

The corresponding pressure coefficient are shown in Table 6:

Zone	A		B		C		D		E	
h/d	$C_{pe}10$	$C_{pe}1$	$C_{pe}10$	$C_{pe}1$	$C_{pe}10$	$C_{pe}1$	$C_{pe}10$	$C_{pe}1$	$C_{pe}10$	$C_{pe}1$
5	-1.2	-1.4	-0.8	-1.1	-0.5		0.8	1	-0.7	
≤ 1	-1.2	-1.4	-0.8	-1.1	-0.5		0.8	1	-0.5	

Table 6 Recommended values of external pressure coefficients for vertical walls of rectangular plan buildings

Wind suction:

Cpe, A = -1.2 (external suction)
Cpe, B = -0.8 (external suction)
Cpi = 0.2 (internal overpressure)

Wind pressure:

Cpe, D = 0.8 (external pressure)
Cpi = 0.3 (internal negative pressure)

This gives the following wind load values:

$q_{w,k}$ = (-1.2-0.2)x1.02= -1.43 kN / m^2 (wind suction zone A)

$q_{w,k}$ = (-0.8-0.2)x1.02= -1.02kN / m^2 (wind suction zone B)

$q_{w,k}$ = (0.8 + 0.3)x1.02= 1.12 kN / m^2 (wind pressure)

For the composite analysis in the CLPT, the value of **1.43 kN/m2** was selected as critical wind load.

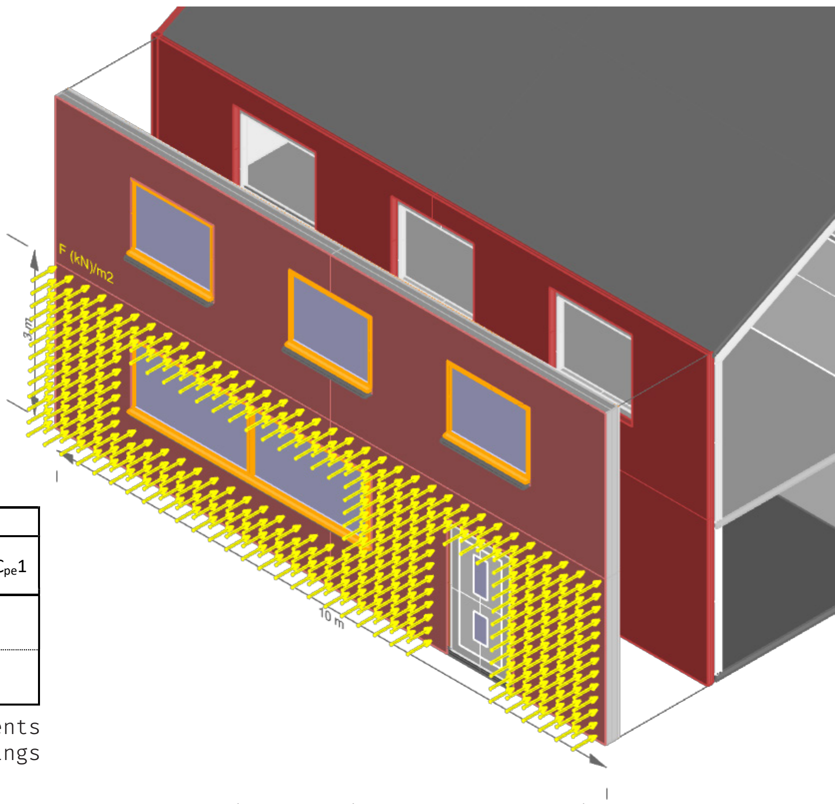


Figure - Wind load configuration

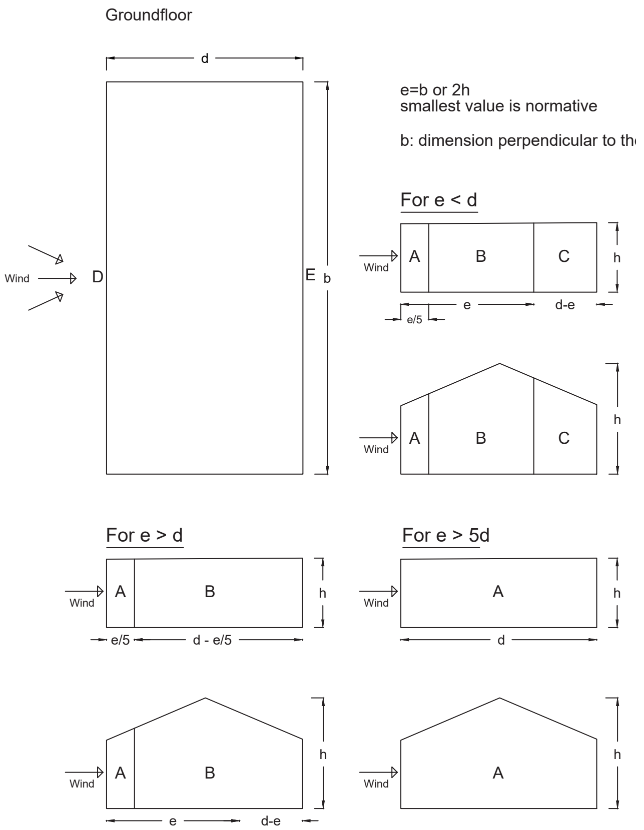


Figure 55 wind load Key for vertical walls

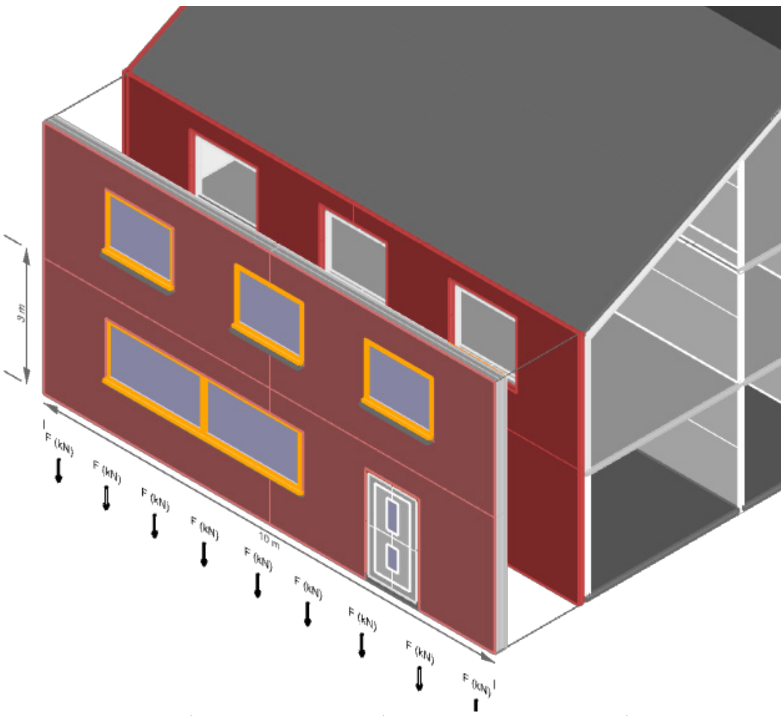


Figure - self-weight load configuration

Permanent loads – Self weight

The calculation of the permanent load is considered as the self-weight of each panel combination. For this, an estimation, the total weight per square meter was calculated for each concept. In total, the CLPT analysis is for 3 concept design, each with 2 cladding systems. Each design system has at least 4 different cores with different mechanical and physical properties. Therefore, in total set of 24 designs are evaluated in this section.

A summary of the initial weights of the panels is presented in Table 7, a detailed description of these values is provided in Appendix C, D and E.

	Concept 1 - Biobased panel	kg/m2
Mineral brick	Cork insulation panels	57.1
	Mycelium insulation board	60.5
	Birch Plywood	64.6
	PLA Foam	97.0
Rear ventilated cladding	Cork insulation panels	111.9
	Mycelium insulation board	115.3
	Birch Plywood	119.4
	PLA Foam	151.8

	Concept 2 - Double board panel	kg/m2
Mineral brick	Cork insulation panels	60.7
	Mycelium insulation board	64.1
	Birch Plywood	68.2
	PLA Foam	100.6
Rear ventilated cladding	Cork insulation panels	98.2
	Mycelium insulation board	101.6
	Birch Plywood	105.6
	PLA Foam	138.1

	Concept 3 - Hybrid/frame panel	kg/m2
Mineral brick	Cork insulation panels	113.7
	Mycelium insulation board	120.6
	Birch Plywood	128.7
	PLA Foam	193.5
Rear ventilated cladding	Cork insulation panels	126.6
	Mycelium insulation board	130.0
	Birch Plywood	134.0
	PLA Foam	166.5

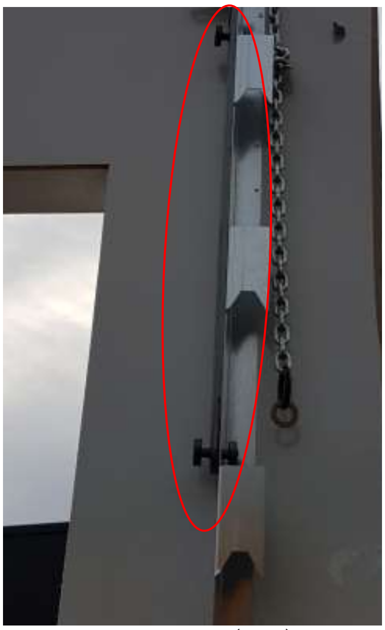
Hoisting for installation.

The facade elements are typically transported on frames on top of flatbeds. A maximum of 2 elements per frame is transported. The hosting preparations per panel affect the loading conditions and therefore the strains and stresses. The location of hoisting points will depend on the assembly sequence on site, the construction speed, and the dimensions of the panels concerning the use of the type of truck. RC Panels mentions that the ideal transport should transport four take panels of 6.2 m long and 3.17m high. However, exceptions can be made to facades with more considerable lengths, such as 10 meters. The maximum length of a flatbed could be set to 15 meters.

For the present investigation, the panels are analyzed with two lifting hooks installed on the edge rails connected on the back of the panels. These hooks can be fitted in a “keyhole” of the anchor rails on the rear of the elements and fitted with a locking pin. Upon arrival at the job site, the facades are disconnected from the truck, and a crane hoists them with a horizontal bar connected to the jib of the crane arm. This allows to lift the panel uniformly in the vertical axes (please refer to Figure 56).

The difference between the loading conditions in the hoisting procedure and the final anchorage system relies on the number of bolts under stress and therefore deforming the panel. When the panels are installed into the final position, all the bolts work together to hold the panel on place. On the other hand, when the panels are hoisted, only the bolts in the rails attached to the “lift hooks” will be deforming the panel. Also, depending on the crane, the speed to which the panels are lifted will affect the acceleration which is likely to be different to the acceleration of gravity. If this acceleration is higher than 9.81 m/s2, the total weight of the panel should be affected by the new acceleration value.

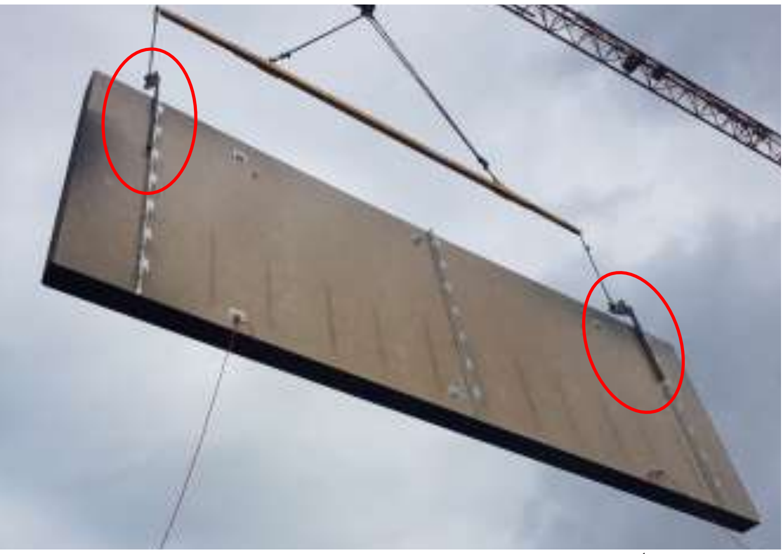
The scenario is with a 10 meters height home, and the panels are expected to be lifted to that maximum height. The crane hoist engine will respond to a specific acceleration depending on how fast the installers want to lift the panels. An average speed value of 0.15 m/s for a 10-ton crane is assumed, with 10-meter height consideration, the panel should reach the desired height in 66 seconds. This time will correspond to an acceleration of 0.0022 m/s2 which is a value below 9.8 m/s2, meaning that the governing acceleration would still be gravity. As 1 minute and 6 seconds was considered an “acceptable time” for the panel to be hoist, no more analysis was done with the acceleration change. Only the deformations on the hoisting points were reviewed.



Figures 56 (top)

Figures 56 (top and bottom) 56 Facade Hoisting

Pictures from RC Panel installation manual



Figures 56 (top and bottom) 56 Facade Hoisting
Pictures from RC Panel installation manual

CLPT Maximum Stress Failure

Regarding Figure 57, Xt denotes tension strength in the x-direction, Xc denotes compression strength in the x direction, Yt and Yc are the corresponding quantities in the y direction. S is the shear strength in the xy plane. For the present analysis, the local stresses at layer coordinate are evaluated with the stren gth.

In the CLPT model, stress is denoted as σ (sigma) for compression or tension, or τ (tau) for shear. A suffix 1 or 2 will denote the local direction of the ply (depending on its orientation), number one will correlate with the "global" X direction and 2 with "global" Y direction of the laminate (Kassapoglou, 2013). If the result of the "σ stress" is negative, it means the ply is under compression, vice versa, if the "σ stress" result is positive it means the ply is under tension.

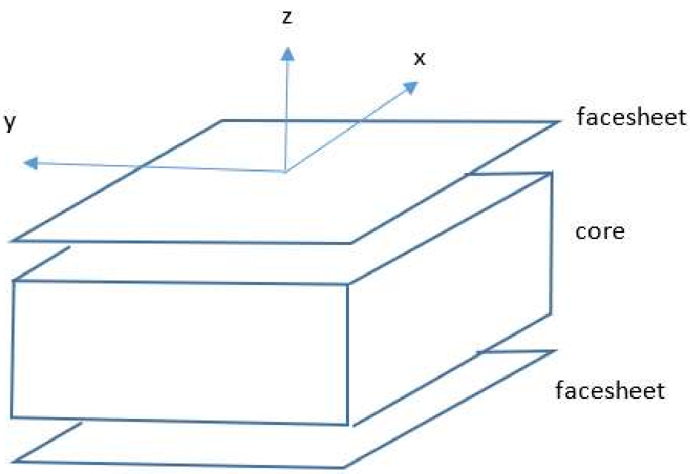


Figure 57 Composite structure orientation

As in any design, the effect of failure should be included in the strength values, the theory related them as "reduced strength" also known as "design values" (Kassapoglou, 2013). These maximum stress failures are related with the materials factors. The relation stress vs strength can be expressed as: Important mentiones is that the shear

$$\sigma_1 < X^t \text{ or } X^c \text{ depending on whether } \sigma_1 \text{ is positive or negative}$$

$$\sigma_2 < Y^t \text{ or } Y^c \text{ depending on whether } \sigma_2 \text{ is positive or negative}$$

$$|\tau_{12}| < S$$

result stress is "absolute" because the magnitude is related to the maximum design shear strength. If the stress is lower than the strenght, there is no failure.

The following values are assumed as materials factors for compressive strength, tensile strength, and shear strength. Also, for the modelling of the strains, these values were assumed for the Young and Shear Modulus.

Sheathing boards γ_m=1.20

Biocomposites: γ_m=1.62 when vacuum injection laminate

Cores: γ_m=1.50 (assumption, not available data for cores reduction factors)

Fixing conditions

RC Panels uses multiple anchorage systems. The selection of such depends on the existing conditions of the dwelling in question. Multiple criteria can affect the location of such elements, examples like the windows arrangement, doors, gutters, ease of access, etc. RC Panels currently uses three types of systems: horizontal rails, vertical rails, and point anchors. These are used in the current Dutch Market, and they can differ from location to location.

The elements are typically supported at the foundation, 1st floor, and roof level. Also, the elements can be provided with vertical or horizontal rails at closer distances, depending on the existing architectural concept. Usually, all the anchors work in pairs, a counter-rail is delivered in parts per story height, the systems work like a puzzle piece, the rails on the panel will be linked with the rails on the wall.

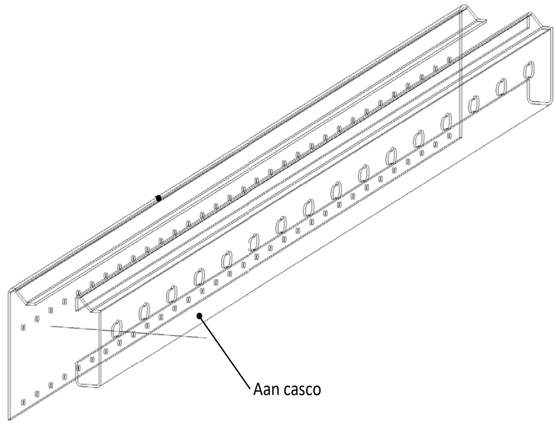


Figure 58 Horizontal Rails

Rails

The rails consist in a pair of galvanized steel elements. As mentioned before, one attached to the existing wall, and another attached to the back of the new panel.

The rails on the panel are attached at a distance between 20 and 400 mm with a 5×35 mm screws (Figure 58 and Figure 59). Each screw goes through the face-sheet membrane on the back and the wood board. This means that the screws need to be sealed after the rails are in position.

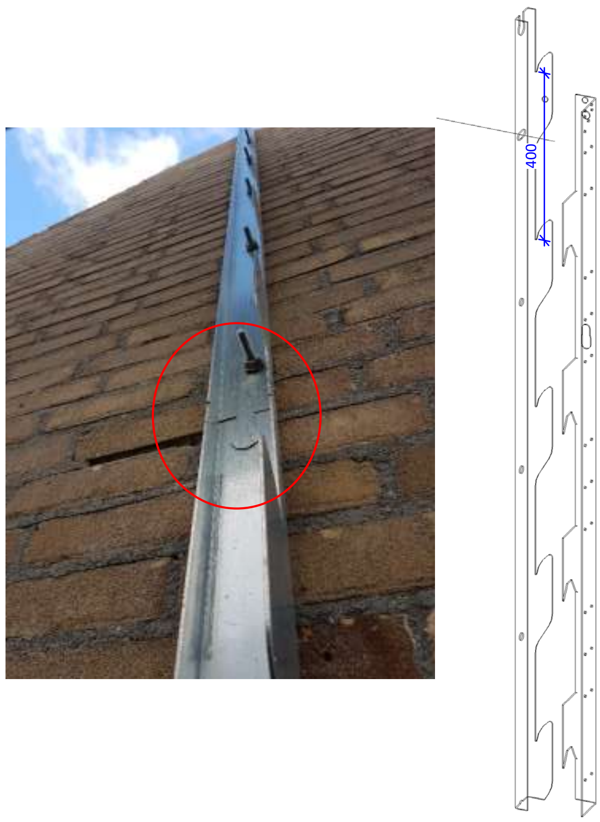


Figure 59 Vertical rails

The maximum cavity between the existing wall and the back of the new façade can me max 20 mm. This will make the panel flushed with the rail grooves matching on both rails. The rails on the exiting walls are provided with Hilti chemical anchors 100mm above the floor depending on the existing hull (Figure 60).

Anchors

Anchors (Figure 61), also referred by the company as “wind anchor” (Burg Anker), are used when the design has high horizontal loads (wind pull or push). They are installed on medium-high buildings where the wind loads are higher and therefore the anchors are design for such conditions. They are provided with a set of 25 screws of 5×35 mm each. Normally, they are installed at the corners and at closes intervals in between. Also, they are installed with a horizontal rail on the bottom and the anchors starts from the first-floor level, from there the panels are stacked on top of each other (Figure 62)

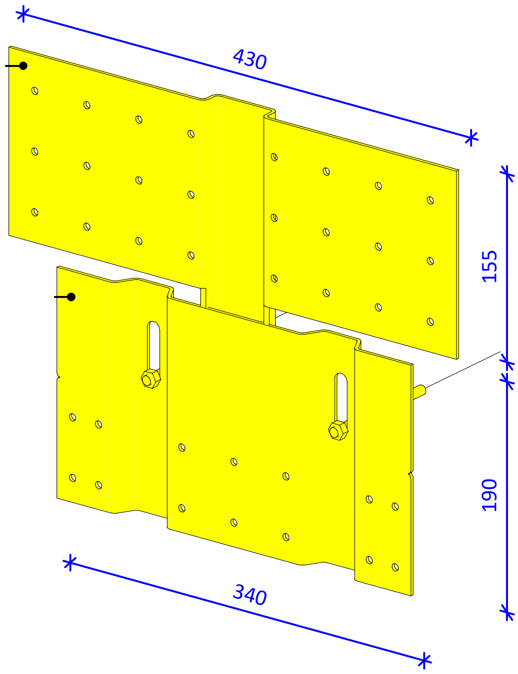


Figure 61 Wind anchors

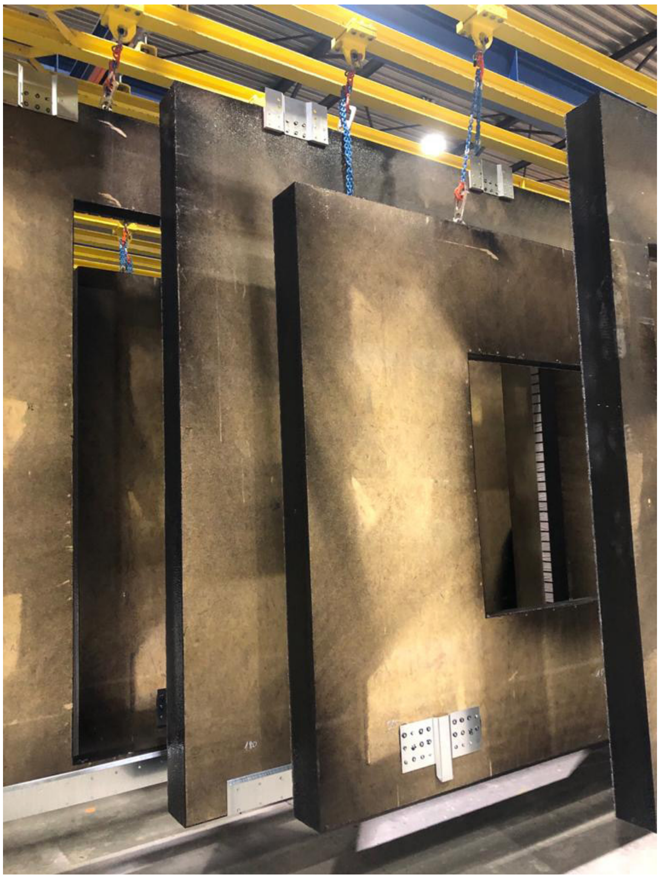


Figure 62 Wind anchors with bottom horizontal rail

For the CLPT the selection of the fixing condition was selected with vertical rails since they could represent a more critical scenario where fewer screws are involved. The vertical rails were set in 3 positions, two at the edge and one in the centre. The diameter of the screws is 35 mm, and the distances selected was 200 mm between each other. Multiple integrations of the fixing system can be evaluated, and further research can be done to make the anchorage more efficient with the CPLT model created in this research.

On the next page, a summary of the 24 designs is presented. Each chart provides the material layer, thickness, and weight per m2. The correct way to read the charts is from left to right. The three concepts are labelled of the far left, then the cladding systems change vertically and the cores horizontally. As mentioned before, for each concept, two cladding systems are analyzed and four insulation cores. For further reference in the stress on each coordinate of the layers, please refer to appendices A and B.

Insulation materials

Cladding system

Concept 1
Biobased sandwich panel

	Panel Structure	Concept 1 - Biobased panel *Cladding: Rendering mortar* Thickness (mm)	Density (kg/m3)	Weight/m2
Inside				
	Composite: flax + bioepoxy	2	1,350	2.70
	Birch Plywood	18	500	9.00
	Cork insulation panels	253	130	32.89
	Composite: flax + bioepoxy	2	1,350	2.70
Outside	Mineral brick slip	6	1,800	9.00
	6.99		Total	56.29

	Panel Structure	Concept 1 - Biobased panel *Cladding: Rendering mortar* Thickness (mm)	Density (kg/m3)	Weight/m2
Inside				
	Composite: flax + bioepoxy	2	1,350	2.70
	Birch Plywood	18	500	9.00
	Mycelium insulation board	274	133	36.31
	Composite: flax + bioepoxy	2	1,350	2.70
Outside	Mineral brick slip	6	1,800	9.00
	7.00		Total	59.71

	Panel Structure	Concept 1 - Biobased panel *Cladding: Rear ventilated facade* Thickness (mm)	Density (kg/m3)	Weight/m2
Inside				
	Composite: flax + bioepoxy	2	1,350	2.70
	Birch Plywood	18	500	9.00
	Cork insulation panels	253	130	32.89
	Composite: flax + bioepoxy	2	1,350	2.70
	Sawn wood studs	n.a	350	17.35
	Alumnimun stud	n.a	2,700	4.48
Outside	Mechslip think brick cladding	n.a	n.a	42.00
			Total	111.12

	Panel Structure	Concept 1 - Biobased panel *Cladding: Rear ventilated facade* Thickness (mm)	Density (kg/m3)	Weight/m2
Inside				
	Composite: flax + bioepoxy	2	1,350	2.70
	Birch Plywood	18	500	9.00
	Mycelium insulation board	274	133	36.31
	Composite: flax + bioepoxy	2	1,350	2.70
	Sawn wood studs	n.a	350	17.35
	Alumnimun stud	n.a	2,700	4.48
Outside	Mineral brick slip	n.a	n.a	42.00
			Total	114.54

Insulation materials

Cladding system

Concept 2
Double board panel

	Panel Structure	Concept 2 - Double board panel *Cladding: Rendering mortar* Thickness (mm)	Density (kg/m3)	Weight/m2
Inside				
	Birch Plywood	18	500	9.00
	Cork insulation panels	248	130	32.24
	Birch Plywood	18	500	9.00
Outside	Mineral brick slip	6	1,800	9.00
			Total	59.24

	Panel Structure	Concept 2 - Double board panel *Cladding: Rendering mortar* Thickness (mm)	Density (kg/m3)	Weight/m2
Inside				
	Birch Plywood	18	500	9.00
	Mycelium insulation board	268	133	35.51
	Birch Plywood	18	500	9.00
Outside	Mineral brick slip	6	1,800	9.00
			Total	62.51

	Panel Structure	Concept 2 - Double board panel *Cladding: Rear ventilated facade* Thickness (mm)	Density (kg/m3)	Weight/m2
Inside				
	Birch Plywood	18	500	9.00
	Cork insulation panels	248	130	32.24
	Birch Plywood	18	500	9.00
	Alumnimun stud	n.a	2,700	4.48
Outside	Mechslip think brick cladding	n.a	n.a	42.00
			Total	96.72

	Panel Structure	Concept 2 - Double board panel *Cladding: Rear ventilated facade* Thickness (mm)	Density (kg/m3)	Weight/m2
Inside				
	Birch Plywood	18	500	9.00
	Mycelium insulation board	268	133	35.51
	Birch Plywood	18	500	9.00
	Alumnimun stud	n.a	2,700	4.48
Outside	Mineral brick slip	n.a	n.a	42.00
			Total	99.99

Insulation materials

Cladding system

Concept 3
Hybrid frame/sandwich panel

	Panel Structure	Concept 3 - Hybrid/frame panel *Cladding: Rendering mortar* Thickness (mm)	Density (kg/m3)	Weight/m2
Inside				
	Birch Plywood	18	500	9.00
	Sawn wood studs	n.a	350	17.35
	Cork insulation panels	254	130	33.02
	Sawn wood studs	n.a	350	17.35
	Composite: flax + bioepoxy	2	1,350	2.70
Outside	Mineral brick slip	6	1,800	9.00
			Total	88.42

	Panel Structure	Concept 3 - Hybrid/frame panel *Cladding: Rendering mortar* Thickness (mm)	Density (kg/m3)	Weight/m2
Inside				
	Birch Plywood	18	500	9.00
	Sawn wood studs	n.a	350	17.35
	Mycelium insulation board	274	133	36.31
	Sawn wood studs	n.a	350	17.35
	Composite: flax + bioepoxy	2	1,350	2.70
Outside	Mineral brick slip	6	1,800	9.00
			Total	91.71

	Panel Structure	Concept 3 - Hybrid/frame panel *Cladding: Rendering mortar* Thickness (mm)	Density (kg/m3)	Weight/m2
Inside				
	Birch Plywood	18	500	9.00
	Sawn wood studs	n.a	350	17.35
	Cork insulation panels	254	130	33.02
	Sawn wood studs	n.a	350	17.35
	Composite: flax + bioepoxy	2	1,350	2.70
	Alumnimun stud	n.a	2,700	4.48
Outside	Mechslip think brick cladding	n.a	n.a	42.00
			Total	125.90

	Panel Structure	Concept 3 - Hybrid/frame panel *Cladding: Rendering mortar* Thickness (mm)	Density (kg/m3)	Weight/m2
Inside				
	Birch Plywood	18	500	9.00
	Sawn wood studs	n.a	350	17.35
	Mycelium insulation board	274	133	36.31
	Sawn wood studs	n.a	350	17.35
	Composite: flax + bioepoxy	2	1,350	2.70
	Alumnimun stud	n.a	2,700	4.48
Outside	Mechslip think brick cladding	n.a	n.a	42.00
			Total	129.19

Figure 63 Summary of structural design iterations

Insulation materials

Cladding system

Concept 1
Biobased sandwich panel

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
	Concept 1 - Biobased panel *Cladding: Rendering mortar*			
Inside	*Composite: flax + bioepoxy*	2	1,350	2.70
	Birch Plywood	18	500	9.00
	Wood fiber panels	288	140	40.32
	Composite: flax + bioepoxy	2	1,350	2.70
Outside	*Mineral brick slip*	6	1,800	9.00
			Total	63.72

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
	Concept 1 - Biobased panel *Cladding: Rendering mortar*			
Inside	*Composite: flax + bioepoxy*	2	1,350	2.70
	Birch Plywood	18	500	9.00
	PLA Foam	336	215	72.07
	Composite: flax + bioepoxy	2	1,350	2.70
Outside	*Mineral brick slip*	6	1,800	9.00
		7.01	Total	95.47

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
	Concept 1 - Biobased panel *Cladding: Rear ventilated facade*			
Inside	*Composite: flax + bioepoxy*	2	1,350	2.70
	Birch Plywood	18	500	9.00
	Wood fiber panels	288	140	40.32
	Composite: flax + bioepoxy	2	1,350	2.70
	Sawn wood studs	n.a	350	17.35
	Alumnimun stud	n.a	2,700	4.48
Outside	*Mineral brick slip*	n.a	n.a	42.00
			Total	118.55

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
	Concept 1 - Biobased panel *Cladding: Rear ventilated facade*			
Inside	*Composite: flax + bioepoxy*	2	1,350	2.70
	Birch Plywood	18	500	9.00
	PLA Foam	336	215	72.07
	Composite: flax + bioepoxy	2	1,350	2.70
	Sawn wood studs	n.a	350	17.35
	Alumnimun stud	n.a	2,700	4.48
Outside	*Mineral brick slip*	n.a	n.a	42.00
			Total	150.30

Insulation materials

Cladding system

Concept 2
Double board panel

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
	Concept 2 - Double board panel *Cladding: Rendering mortar*			
Inside	*Birch Plywood*	18	500	9.00
	Wood fiber panels	282	140	39.48
	Birch Plywood	18	500	9.00
Outside	*Mineral brick slip*	6	1,800	9.00
			Total	66.48

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
	Concept 2 - Double board panel *Cladding: Rendering mortar*			
Inside	*Birch Plywood*	18	500	9.00
	PLA Foam	329	215	70.57
	Birch Plywood	18	500	9.00
Outside	*Mineral brick slip*	6	1,800	9.00
			Total	97.57

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
	Concept 2 - Double board panel *Cladding: Rear ventilated facade*			
Inside	*Birch Plywood*	18	500	9.00
	Wood fiber panels	282	140	39.48
	Birch Plywood	18	500	9.00
	Alumnimun stud	n.a	2,700	4.48
Outside	*Mineral brick slip*	n.a	n.a	42.00
			Total	103.96

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
	Concept 2 - Double board panel *Cladding: Rear ventilated facade*			
Inside	*Birch Plywood*	18	500	9.00
	PLA Foam	329	215	70.57
	Birch Plywood	18	500	9.00
	Alumnimun stud	n.a	2,700	4.48
Outside	*Mineral brick slip*	n.a	n.a	42.00
			Total	135.05

Insulation materials

Cladding system

Concept 3
Hybrid frame/sandwich panel

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
	Concept 3 - Hybrid/frame panel *Cladding: Rendering mortar*			
Inside	*Birch Plywood*	18	500	9.00
	Sawn wood studs	n.a	350	17.35
	Wood fiber panels	288	140	40.32
	Sawn wood studs	n.a	350	17.35
	Composite: flax + bioepoxy	2	1,350	2.70
Outside	*Mineral brick slip*	6	1,800	9.00
			Total	95.72

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
	Concept 3 - Hybrid/frame panel *Cladding: Rendering mortar*			
Inside	*Birch Plywood*	18	500	9.00
	Sawn wood studs	n.a	350	17.35
	PLA Foam	336	215	72.07
	Sawn wood studs	n.a	350	17.35
	Composite: flax + bioepoxy	2	1,350	2.70
Outside	*Mineral brick slip*	6	1,800	9.00
			Total	127.47

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
	Concept 3 - Hybrid/frame panel *Cladding: Rendering mortar*			
Inside	*Birch Plywood*	18	500	9.00
	Sawn wood studs	n.a	350	17.35
	Birch Plywood	288	140	40.32
	Sawn wood studs	n.a	350	17.35
	Composite: flax + bioepoxy	2	1,350	2.70
	Alumnimun stud	n.a	2,700	4.48
Outside	*Mechslip think brick cladding*	n.a	n.a	42.00
			Total	133.20

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
	Concept 3 - Hybrid/frame panel *Cladding: Rendering mortar*			
Inside	*Birch Plywood*	18	500	9.00
	Sawn wood studs	n.a	350	17.35
	PLA Foam	336	215	72.07
	Sawn wood studs	n.a	350	17.35
	Composite: flax + bioepoxy	2	1,350	2.70
	Alumnimun stud	n.a	2,700	4.48
Outside	*Mechslip think brick cladding*	n.a	n.a	42.00
			Total	164.95

Figure 63 Summary of structural design iterations


Reference: Circulytics: New Tool Helps Companies Measure &
Track Circularity (greenqueen.com retrived on june 2021)

Life cycle assessment

Life Cycle Assessment (LCA) is a methodology developed to quantify environmental ‘impacts’ of products and/or processes. The tool was created in The Netherlands by the Leiden University and the rules were formally later established by the ISO 14040 and ISO 14044 norms. For construction works the standards are the EN 15978 and EN 15804 (Sustainability of construction works - Environmental product declarations).

There are specific softwares available to support companies performing LCA. Multiple consultancies around the world have developed them in line with the EN and ISO standards. The procedure evaluates all the environmental effects required by the extraction of raw materials, including inputs of energy and outputs of emissions over the product life cycle, the results are typically presented as ‘environmental profiles’ in form of graphics. Some companies assess the impacts of their products in a ‘cradle to gate’ basis from A1 to A5 phase or from A1 to B5 phase. However, the norm marks the complete “clade to grave” analysis from A1 to C4 phases or even a “Cradle to Cradle” strategy beyond the building life cycle, this if reusable materials remaining after the end of life (EoL) are available (please refer to Figure 64).

To assess the environmental impacts and sustainability of the new design alternatives, each of the concepts and their own variants are assessed with lifecycle assessment methodology. Then, compare each other with the original study performed by TU Gent for the INDU ZERO Project.

The original idea was to make a one-to-one analysis with the same strategy followed for such project. However, due to access limitations to the software SimaPro and the Swiss Ecoinvent database, the LCA phase for the present research was done with a different methodology, platform, and database. Therefore, the original design needs to be assessed again so the comparisons are equal to each other’s methodologies and data inventory.

The new simulation tool used is One Click LCA, this was done with a license owned by TU Delft. The license is a student permission, the tool allows different simulations for environmental assessment in an online basis. The software for construction sector applications, using the EN 15804 standards, the system integrates data from nearly all the available environmental product declarations (EPD) platforms in the world.

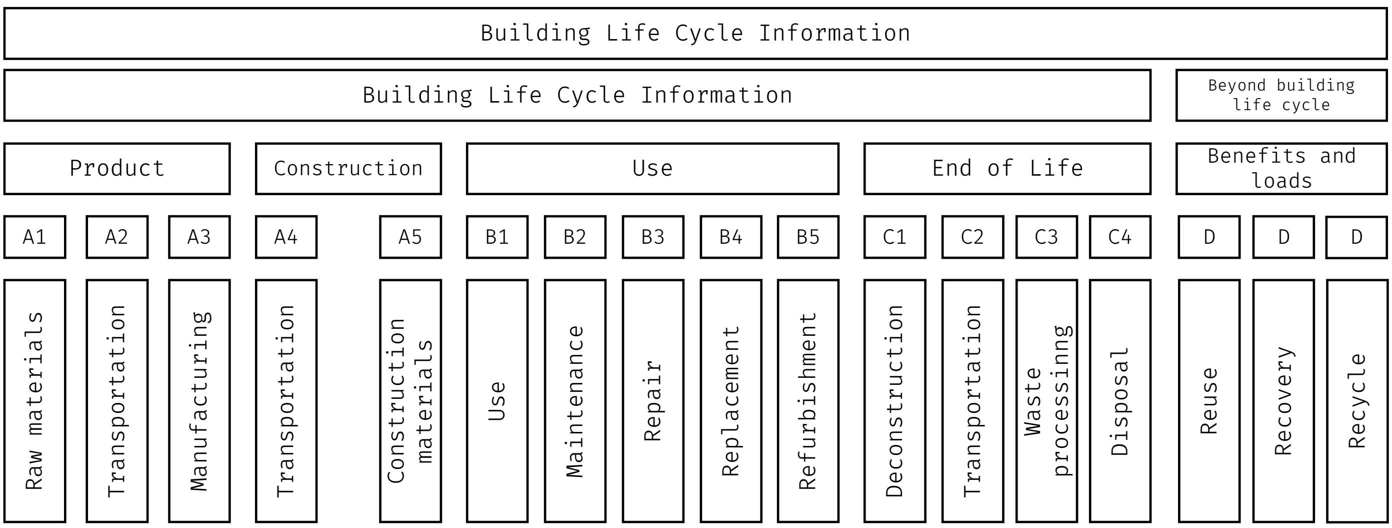


Figure 64 Life cycle stages considered in NEN-EN 15804:2012

The main goals of the LCA phase are:

- Identify the life cycle phases affecting most the total environmental impact of RC Panel and new design proposals.

- Identify the modules (A1-5, B1-5. C1-4) including the largest impacts of the life cycle to the overall analysis.

- Compare the alternatives with the original design and collect information for a future product development.

The procedure, following the ISO 14040 standard, will include the following four specific steps framework

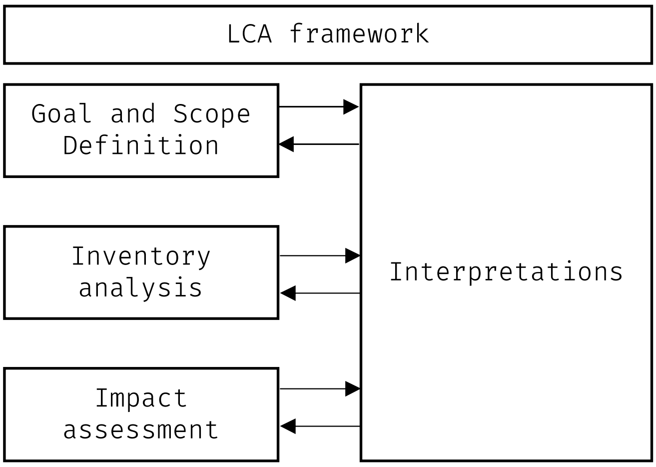


Figure 65 LCA Framework

Definition of the goal and scope of the study.

As mentioned before, the application of the study is meant to improve the circularity and sustainability of the current product developed by RC Panels. This phase has as information input the design evaluated in the design development stage. The intended application of the study is to provide a comparison of products that fulfill the same function as the original RC Panel. Also, identification of environmental phases in the new products that contribute the most to the life cycle scenarios.

The main reason why this study is developed is to support the business strategies in RC Panel in pursue of further testing, development, and optimization of a new panel. Also, for educational purposes in concluding how The Netherlands retrofitting strategies can be developed.

Functional unit

The functional unit of the study at a building level is 1m² of renovation element with the same thermal resistance of 7 m2·K/W.

There are two boundaries' conditions for different studies:

First, a 60-year analysis for the original RC Panel is performed. The intention is to match the system boundaries between the comparisons, mainly because the database is changed, and the base point of comparison is needed for the new designs.

Since the TU Ghent analysis does not include the End of Life (phase C), first, a "Cradle to Gate" (A1 to B5) is analyzed to compare with their original study. Please refer to Figure 66. Then, a "Cradle to grave" (A1 to C4) is performed to present the "complete" life cycle scenario. Please refer to Figure 67. Conclusions and interpretations of the results are given after the study.

After the original design is assessed with the new methodology, a second study of 100 years of analysis for the new designs is performed. Each design will be compared with the Original RC Panel in the same time frame. Also, circularity scenarios will be included as a "Cradle to Cradle" strategies (, each result will include 3 different circularity scenarios in the 100 years life span. The circularity scenarios are:

1) 100 years with one terrace home, including the correct technical cycles for maintenance and replacement of the main components of the panel.

2) 100 years with two terrace homes, after the first retrofitted home is used for 50 years, a second home will receive the still "usable" materials and reuse them for next 50 years. In between the time spans, the correct maintenance and replacement of the main components will be included.

3) 100 years with four terrace homes, after the first retrofitted home is used for

25 years, a second home will receive the still “usable” materials and reuse them for the following 25 years. The process will repeat itself until the panel reaches the 4th home in the 100 years’ time frame.

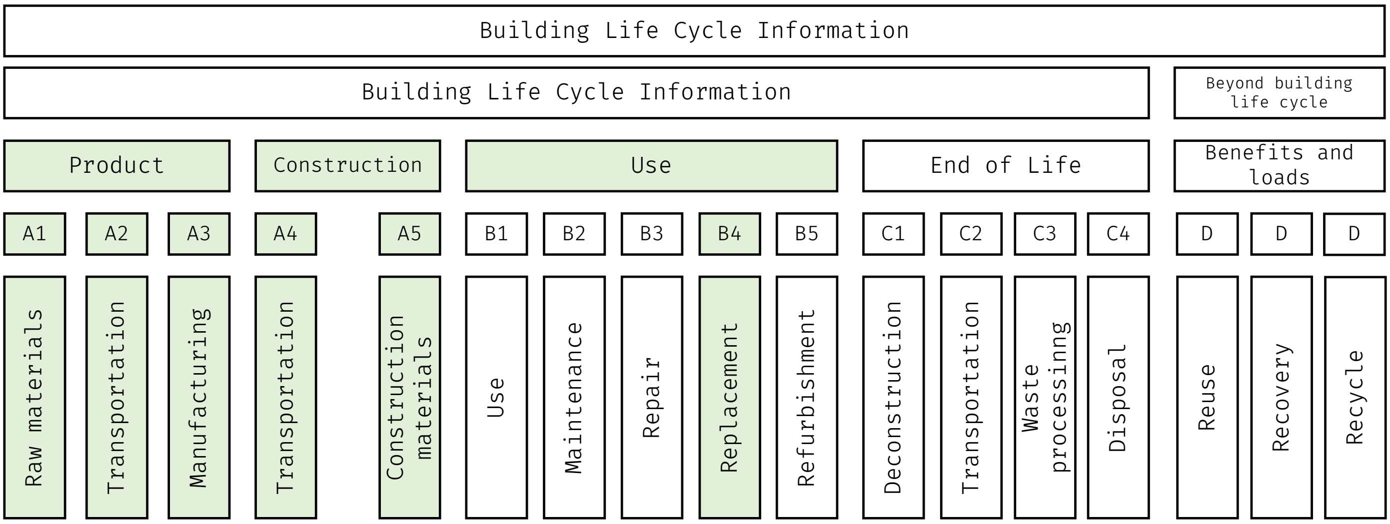


Figure 66 Cradle to Gate analysisW

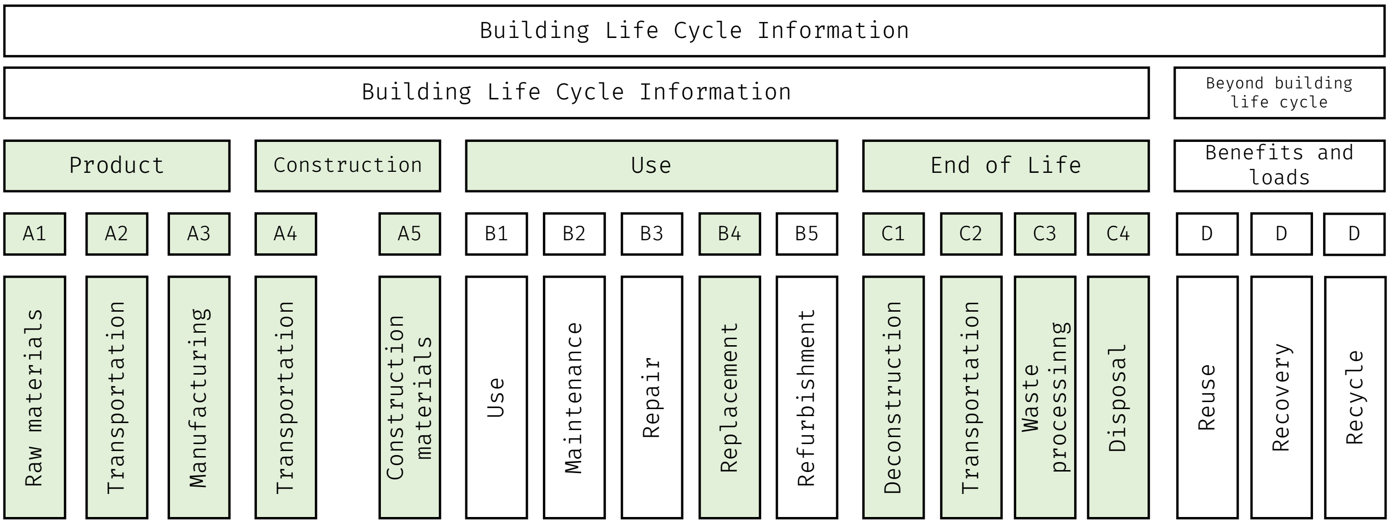


Figure 67 Cradle to Grave analysis

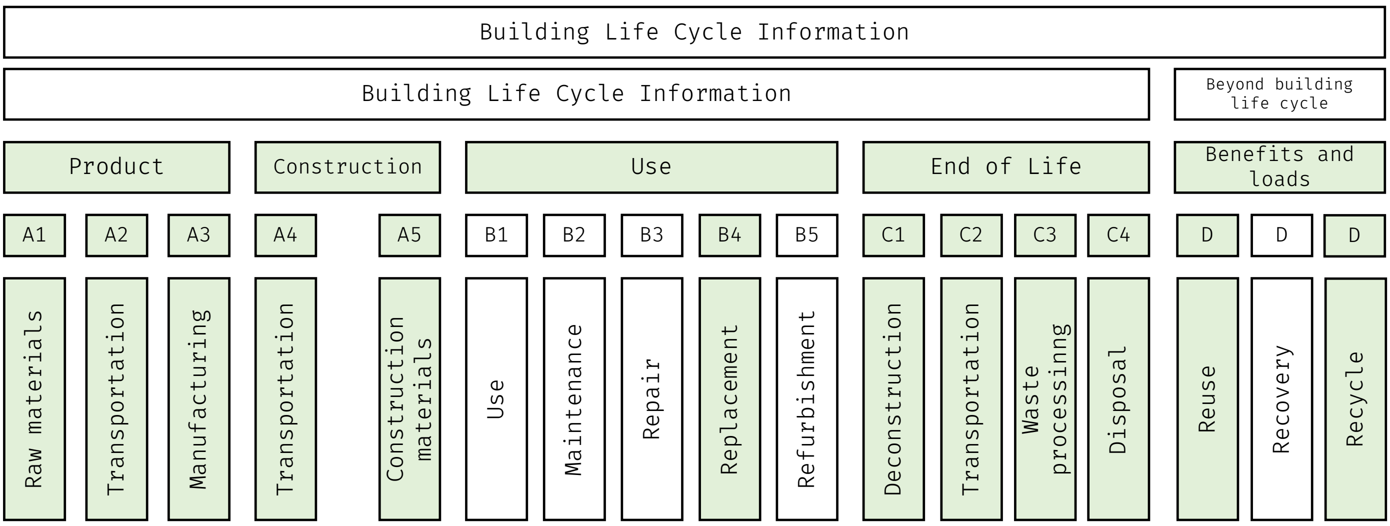


Figure 68 Cradle to Cradle analysis

In the Netherlands, the Dutch "Bouwbesluit 2012" requires eleven specific environmental impacts categories, all calculation must be including these "basic impact effects" in an LCA. Since the license for One Click LCA has a student permission, only five out of eleven categories can be obtained for the present assessment.

The following are the eleven environmental categories required by the code out of which this thesis includes numbers "one, two, seven, eight , and nine". Also, the simulation tool provides an estimation of the total embodied energy (mega joules) which could be translated as "Abiotic depletion potential fuel", however the units are not provided in "units equivalent " it only gives the energy usage, therefore this will remain as a separate concept and not considered for the analysis.

1. Global warming potential (GWP)

2. Ozone layer Depletion Potential (ODP)

3. Human Toxicity Potential (HTP)

4. Freshwater Aquatic EcoToxicity Potential (FAETP)

5. Marine Aquatic EcoToxicity Potential (MAETP)

6. Terrestrial EcoToxicity Potential (TETP)

7. Photochemical Oxidation Potential (POCP)

8. Acidification Potential (AP)

9. Eutrophication Potential (EP)

10. Abiotic Depletion Potential Fuel (ADP-fuel) (energy use)

11. Abiotic Depletion Potential Non-Fuel

"One-click LCA" has a database including Life Cycle inventory (LCI) data for each category previously mentioned. From raw materials and processes, this information comes from environmental product declarations. As real-life, due to the many inputs of natural resources and processes during the product, use and end-of-life phases, the used LCI data will be taken from the existing EPDs. In the particular case where a product was not in the database, a similar profile was chosen, or a paper is introduced with the correct references and environmental categories. In any case, the reference and data can be review in appendices D to AA.

Original RC Panel LCA
Base point for comparison

Cradle to Gate analysis

The materials inventory for 1 m2 of the original design was taken from the manual from RC Panels and the quantities explained in this report's "RC Panels" section.

The Life Cycle Inventory (LCI) analysis has all the environmental relevant inputs (natural resources and processes needed) in the product´s life cycle 'entering' the system´s boundary. Also, it includes all the outputs such as wastes and emissions 'leaving' the system. This analysis is presented as a "process tree" in Figure 69

The required materials for make the retrofitting panel are a mix of different products such as Glass fibre polyester (GFP), Oriented strand board (OSB), Expanded Polystyrene board (EPS), Mineral render finish, and polyurethane glue.

One-click LCA works with environmental product declarations from specific companies. Therefore the analysis of the A1-A3 phases will include the extraction of the raw materials, transportation to their mixing plants and the final manufacturing process of the (sub)products. As input for the tool, the location of the factory of RC Panels is provided in The Netherlands. The products are transported to the factory where the renovation panel is produced. The transportation methods for each product are given in the A4 phase. For the GFP, OSB, EPS, and Render, the transportation is a 40-ton delivery truck with distances of 430 km, 340 km, 430 km 110 km, and 470 km from the factory.

In the factory, the panel assembly starts (please refer to the "RC Panels" section in the literature review for further reference of the process). Once the panel is finished, its positioned on top of flatbeds and delivered to the home's address to be renovated. For this, 110 km from the factory is the selected distance. Please refer to Figure 70.

According to the report done by SKG-IKOB, the panel life span relies on the rendering mortar system, and the expected lifetime is 50 years. Since LCA done by TU Ghent is for 60 years, the panel needs to be recoated one time more during the 60 years service life. In year 50, the façade is disassembled from the renovated home and taken back to the factory (transported again by truck, 110 km).

The chemical bonding between the render mortar and the exterior glass fiber polyester layer makes impossible to give a proper maintenance only to the render. Hence, the complete exterior membrane needs to be peeled from the core. This process was discussed with RC Panels, and it was mentioned that is possible to do it in the current factory. Once the panel is recoated is positioned on a flatbed and transported back to the home. The disposal to a landfill or the waste treatment was not included in the TU Ghent analysis, therefore this LCA will not include the "End of life" (C1-C4) and the "Remaining value" (D) is also neglected.

Figure 70 Distance from RC Panels factory

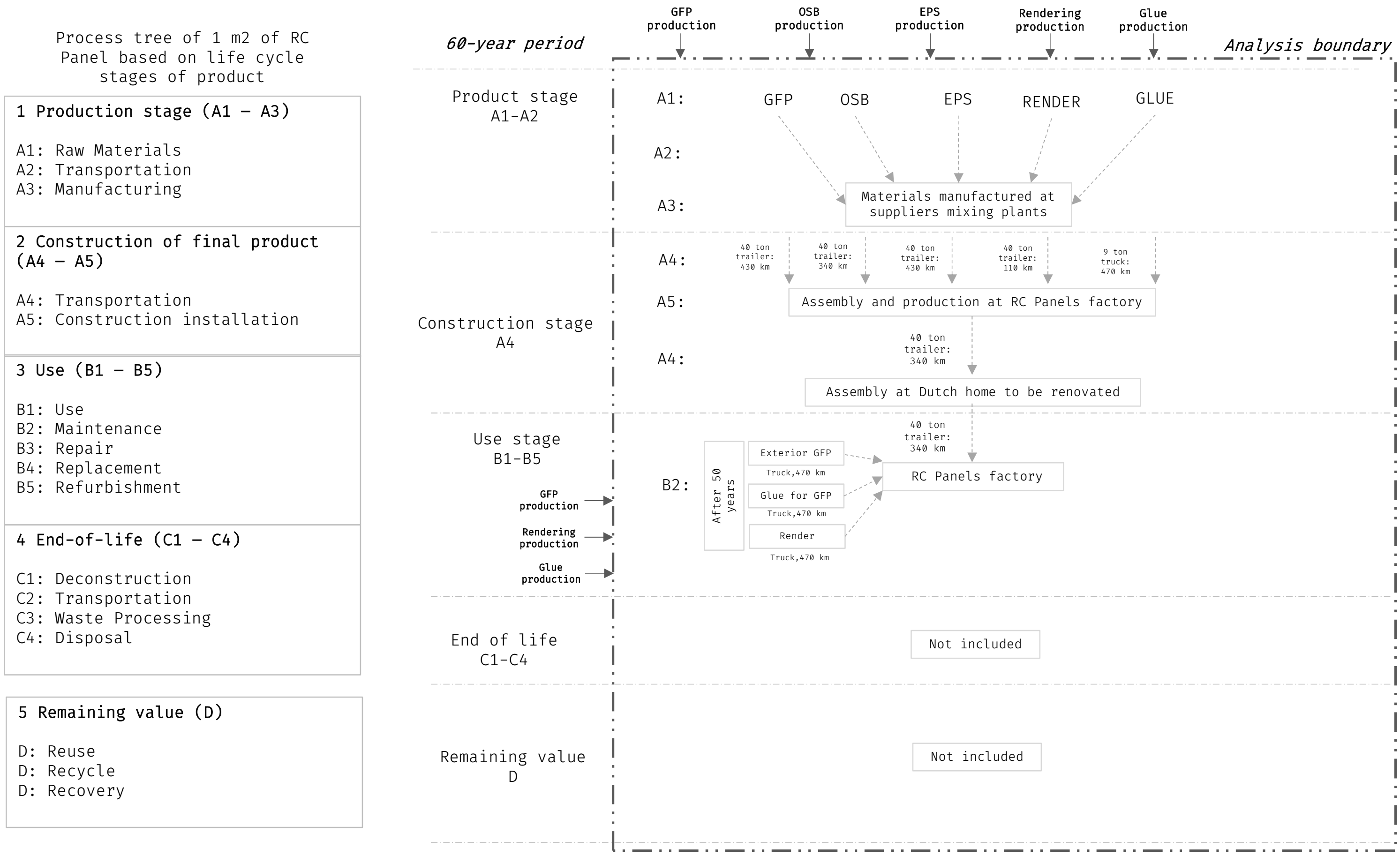


Figure 69 Original RC Panel "Cradle to Gate" process tree - One click LCA tool

The environmental ''indicator result'' can be presented in the form of values for 'midpoints' or 'endpoints', such as in the INDU Zero project is analyzed. However, the ReCiPe methodology is not used in this thesis and the quantification of the environmental impacts is done in terms of money, making it easy to standardize, compare and understand. This monetary value is also known as Environmental Cost Index (ECI). Ideally, the money calculated in this phase represents the burden costs needed to develop technologies that reduce and remove the environmental impacts undone or bring it to a 'sustainable' level. This cost is also typically referred as "shadow cost" and, if included in the sale price, a product can be called "sustainable".

The 'Bouwbesluit 2012' in marks that for all houses and office buildings constructions built after 2013 with more than 100 m2, an environmental impact calculation needs to be included. The analysis must include at least the 11 categories and environmental costs for the involved emissions. The code is not yet 100% clear with the utilization of such products for renovations. For further calculations, the cost assigned for the environmental categories "units equivalents" according to the EN 15978 and EN 15804 standards are:

- Global warming potential (GWP)
  0.05 EUR / kg CO2 equivalent
- Ozone layer Depletion Potential (ODP)
  30.00 EUR / kg CFC11 equivalent
- Acidification Potential (AP)
  4.00 EUR / kg SO2 equivalent
- Eutrophication Potential (EP)
  9.00 EUR / kg PO4 equivalent
- Photochemical Oxidation Potential (POCP)
  30.00 EUR / kg Ethene equivalent

Figure 71 shows the contribution (%) of each environmental category analyzed for 1 m2 of the RC Panel. The result shows contribution of 53% for GWP, 30% for Photochemical Oxidation, 11% for acidification potential, 6% to Eutrophication potential and less than 0.1% to Ozone layer depletion.

Figure 72 shows the contribution (%) of each material individually, the result shows contribution of 42% from the EPS, a 20% from the Glass fiber polyester, a 13% from the OSB, a 16% for the glue and a 9% for the plaster. Finally, the total ECI for 1 m2 of RC Panel calculated is 4.92 EUR out of which most comes from the contributions of GWP and POCthe contributions of GWP and POCP. (Please refer to appendix F).

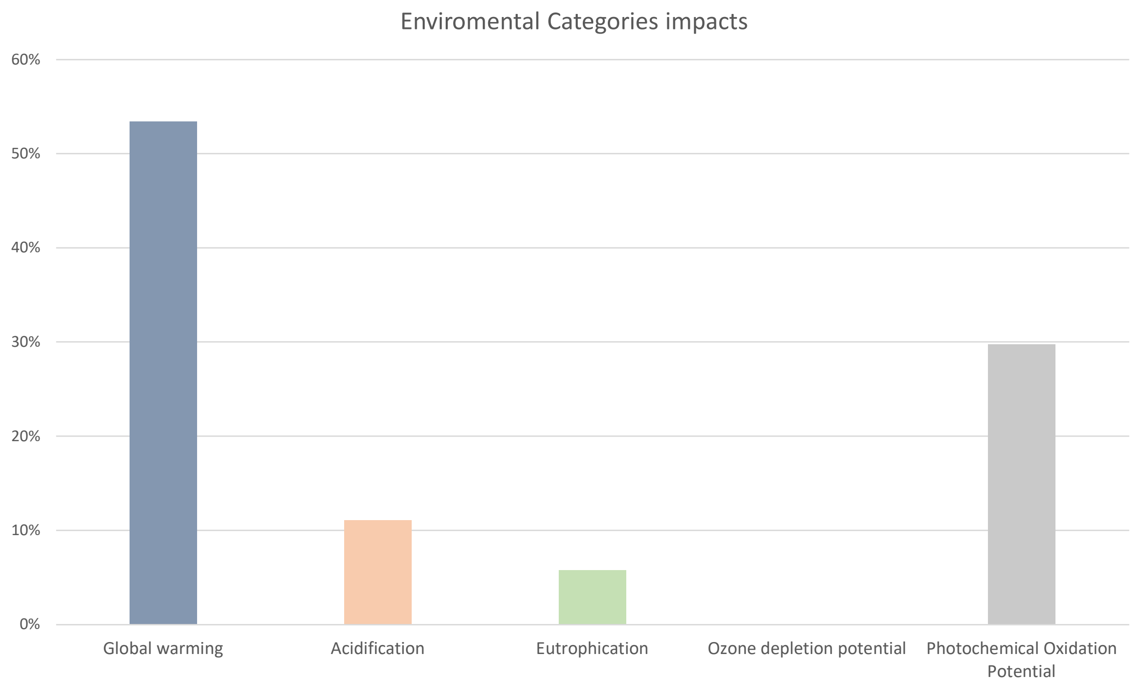
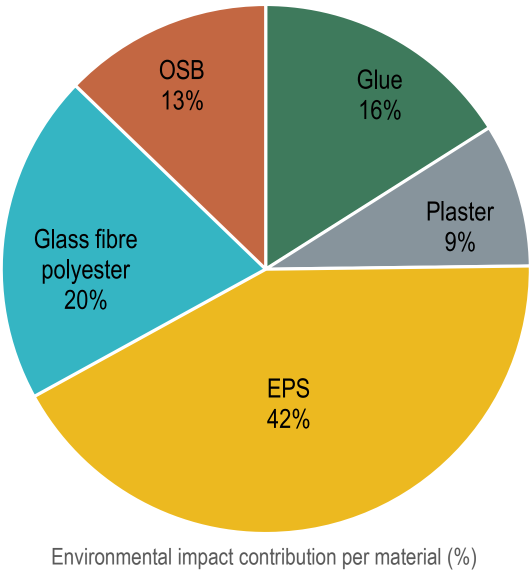


Figure 71 Environmental categories impacts (%) cradle to gate.



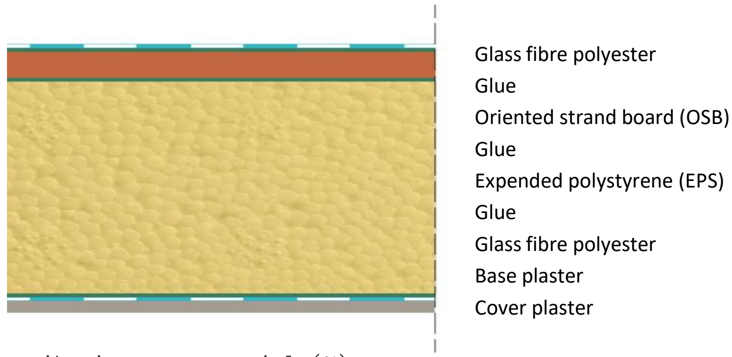
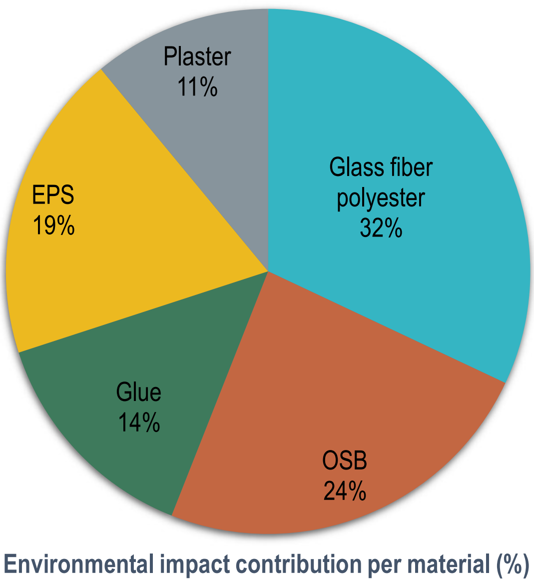


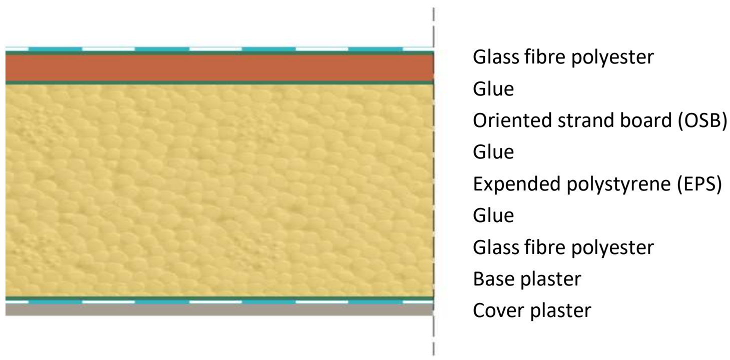
Figure 72 Environmental contribution per material (%)

When the LCA performed for the INDU Zero project is compared with these new results, the contribution (%) per material changes. As mentioned before, one click LCA works with environmental product declarations and the type of resources that are used in the assessment can be reviewed quickly by downloading the EPD from the platform of such products. For example, in the tool one can take the render mortar Manufactured by STO and we correlate that in fact, this material is the same as RC Panels uses in their factory.

Unfortunately for the LCA done by TU Ghent, the actual values and products used for the assessment were not available to share along with the study in ANNEX AA. The main differences are in the contributions of the Glass fiber polyester (GFP), Oriented Strand Board (OSB), and Expande polystyrene (EPS).

GFP changed from 32% to a 20%, EPS changed from 19% to 42% and the OSB from 24% to 13%. Whereas the render and the glue showed small differences from 11% to 9% for the plaster and 14% to 16%. For an exact explanation of the changes in the percentage in the materials, such resources used in Simapro need to be extracted from the software and compared. However, it can be said that the LCA was done two year ago, the databases are constantly updated and changing, this could explain some of the differences.





INDU ZERO - Environmental contribution per material (%)

Original RC Panel LCA
Cradle to Grave analysis

The previous LCA was performed to compare it one-to-one with the LCA performed for the company two years ago. Now, the original panel will be introduced to a "Cradle to Grave" analysis where the end of life (C1-C4) is included. The idea is to provide a comparison between the "Cradle to gate" vs the "Cradle to grave" with the same boundary conditions previously described, this will give the percentage "neglected" by not including the disposal and processing of the materials once they are not needed.

The new Life Cycle Inventory (LCI) is presented in the "process tree" in Figure 73. The panel life span is kept the same (50 years). This means that the panel gets recoated in year 50 and the materials replaced are disposed and their environmental impacts are now included. Also, in year 60 when the panels is not needed anymore, all the materials are disposed.

The interior GFP glued with a polyurethane adhesive to the OSB3, is a mix of materials from different resources. From wood fibers and glue in the OSB and polyester matrix and glass fiber. This chemical joint is almost impossible to separate, and further reuse or recycle is not possible. Hence, these three layers are sent to incineration after the 60 years period is completed. The same happens to the render mortar, exterior GFP and polyurethane adhesive, however, this can be granulated and sent to landfilling. Finally, for the EPS core it most be noted that I can be detached panel, by peeling the exterior membrane and using a thin metal wire to be removed it from the OSB board. Hence, this material could be potentially reused, however, the cradle to grave analysis excludes the possibility to reuse it and therefore the material is also sent to incineration.

Figure 74 shows the new contribution (%) of each environmental category analyzed for 1 m2 of the RC Panel including the EoL scenarios. The result shows now a contribution 57% instead of 53% for GWP, 27% instead of 30% for Photochemical Oxidation, 10% instead of 11% for Acidification potential, 5% instead of 6% tfor Eutrophication potential and still less than 0.1% to Ozone layer depletion.

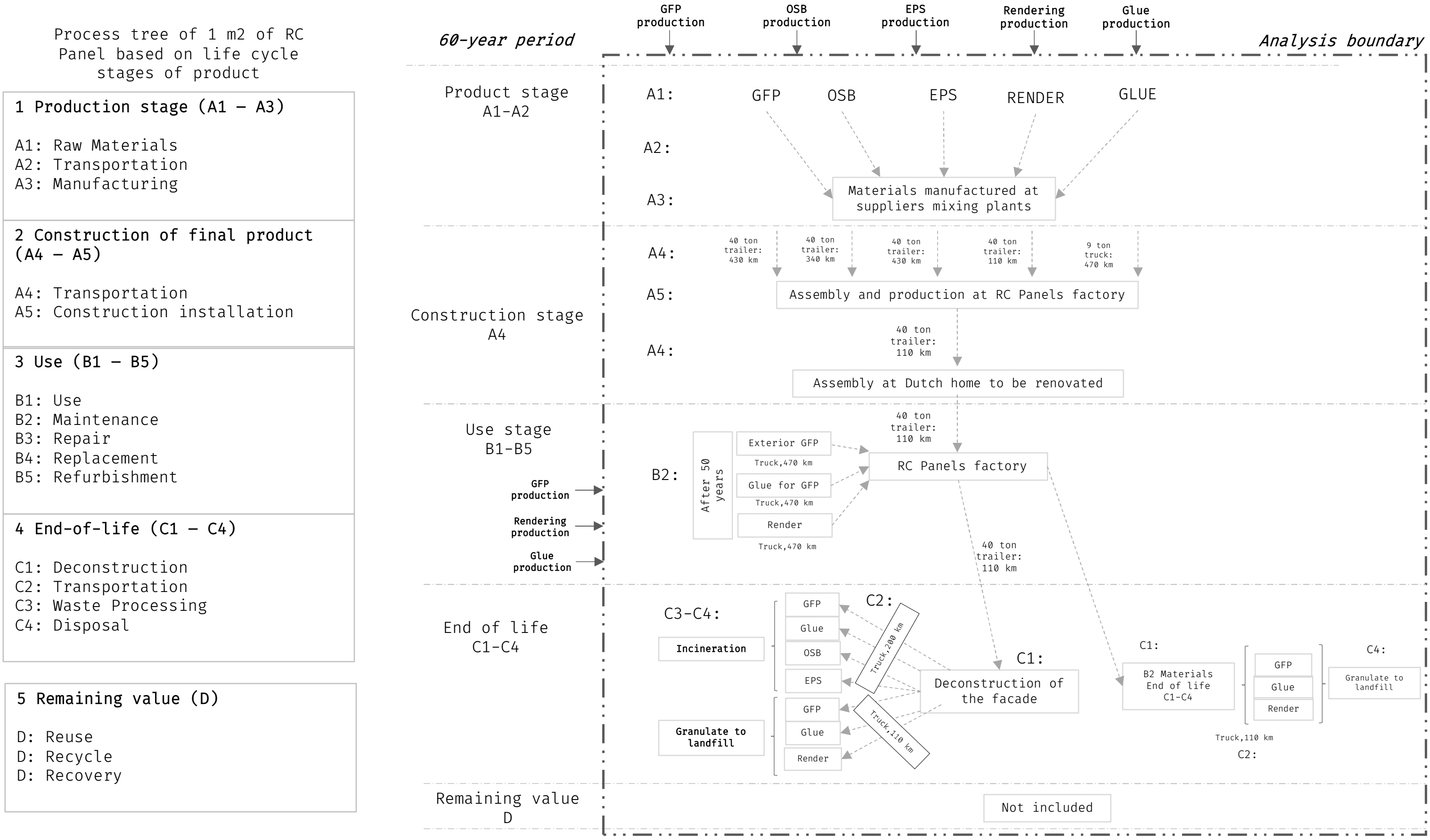


Figure 73 Figure 53 Original RC Panel "Cradle to Grave" process tree - One click LCA tool

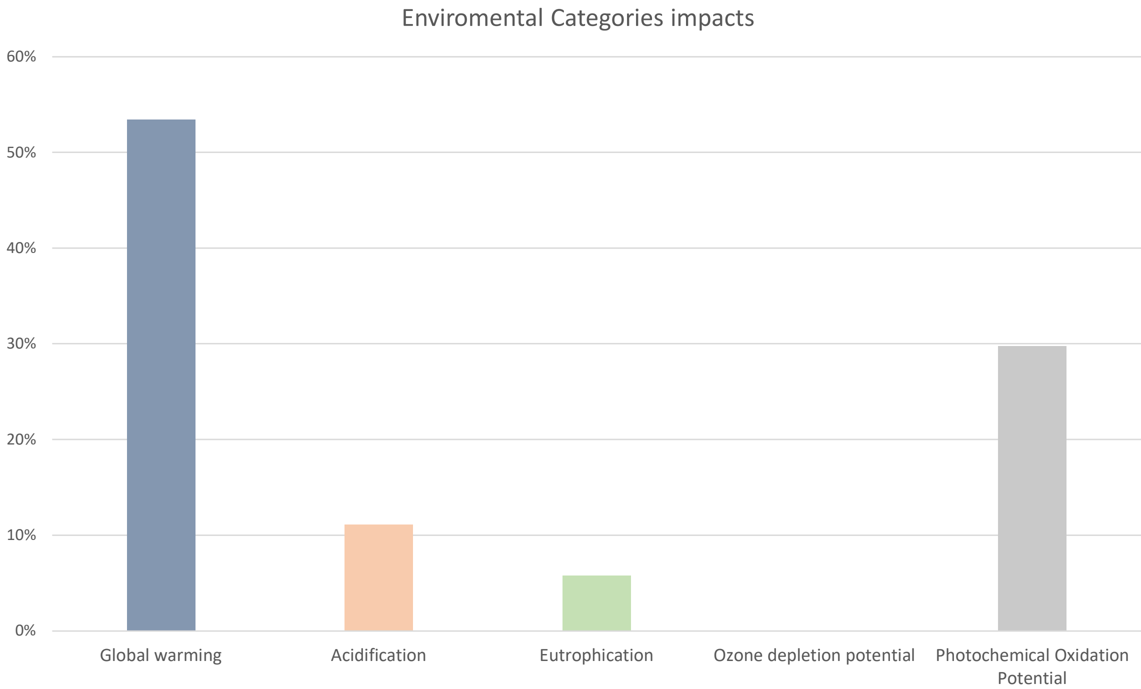
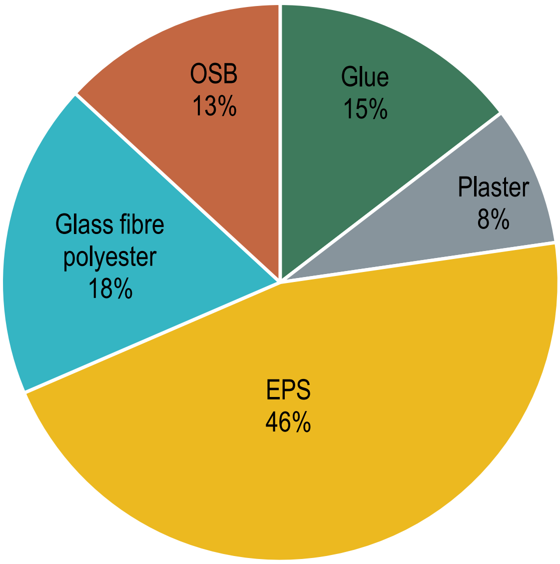


Figure 74 Environmental categories impacts (%) cradle to grave

Figure 75 shows the contribution (%) of each material individually, the result shows contribution of 46% from the EPS, a 18% from the Glass fiber polyester, a 13% from the OSB, a 15% for the glue and a 8% for the plaster. Also, Figure 76 shows the contribution (%) per phase where the product phase contributes the most with a 75%, the Use phase a 15% and the End of Life a 10%. Finally, the total ECI for 1 m2 of RC Panel calculated is 5.48 EUR out of which most comes from the contributions of GWP and POCP. of GWP and POCP.



Environmental impact contribution per material (%)

Figure 75 Environmental contribution per material (%) cradle to grave

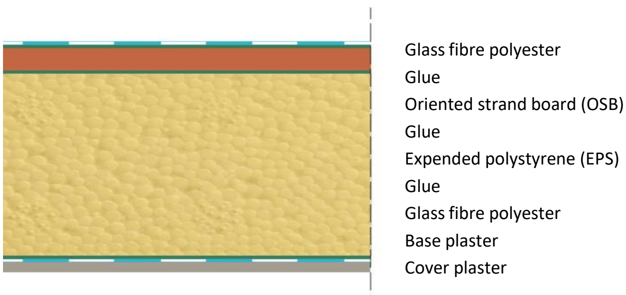
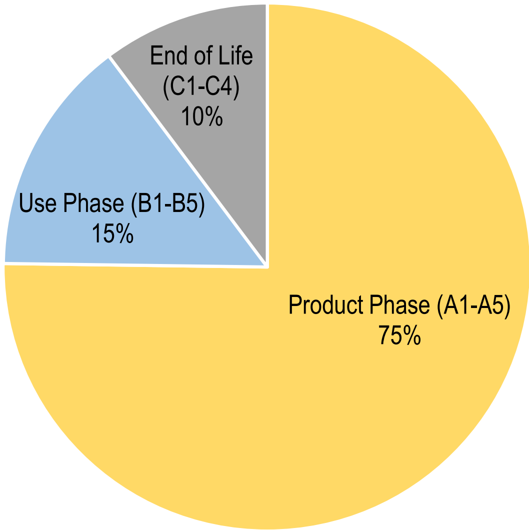


Figure - RC Panel



Environmental impact contribution per phase (%)

Figure 76 Environmental contribution per phase (%) cradle to grave

Interpretations

After analysing both “cradle to gate” and “cradle to grave” LCA of the original design, it can be noticed that the environmental effects do change when EoL scenarios are included. It is essential to avoid neglecting the “outputs” of the materials at their end-of-service. RC Panels follows a “narrow resources” strategy where the company aims to use as few materials as possible to create its product. With these strategies is even more important to acknowledge the time component at all the material phases because it’s known that they are aimed to speed up sales by “selling more of a more efficient product” (Bocken et al., 2016).

Further, the environmental cost index increases 11.35 % when the end of life included. This percentage is mainly driven by the disposal of the EPS and the OSB panel. The equivalent kilograms of CO2 emitted when the materials are processed makes the panel increase its environmental impacts. EPS could be downcycled by shredding it; however, that would delay the “cradle to grave” strategy and the materials in the same scenario. Also, it has been mentioned by RC Panels that there are new techniques in recycling EPS into insulation with the properties of the same material. Unfortunately, the environmental impacts of such processes are not yet “freely” available, and it was not possible to obtain them.

The distribution of the impacts per phase shows that 75% comes from product manufacturing. The raw materials extraction, transportation, and manufacturing of the product have a significant influence on the panel's impacts. The design strategy followed in this thesis, trying to enhance sustainable materials, is expected to reduce the impact of these phases. However, the panel already uses few materials. EPS has an exceptionally low density and thermal conductivity, one of its best advantages. In this matter, the circularity scenarios described previously are also expected to reduce the environmental impacts. It is likely certain strategies will have higher use of materials at the beginning, however when technical cycles like "reusing" are introduced, the "remaining value" will have an important impact because when a second or third home is introduced in the analysis the materials with "remaining value" will be reused repeated time.

The new design proposals assessments will start with the "cradle to grave" base for comparison. The analysis will be for 100 years with different scenarios, including phase "D". The original design as well as they new proposals will be reviewed with life scenarios where the materials enter into technical cycles. This is done to review how much a "Cradle to Cradle" strategy can help to improve the environmental impacts and introduce the product to a "circular economy".

Cradle to Cradle analysis

From linear to circular

The ‘cradle to cradle’ analysis aims to minimize finite ‘raw’ materials instead of relying on renewables and mined resources. Ideally, this should be technically achieved and should at the same time also result in a substantially lower environmental impact in comparison to the traditional linear approach.

The new design options coming from the design development comprehend a set of twenty-four options. The numbers come from the three design concepts with two cladding systems and four different insulation cores. Unfortunately, due to the limitation of data, the environmental impacts of the mycelium hemp panel and the PLA foam could not be further research in this phase. One-Click LCA does not provide any profile regarding the use of these materials. After reviewing some literature, the analysis of their environmental effects could be comparable because the databases and methodologies are different again. Both materials need further research with these applications.

The remaining twelve options with Expanded cork and Wood fibre cores are further analyzed. First, the expanded cork will be set as an insulation core for its six different variants. Then, when the best environmental options are selected, wood fibre will be introduced to compare and analyze the change of the core.

After analysing each concept design with the 1st circularity scenario, a list of the materials that could form part of the mining of the material and reuse when more than 1 home is evaluated (2nd and 3rd circularity scenarios) will be presented at the end of the Life cycle inventory.

1st Circularity Scenario

For this cradle-to-cradle strategy, the time analysis comprehends 100 years. As mentioned before, the first six new designs will be compared with the Original RC Panel in this time frame. The first circularity scenario is analyzing one single terrace home. This means that the dwelling will never change its skeleton, and only maintenance or replacement cycles of the façade will be included. Here circularity is seen as a “extension of the final product´s life” by using it as much as possible in the same home.

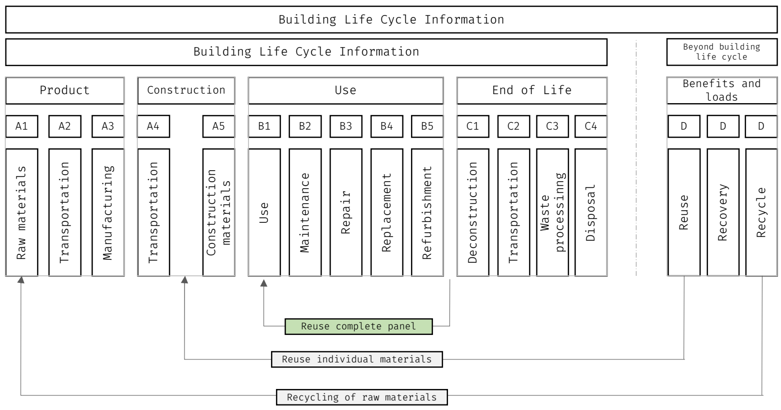


Figure 77 Cradle to Cradle - 1st circularity analysis

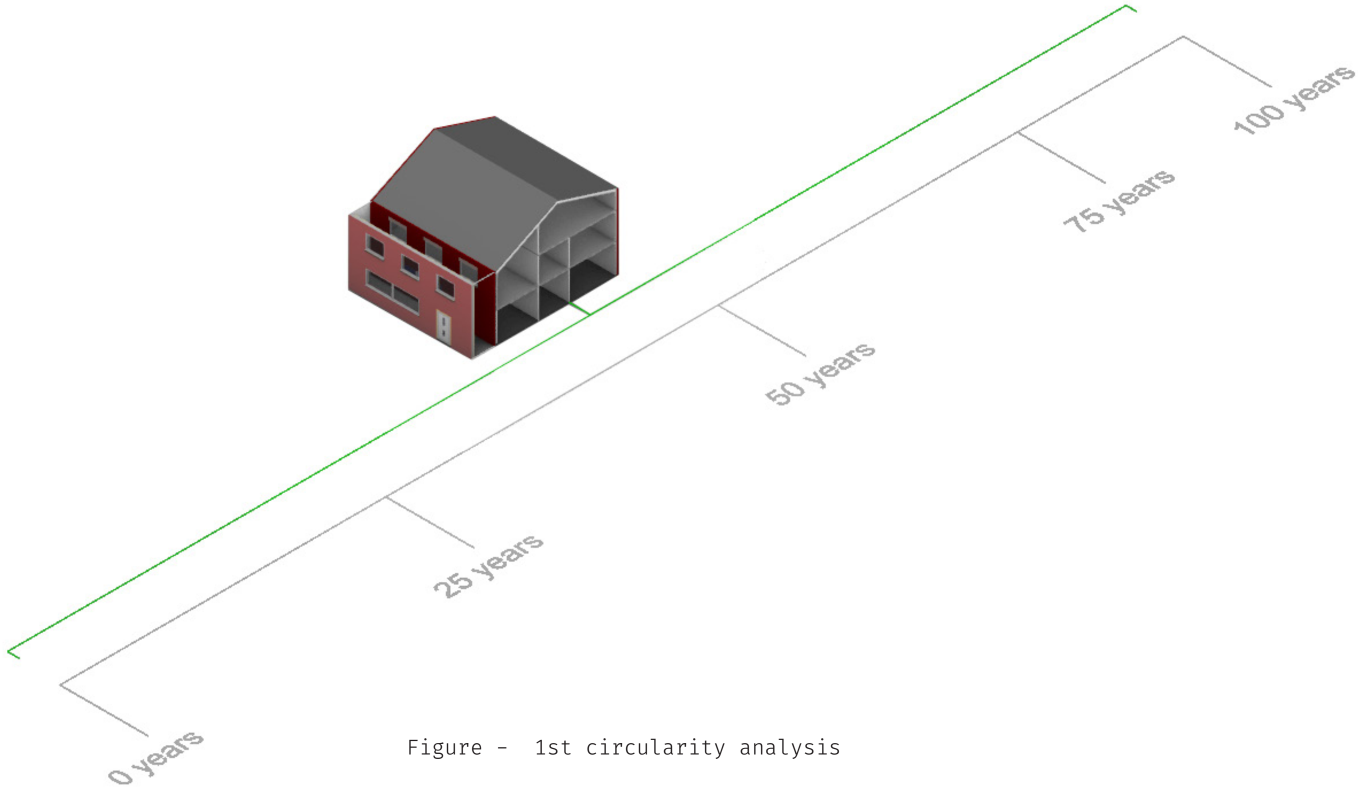


Figure - 1st circularity analysis

Functional unit

The functional unit for the materials inventory is the same 1 m2 for all six designs, and each materials quantities can be reviewed in appendix XX

The Life Cycle Inventory (LCI) analysis has all the environmental relevant inputs (natural resources and processes needed) in the product´s life cycle ‘entering’ the system´s boundary. Also, it includes all the outputs such as wastes and emissions ‘leaving’ the system and the materials going back into a possible recycle o reuse cycle. It is essential to mention that only materials with primary recycling are sent back to the “materials phase”. If they cannot be recycled in this way, they are processed and disposed. This analysis is presented in Figure 77.

Concept 1 - Life cycle assessment. Cladding: Stucco

The LCIA process trees are shown in Figure 78 for the stucco cladding, and Figure 79 for the rear ventilated cladding.

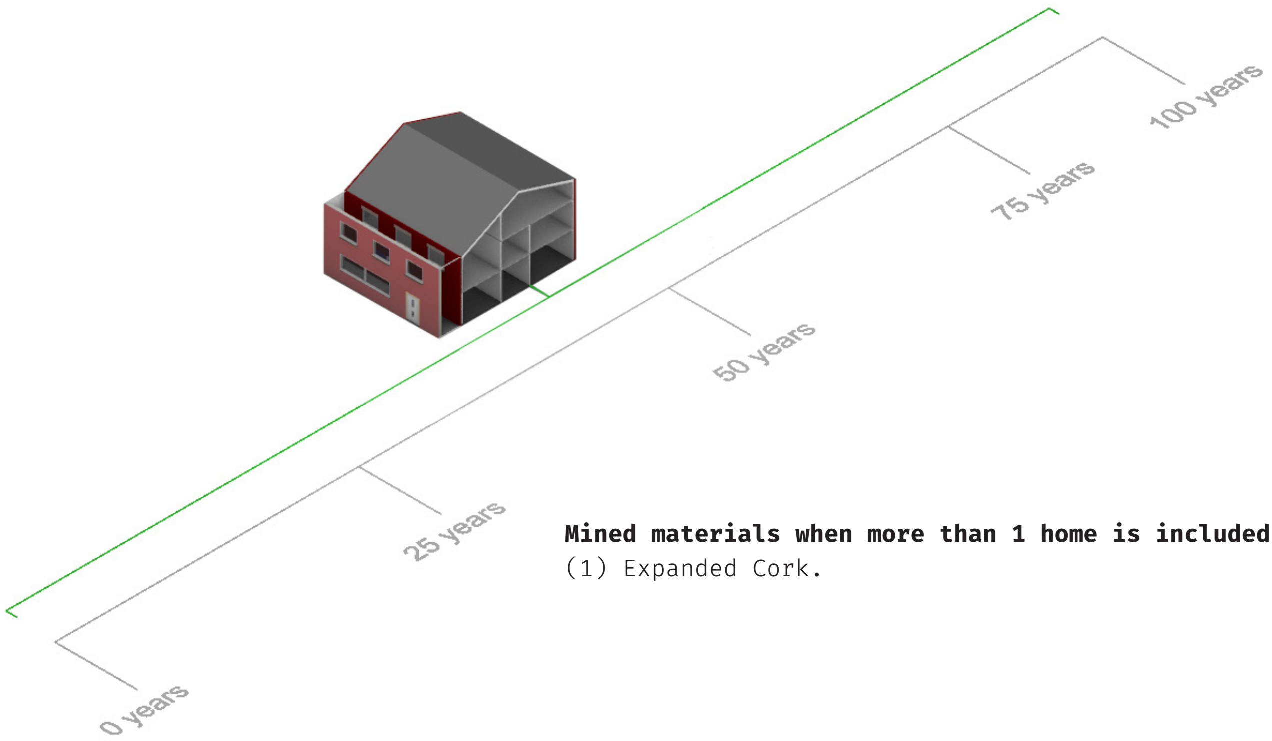
For the stucco cladding, the panel life span is set according to the report done by SKG-IKOB, relying on the 50 years conclusion. This LCA is analyzed for 100 years, and similarly to the original panel, this biobased sandwich needs to be recoated one time more during the service life. In year 50, the façade is disassembled from the renovated home and taken back to the factory (transported again by truck, 110 km).

The bonding between the render mortar and biocomposite made by flax fibre and a bioepoxy is a mix of nutrients and that could not be easily separated back. Hence, the complete exterior membrane is again peeled from the core. Once the panel is recoated and with a new biocomposite on the exterior, is transported back to the home. The End of life of the replaced materials is now included, and ideally a biocomposite should be sent to a biological cycle. However, after reviewing the matrixes available in the market for such applications, they are only partially biobased and therefore, they cannot be processed as such. The scenario selected is an incineration disposal for the biocomposite and landfilling for the exterior render.

The exterior render + biocomposite is analyzed as the first line of defense in this concept. Everything behind avoids any contact with sun, moisture and it is assumed that is completely protected against insects, bugs or fungus. Therefore, the façade does not present any “atypical” damaged and all the materials behind this layer are expected to last the 100 years analysis.

The biocomposite glued to the plywood, is also mix of materials from different resources. None of these is biodegradable since the glue use in the plywood is polyurethane and the matrix in the biocomposite is not 100% biobased. Therefore, recycling is also not possible, and these materials are also sent incineration after the 100 years period. Finally, the cork core can be detached panel, after peeling the exterior membrane and removing it from the plywood board; this material is sent to recycling after the 100 years. This process was discussed with an expanded cork supplier and they said, even though is was not a current practice, it is possible to do it.

For the weighting factors, please refer to appendix I.



Mined materials when more than 1 home is included:
(1) Expanded Cork.

Process tree of 1 m2 of RC Panel based on life cycle stages of product

1 Production stage (A1 – A3)

A1: Raw Materials
A2: Transportation
A3: Manufacturing

2 Construction of final product (A4 – A5)

A4: Transportation
A5: Construction installation

3 Use (B1 – B5)

B1: Use
B2: Maintenance
B3: Repair
B4: Replacement
B5: Refurbishment

4 End-of-life (C1 – C4)

C1: Deconstruction
C2: Transportation
C3: Waste Processing
C4: Disposal

5 Remaining value (D)

D: Reuse
D: Recycle
D: Recovery

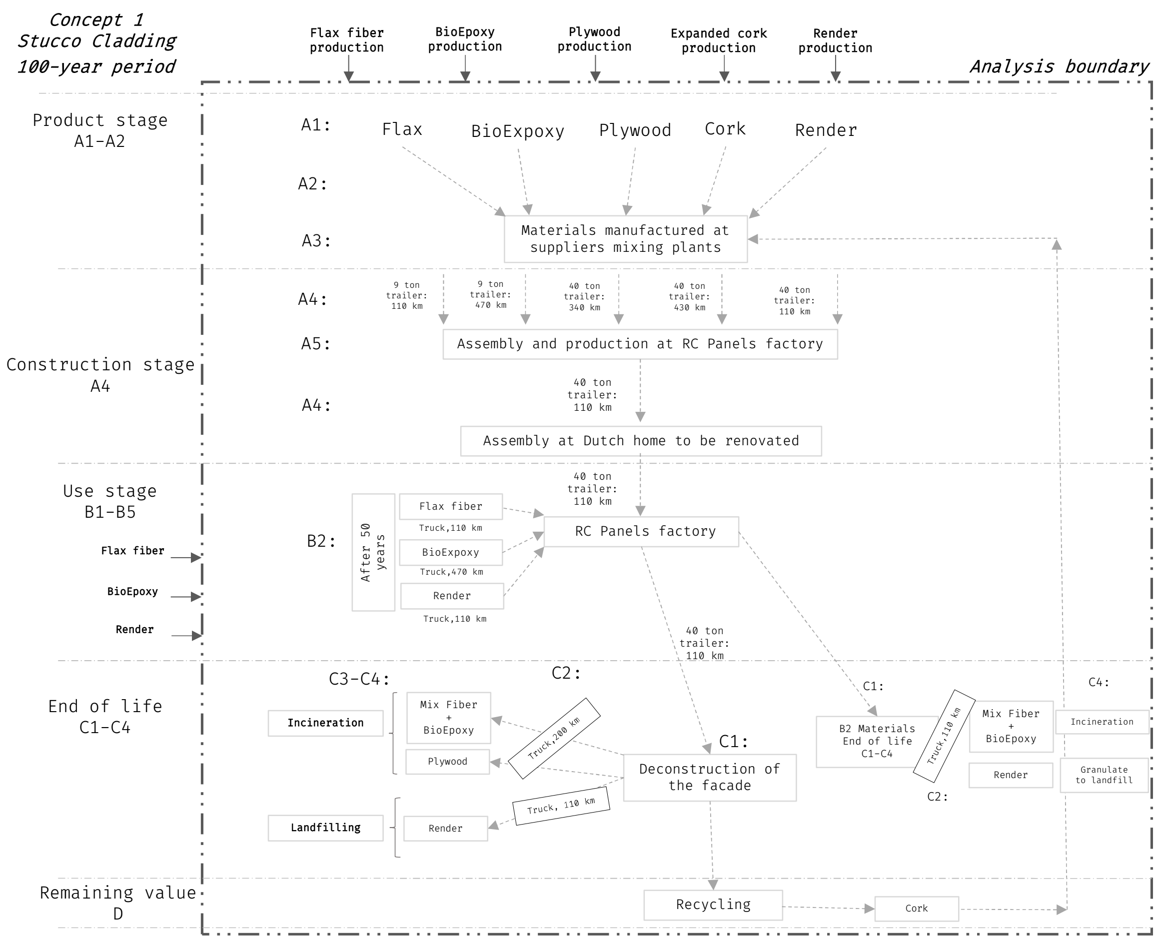


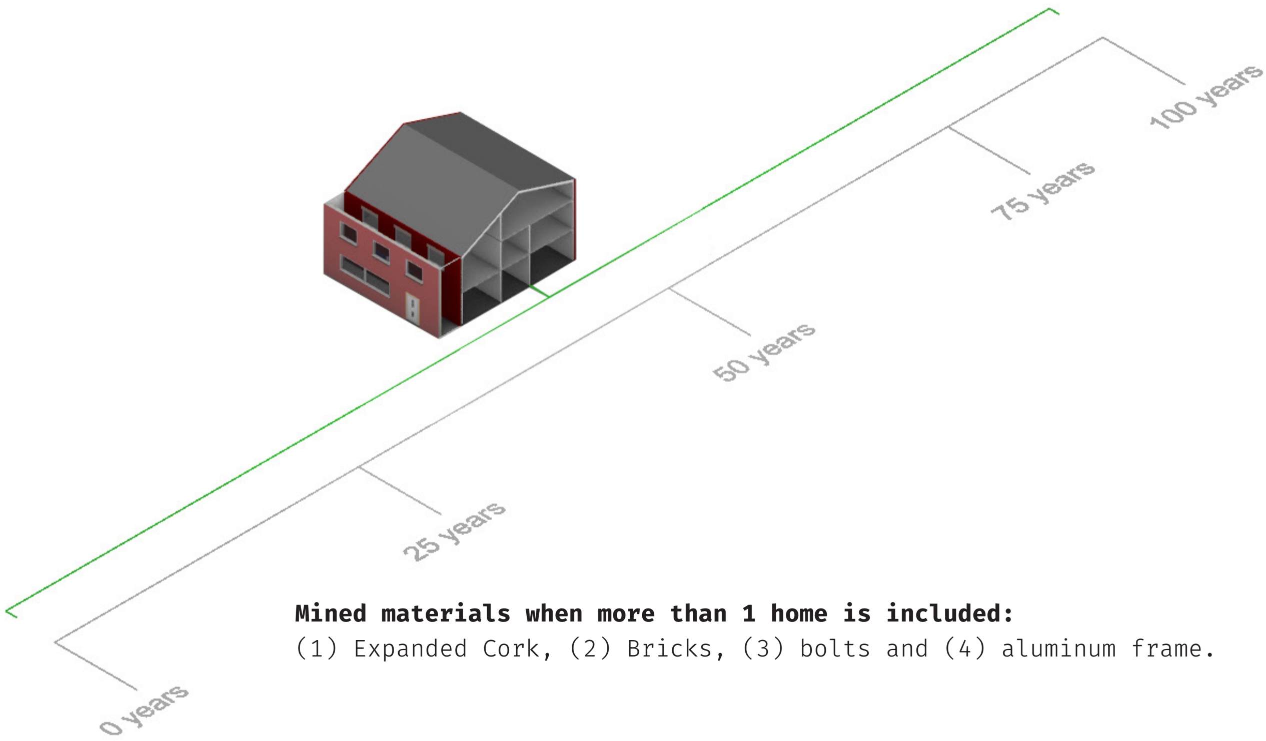
Figure 78 Concept one with Stucco Cladding - One home analysis

Concept 1 - Life cycle assessment. Cladding: Rear ventilated

For the rear ventilated cladding, the 1st line defence of the façade changes. The selected period is again set according to a test performed by SKG-IKOB. As mentioned in the materials section, in the thesis of Merjin Verlinde multiple samples of a “flax+bioexpoxy” biocomposite were tested for methodological exposure looking for the expected service life span. The results interpretations were that for a life span of 50 years, the biocomposite needed to have a 13% increase in the bending stiffness. For this reason, only a durability of 35 years is included in the present analysis (Verlinde, 2017). This also means that the biobased “main thermal sandwich” needs a new biocomposite behind the cladding. These materials will be replaced twice, one time in year thirty-five and one more in year seventy. In both cases, the façade is disassembled from the renovated home and taken back to the factory where the bricks and aluminium rails are removed, the existing biocomposite is peeled from the core, and a new membrane is installed.

The biocomposite is assumed as the first line, and, as previously, the main “thermal panel” of the façade is assumed to have no contact with the exterior environment. Also, any “atypical” damage is expected behind this layer. Therefore the rest of the materials are expected to last the 100 years analysis. At the end of life, the materials suffering a chemical connection such as the two biocomposite membranes and the plywood, are sent to incineration. The rest of the modular components coming from the rear ventilated cladding (bricks, bolts, and aluminium) and the cork core are sent to a technical recycling cycle.

For the weighting factors, please refer to appendix J



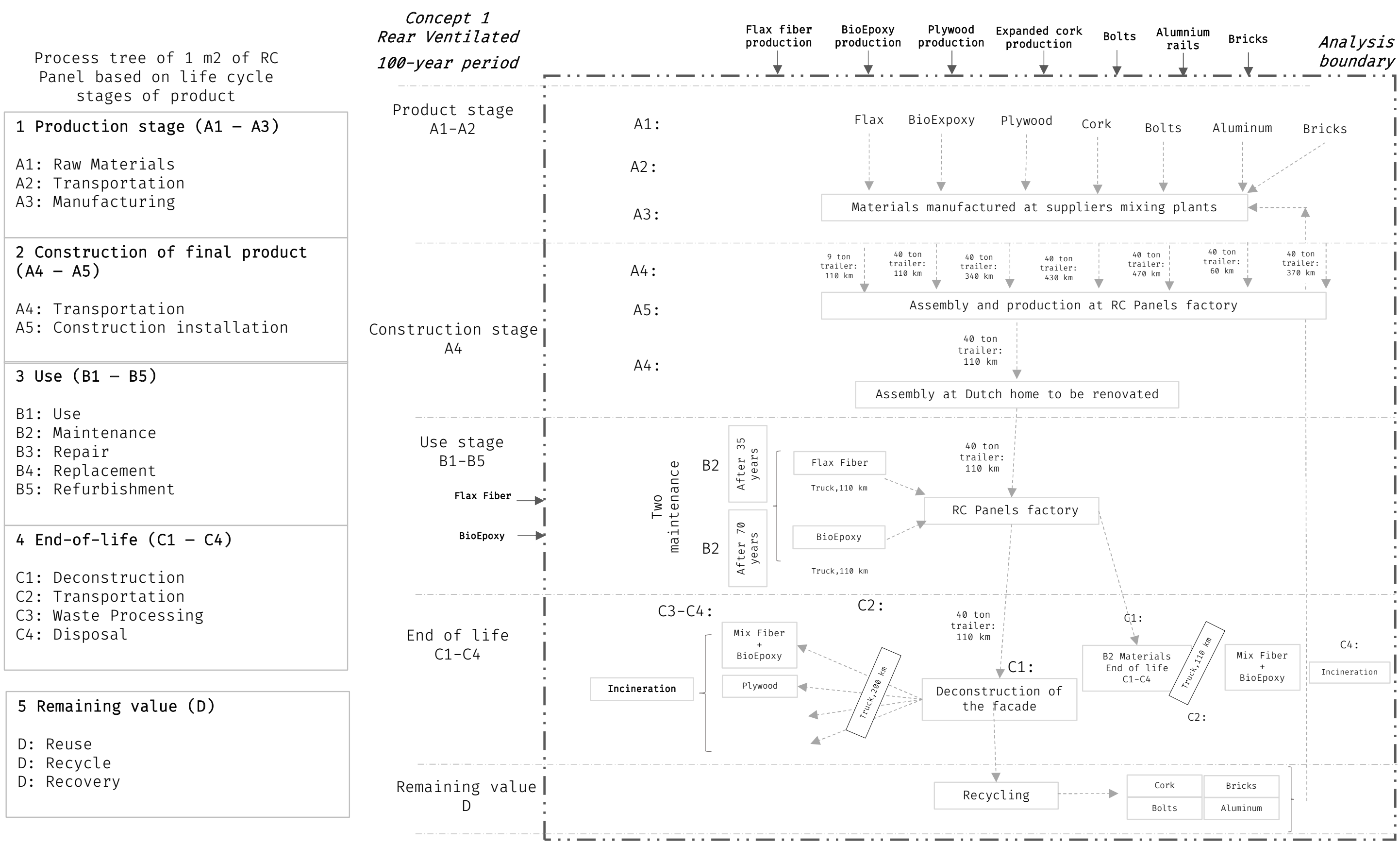


Figure 79 Concept one with Rear ventilated cladding - One home analysis

Concept 2 - Life cycle assessment. Cladding: Stucco

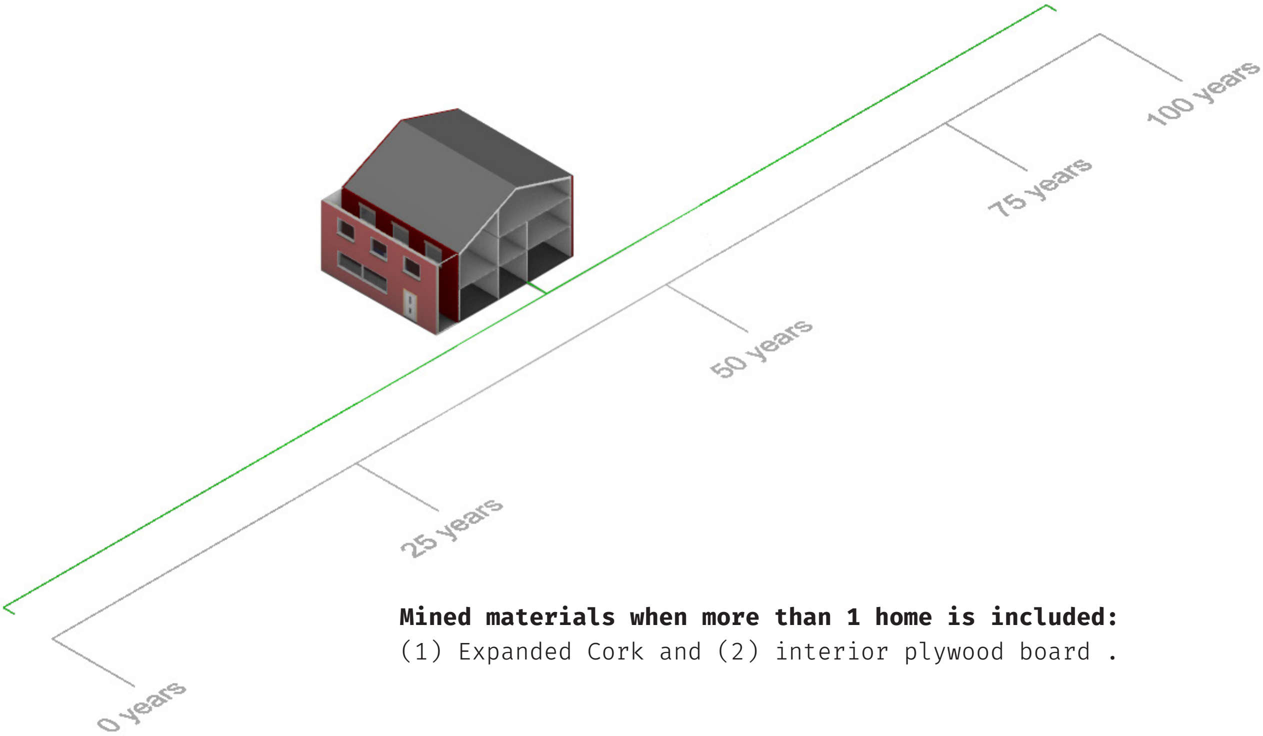
The LCIA process trees are shown in Figure 80 for the stucco cladding, and Figure 81 for the rear ventilated cladding.

For the stucco cladding, the panel life span is again set on the 50 years lifespan. Therefore, this double board panel needs to be recoated on-time more during the service life in year 50.

The bonding between the render mortar and exterior plywood board is again not easily removed. Hence, the plywood and the render are cut from the core. The exterior render + plywood is also considered the first line of defence of the system, and everything behind remains intact in the 100 years.

The mix between the render and the exterior plywood is sent incineration in both maintenances and after the 100 years. The interior plywood board can similarly be detached, and due to the absence of a membrane attached to it, these materials could be reused. However, this scenario does not include a second home for reuse yet, and plywood cannot be primary recycled. According to metsawwod, plywood can be only downcycled to woodchips, for example. Therefore this material disposed and processed. Finally, the cork core is detached from both boards, and the material is sent to recycling.

For the weighting factors, please refer to appendix O.



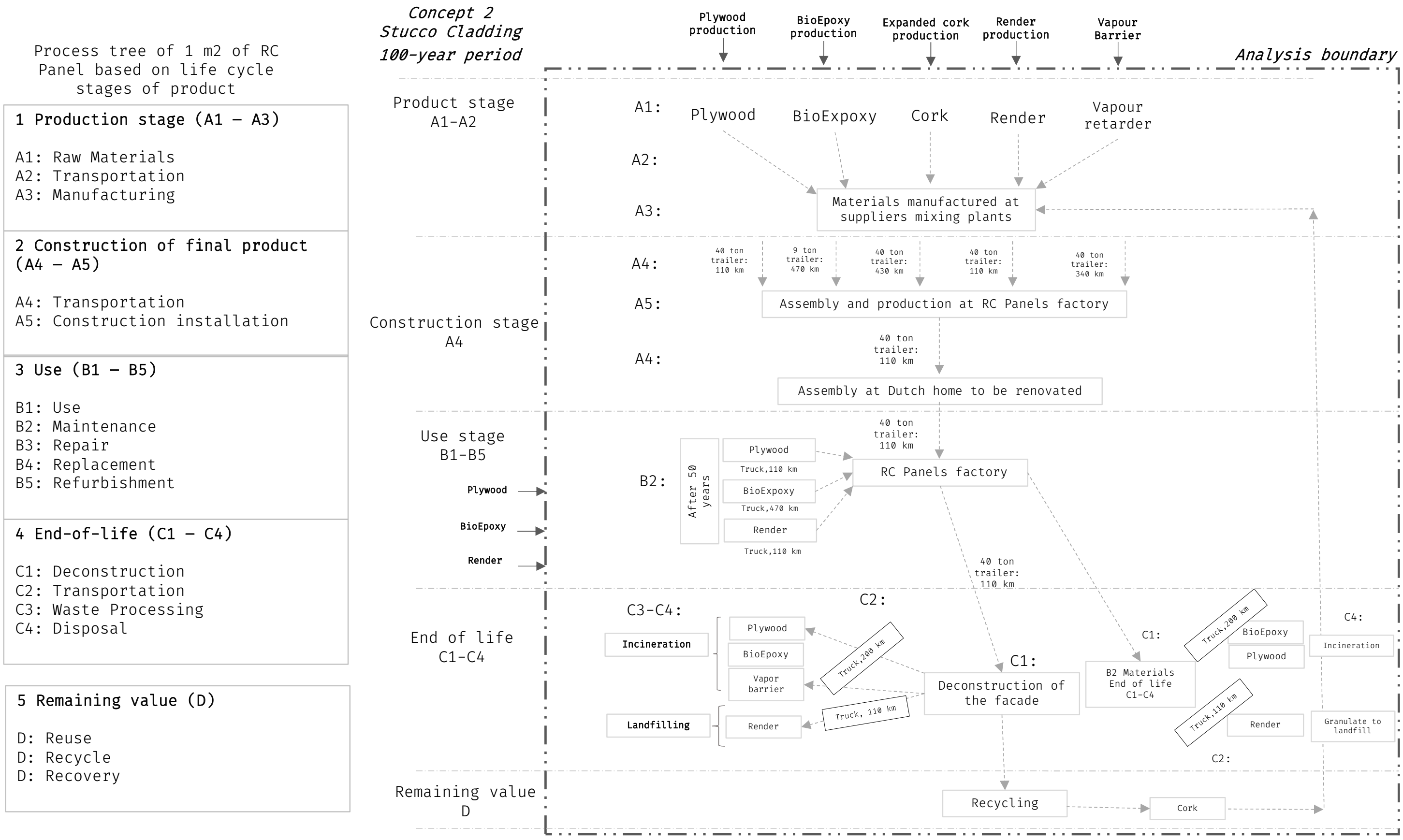


Figure 80 Concept two with Stucco Cladding - One home analysis

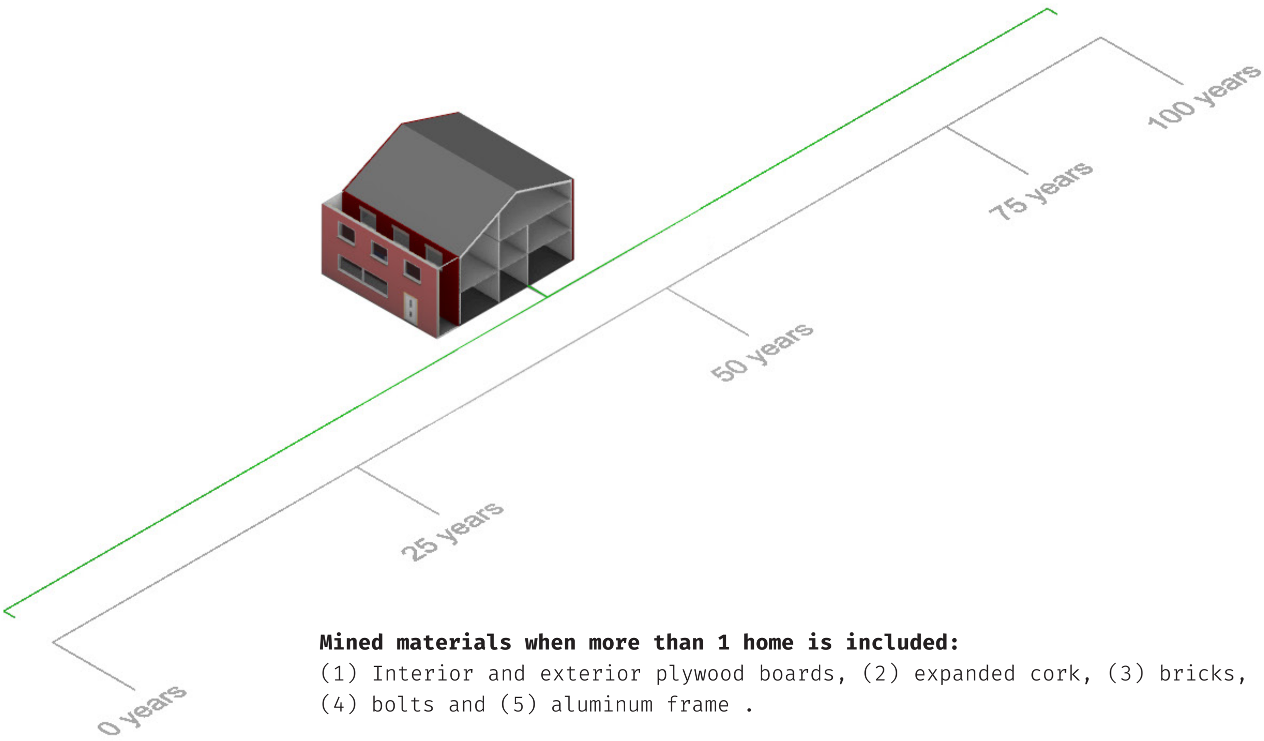
Concept 2 - Life cycle assessment. Cladding: Rear ventilated

For the rear ventilated cladding, the 1st line defence now relies on what is inside the cavity. In this case, there is not a membrane protecting the system but a wood board. Plywood is not weathertight, and water can come behind the ventilated façade. For these reasons, a waterproof membrane was selected. According to the environmental product declaration from "DURAPROOF technologies GmbH", this membrane becomes the first line of defence, and its life expectancy is 40 years. Hence, the "main thermal sandwich" gets a new waterproofing membrane. To avoid any chemical bonding between the plywood board and the waterproofing membrane, butyl tape was selected as a method to seal the membrane sheets. This to allow future reuse of the plywood in the future circularity scenarios when more homes are involved.

The waterproofing membrane and the butyl tape will be replaced twice in forty and one more in year eighty. In both cases, the façade is disassembled from the renovated home and taken back to the factory where the bricks and aluminium rails are removed. The existing waterproofing membrane and tape are removed from the plywood they are disposed.

At the end of the service life, the materials suffering a chemical connection such as the two biocomposite membranes and the plywood are sent to incineration. The rest of the modular components coming from the rear ventilated cladding (bricks, bolts, and aluminium) and the cork core are sent to a technical recycling cycle

For the weighting factors, please refer to appendix P.



Mined materials when more than 1 home is included:
(1) Interior and exterior plywood boards, (2) expanded cork, (3) bricks, (4) bolts and (5) aluminum frame .

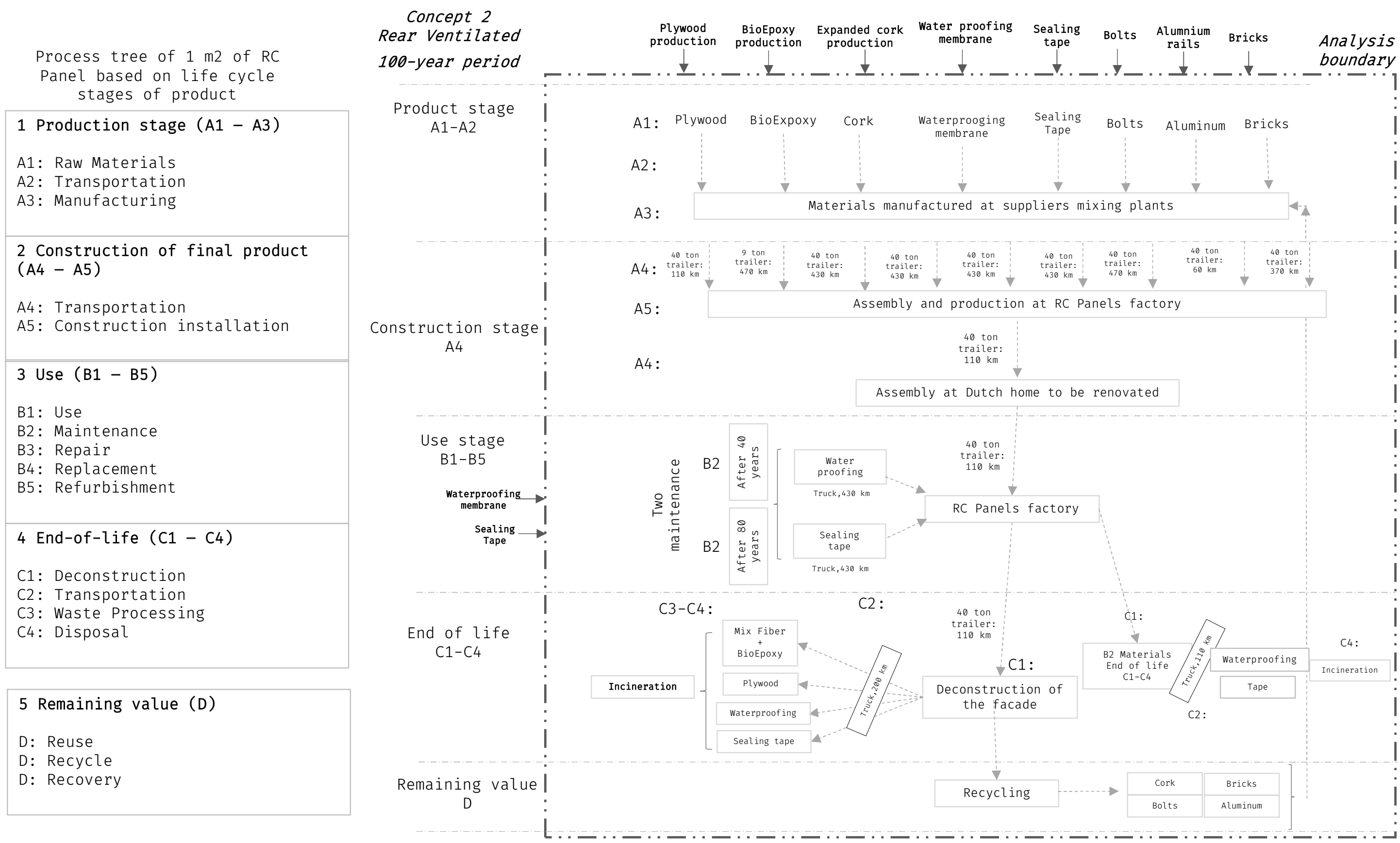


Figure 81 Concept two with Rear ventilated cladding - One home analysis

Concept 3 - Life cycle assessment. Cladding: Stucco

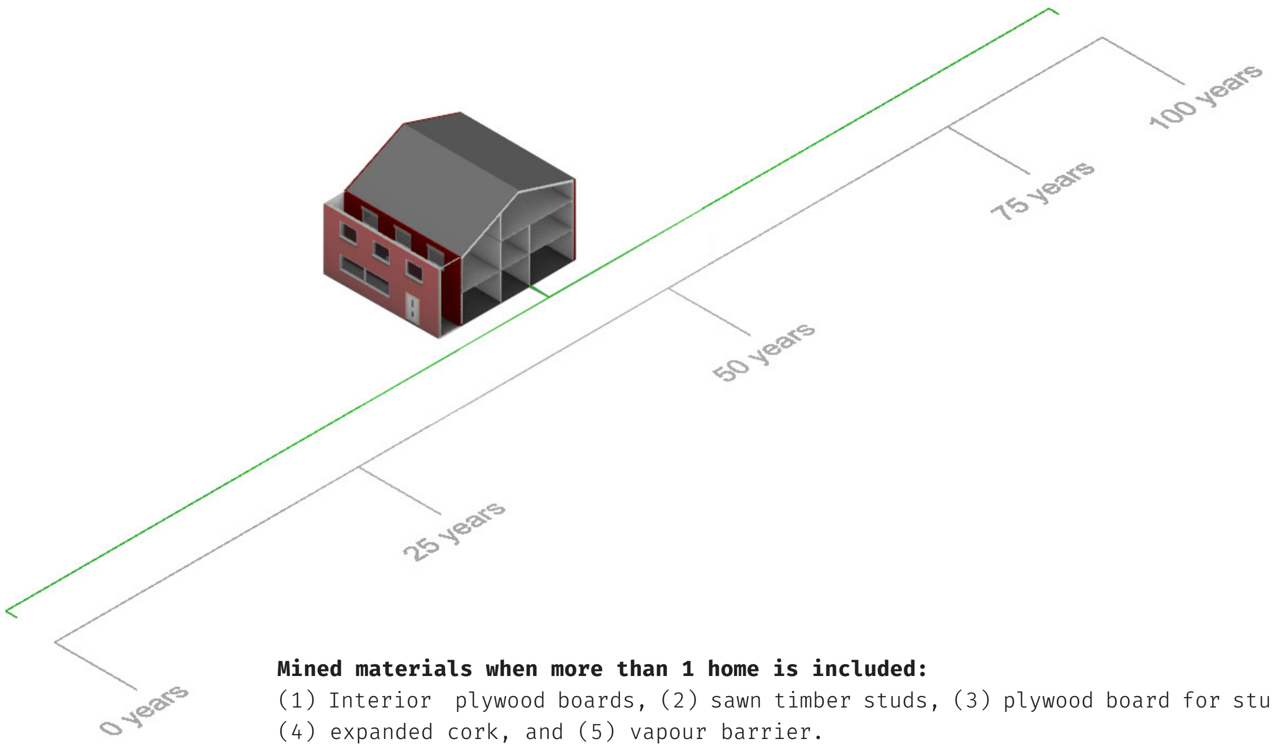
The LCIA process trees are shown in Figure 82 for the stucco cladding and Figure 83 for the rear ventilated cladding.

For the stucco cladding, the panel life span is again set on the 50 years lifespan and the panel is recoated one time more during the service life in year 50. The bonding between the render mortar and exterior biocomposite is again not easily removed. Hence, both materials are peeled from the core.

The exterior render + biocomposite is still the first line of defence of the system, and everything behind remains intact in the 100 years. The mix between the render and the biocomposite is sent incineration in both the maintenance and after the 100 years.

At the end of the service life, the interior biocomposite membrane is sent to incineration as its not 100% biodegradable and the core is extracted and sent to recycling. The interior framing of the panel is meant to be bolted, and therefore, it can be all dismantled and reused. However, this scenario still does not include a second home hence after used they are disposed. In the case of the sawn wood studs, they cannot be primarily recycled, however, they could be sent to a biological cycle where they enter the biosphere by natural degradation. In the sheathing board covering the studs, they are made from plywood which is not a biodegradable resource, and therefore the materials are incinerated.

For the weighting factors, please refer to appendix U.



Mined materials when more than 1 home is included:
(1) Interior plywood boards, (2) sawn timber studs, (3) plywood board for studs, (4) expanded cork, and (5) vapour barrier.

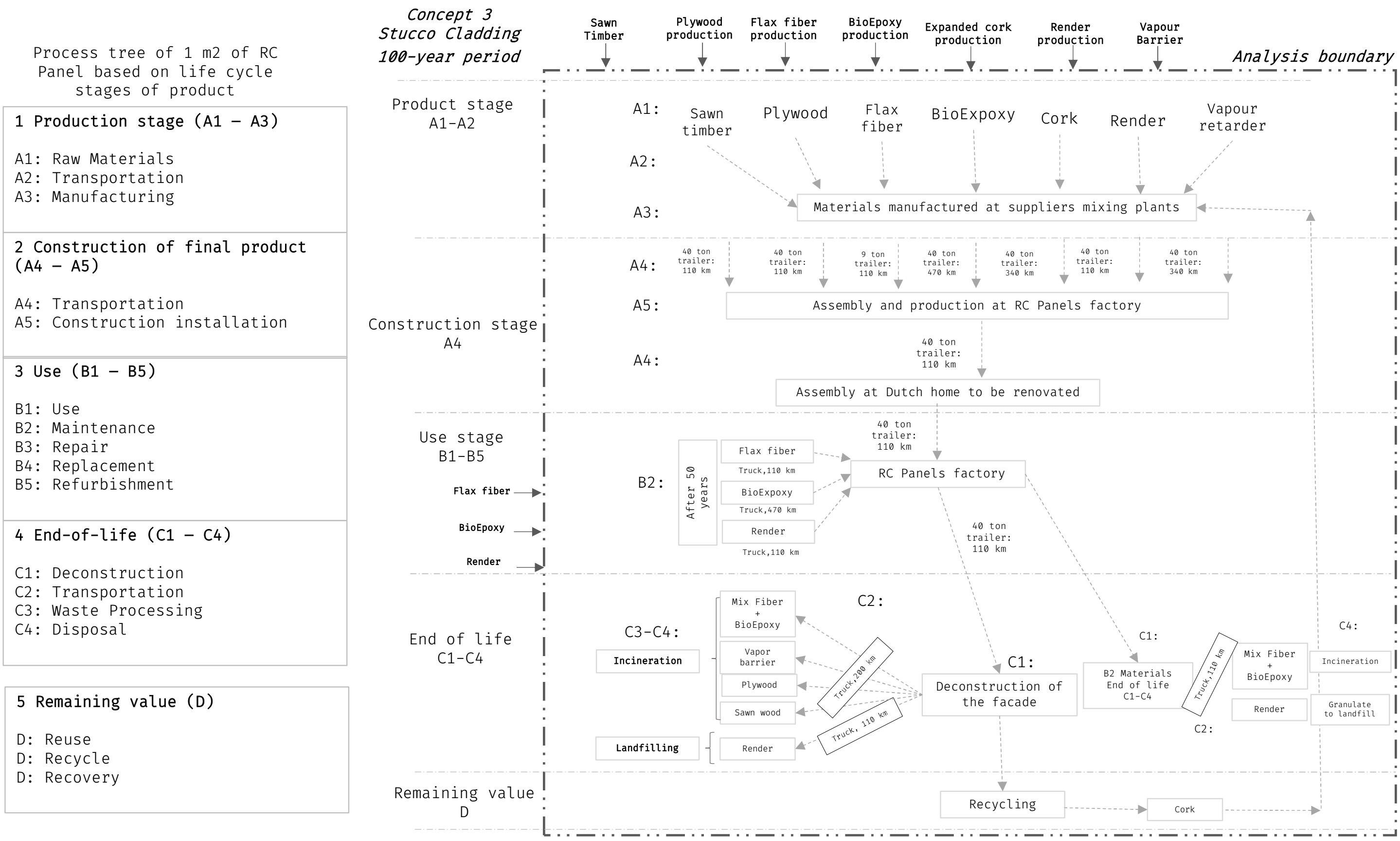


Figure 82 Concept three with Stucco Cladding - One home analysis

CHAPTER | EVALUATION PHASE - LCA

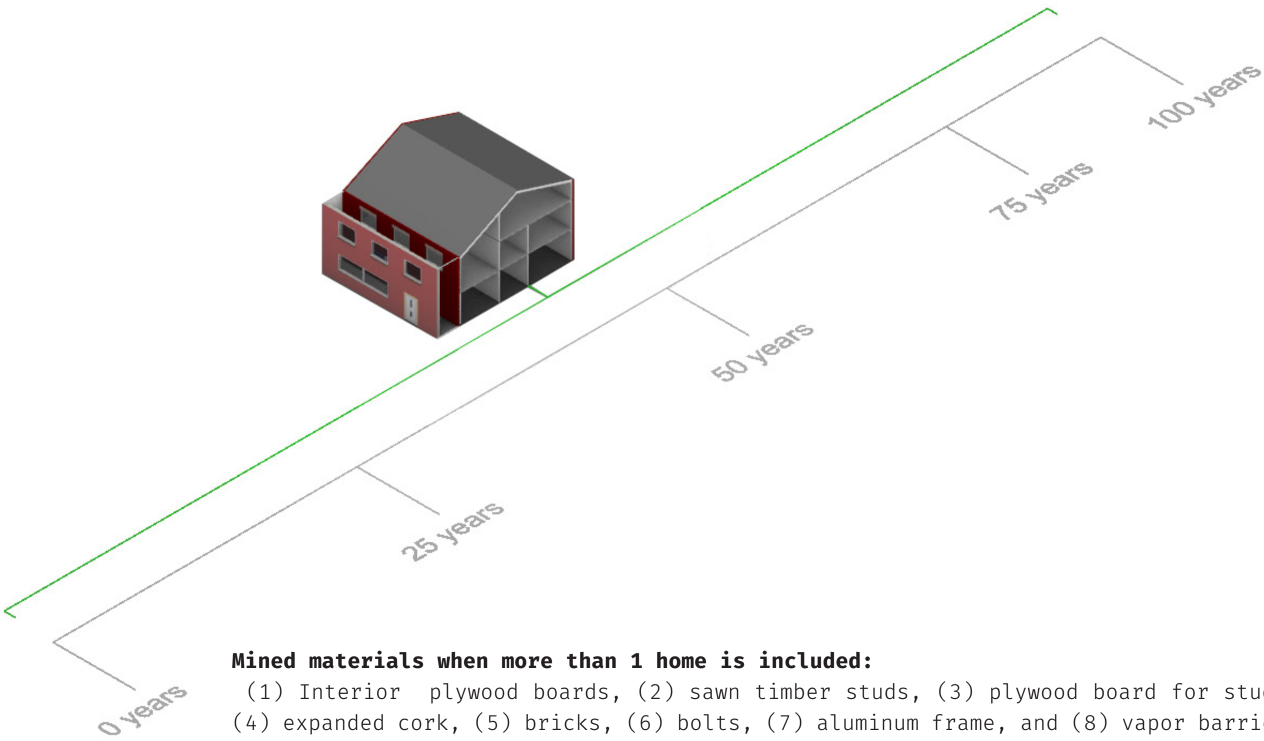
Concept 3 - Life cycle assessment. Cladding: Rear ventilated

For the rear ventilated cladding, the 1st line defence now relies on what is inside the cavity. In this case, there is again a biocomposite protecting the system with thirty-five-year durability as in concept one. Hence, the “main thermal sandwich” gets a biocomposite in years thirty-five and seventy.

In the maintenance’s periods, the panel goes back to the factory. The modular components coming from the rear ventilated cladding (bricks, bolts, and aluminium) are disassembled, and the biocomposite is replaced. Both times the biocomposite is disposed of and incinerated.

At the end of the service life, this concept relies on complete disassembly in all the materials. Still, the exterior biocomposite and the cork could be extracted and recycle or reuse. Suppose second or more homes are included in the analysis. In that case, all the modular materials like horizontal plywood, sawn wood stud, vertical wood, bricks, bolts, and aluminium with no chemical bonding would potentially re-enter the full reuse cycle. However, this is not included in the first circularity scenario. The biobased materials are disposed as done with the stucco cladding, and the rear ventilated façade components are sent to primary recycling.

For the weighting factors, please refer to appendix V.



Mined materials when more than 1 home is included:
(1) Interior plywood boards, (2) sawn timber studs, (3) plywood board for studs, (4) expanded cork, (5) bricks, (6) bolts, (7) aluminum frame, and (8) vapor barrier.

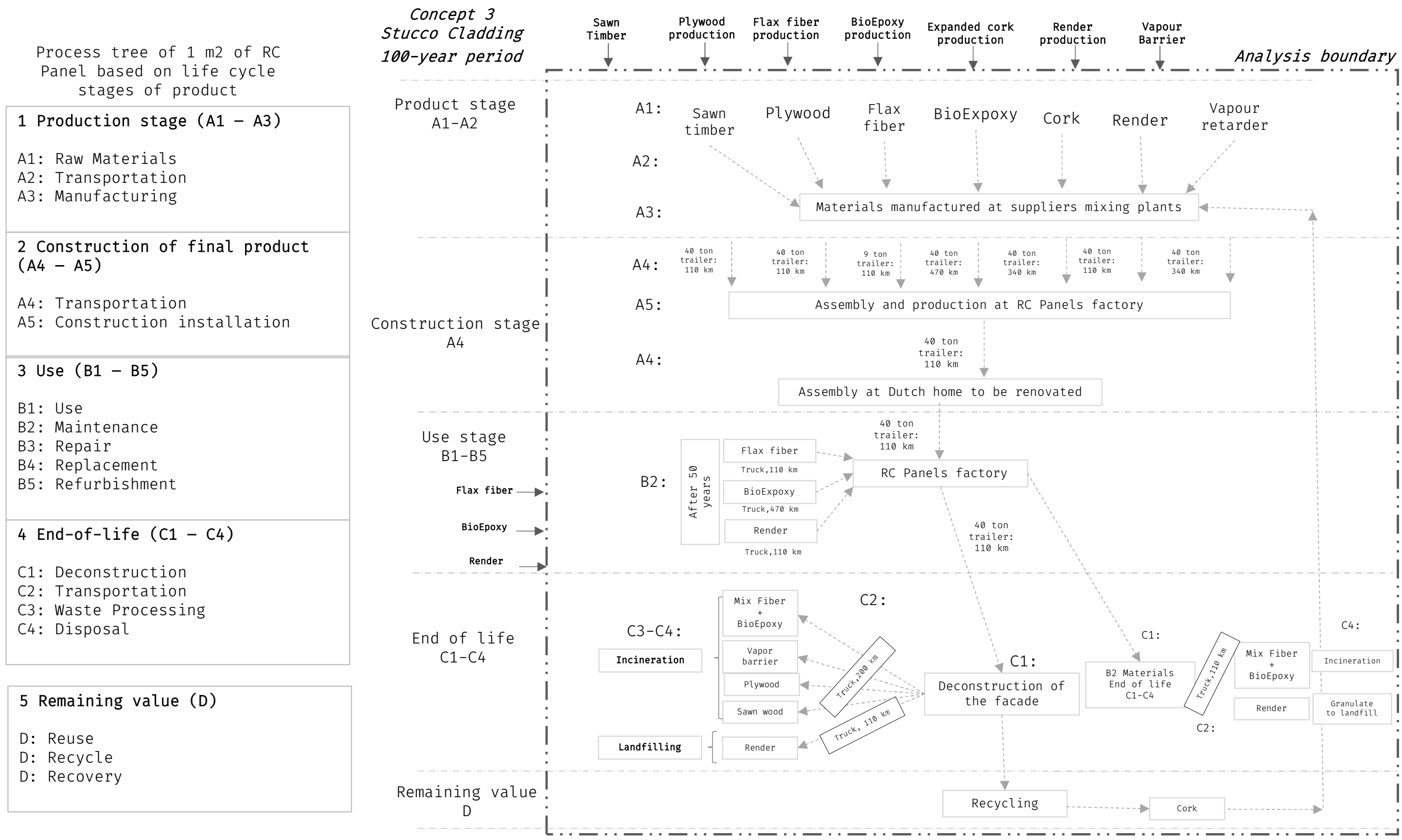


Figure 83 Concept three with Rear ventilated cladding - One home analysis

Cradle to Cradle analysis - 2nd and 3rd Circularity Scenarios

The following two circularity scenarios differ from the first one in the number of homes retrofitted in the 100 years. The first scenario (Figure 84) has two terrace homes where the skeleton of the first retrofitted home is used for 50 years. Then a second home will receive the mined materials and reuse them for the next 50 years. In between the periods, the correct maintenance and replacement of the main components like the first lines of defence are included. Similarly, the third scenario (Figure 85) splits in two the periods and now four homes are included, the first retrofitted home skeleton is used for 25 years then a second home will receive the mined materials and reuse them for the following 25 years. The process will repeat itself until the panel reaches the 4th home and completes the 100 years.

Functional unit

The functional unit for the materials will be the same 1 m2 for all the 12 new variants. These twelve options come from the two new circularity scenarios combined with the three concept design and 2 cladding systems. The expanded cork insulation panel is still the core of the panels. Each materials quantity can be reviewed in the appendix XX

Further, the Life Cycle Inventory (LCI) will include in “phase D” to reuse complete materials going back to the new manufacturing of a façade. This means that the façade panels will be taken down from the first retrofitted homes, taken back to the factory to start deconstruction and separate nutrients that can be “mined and reused” or “processed and disposed”.

Each dwelling has different dimensions in windows, door, balconies, and in their own deformations (one of the main reasons why RC Panels does a cloud scan before starting the manufacturing process). For this reason, materials with a chemical bonding and not allowing complete separation between resources for further reused are processed and disposed. The materials that can be mechanically disassembled will go back to “Phase A5” where the façade for a new home will be manufactured. In all the processes, the waste and emissions ‘leaving’ the system will be considered. This analysis is presented in Figure 86.

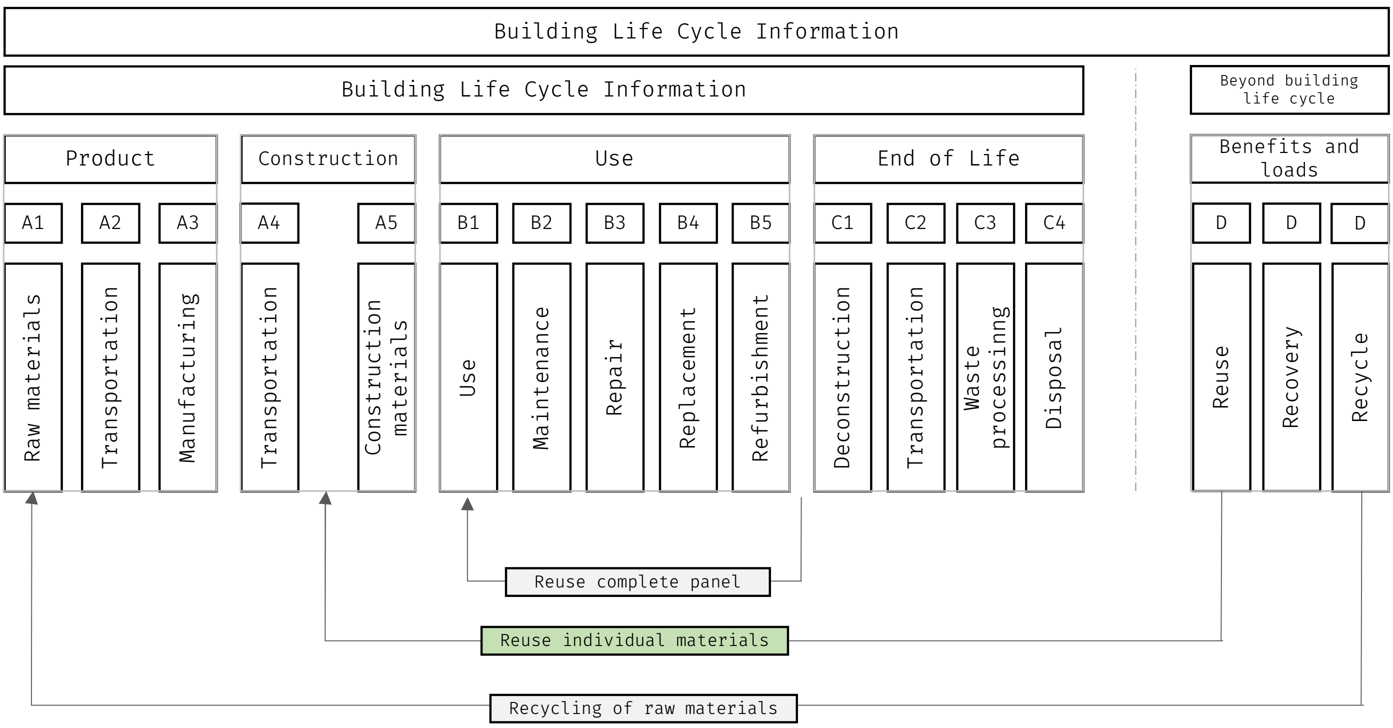


Figure 86 Cradle to Cradle - 2nd and 3rd circularity analysis

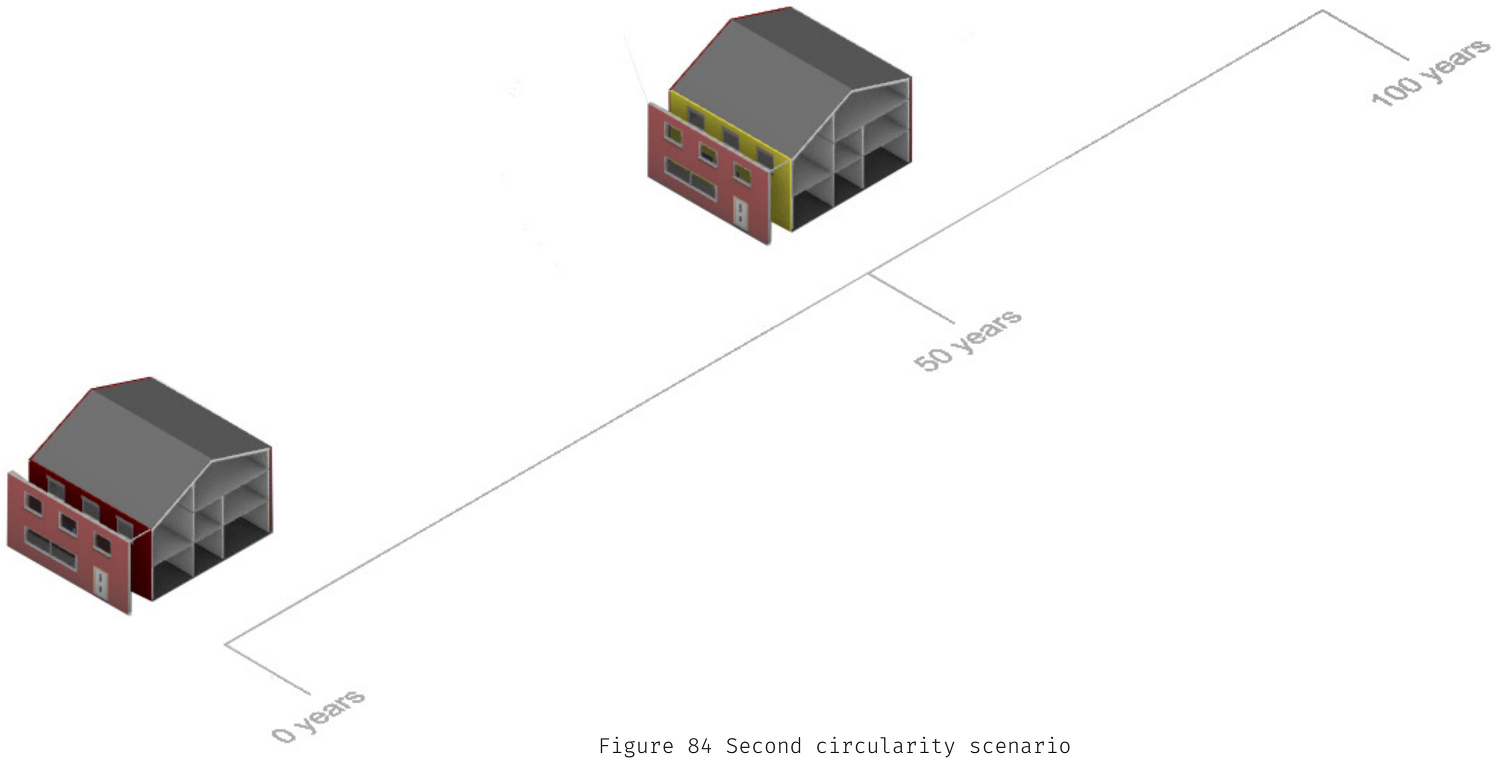


Figure 84 Second circularity scenario

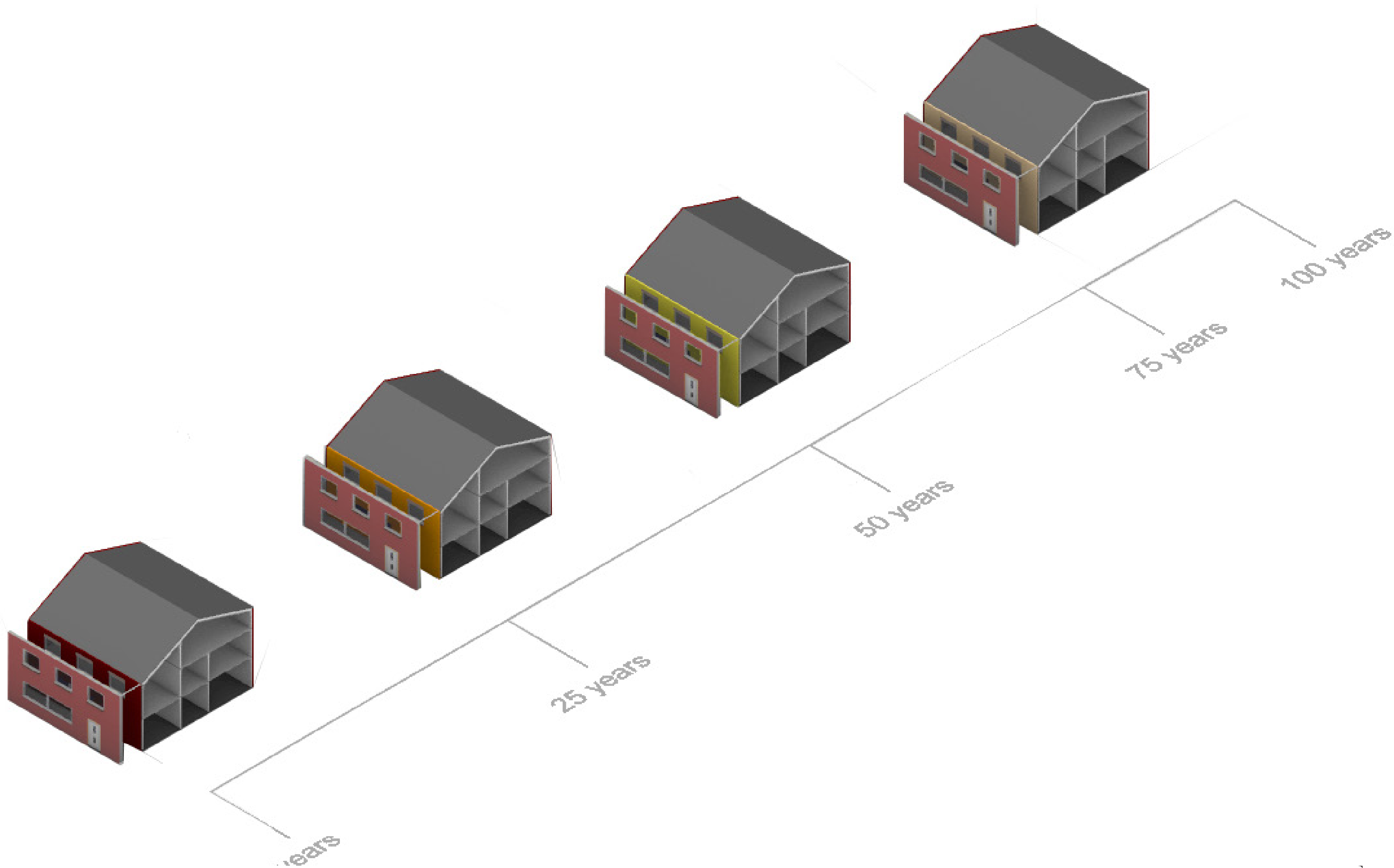


Figure 85 Third circularity scenario

Circularity scenarios results and interpretations.

The results of the three circularity scenarios will be further discussed. First, calculating the environmental impact in the 100 years analysis with one single home is presented. For ease of visualization, the six designs are labelled with a C1, C2 or C3 for concept one, two and three, respectively. Also, each of them has specified the type of cladding used for the analysis; please refer to Figure 87.

All the weighting factors, quantities and materials lists can be found in APPEDIX AAA

The environmental costs index (ECI) of the resources used for each design concept in the first circularity scenario, are presented in Figure 88. As seen in the graph, by using the panels in a single home, only two out of the six new design alternatives result in better ECI than the original design. These two designs are the two "biobased sandwich panels". C1-Mineral brick scores 24.1% better and C1-Rear Ventilated with an 8.2%.

The remaining design options score higher than the original panel, the highest is C3-rear ventilated scoring 26.4% higher: this is the hybrid frame/sandwich panel with a rear ventilated façade. Then, the second worst option is the C2-Rear ventilated façade scoring 13.5% followed by the C2-mineral brick and C3-Mineral brick with 5.5% and 5.1% respectively.

In Figure 89, the environmental effects per product phase are shown. All the design options except for the two biobased sandwich panels have a higher ECI in the product phase. This means that the last four options will have more emissions than the original design at the earliest life cycle phase. Even though some designs rely as much as possible in biobased products, they still have a higher environmental impact.

In the product phase (A1-A5) the biobased sandwich panels score 29% lower for the mineral brick option and 18% lower for the rear ventilated façade. In use Phase (B1-B5) the maintenance of the panel with the mineral brick reduces 2% the environmental effect by using a biocomposite instead of a the GFP layer. Meanwhile, the rear ventilated façade scores 140% than the original design maintenance. This is because the stucco finish has a life span of 50 year whereas the biocomposite only has 35 years when working as the 1st line of defense. This also means that in the rear ventilated cladding the biocomposite is replaced two times as shown in Figure 79.

The option with higher ECI in the product phase is option C2-rear ventilated with 20% more impacts than the original panel. This option uses more materials due to the two-plywood board, aluminum rails, bricks and the water proofing membrane. In the other hand, the option with higher ECI in the Use phase is C3-Rear ventilated, this option uses again as 1st line of defense the biocomposite with a 35-life span which, as mentioned before, needs to be replaced two times in 100 years

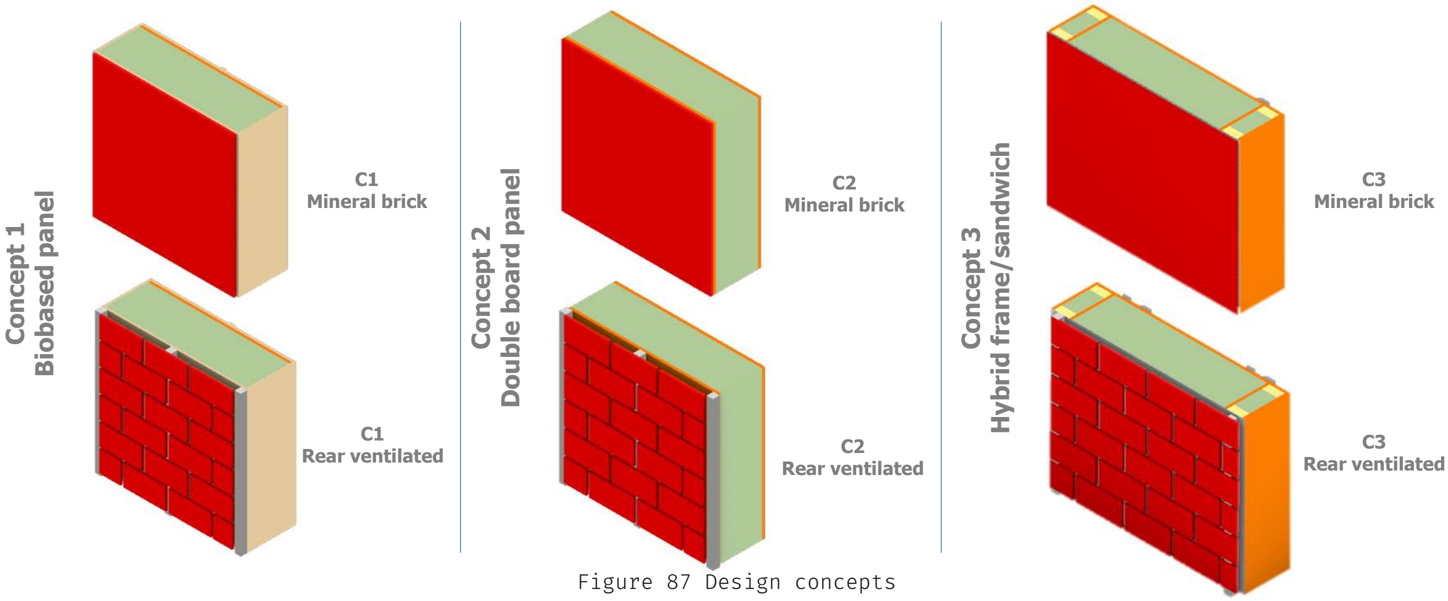
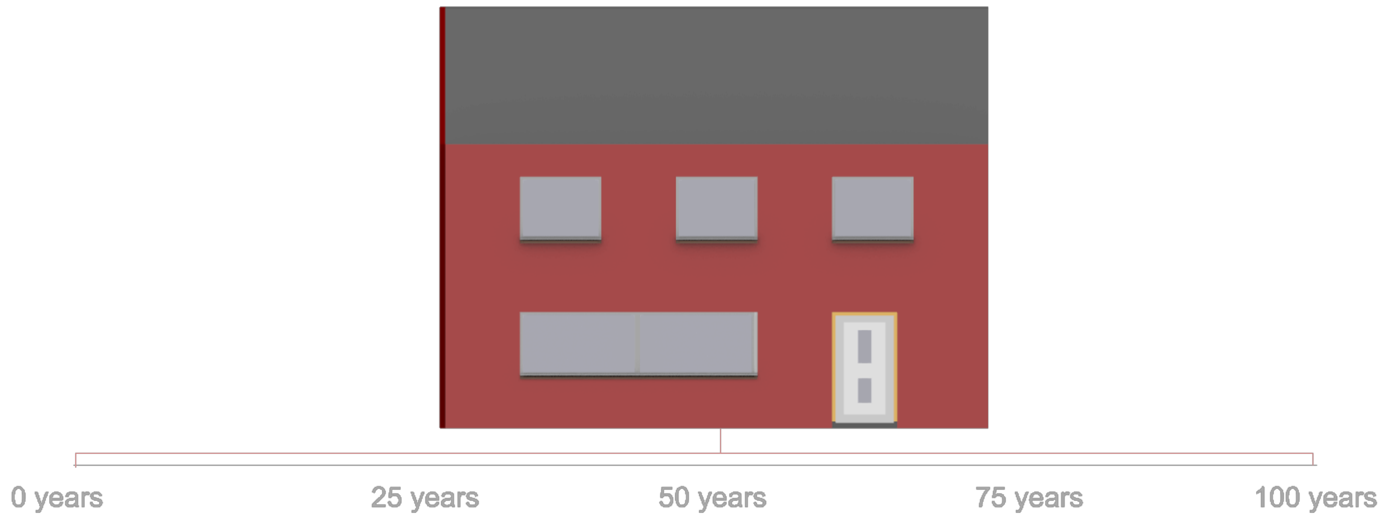


Figure 87 Design concepts



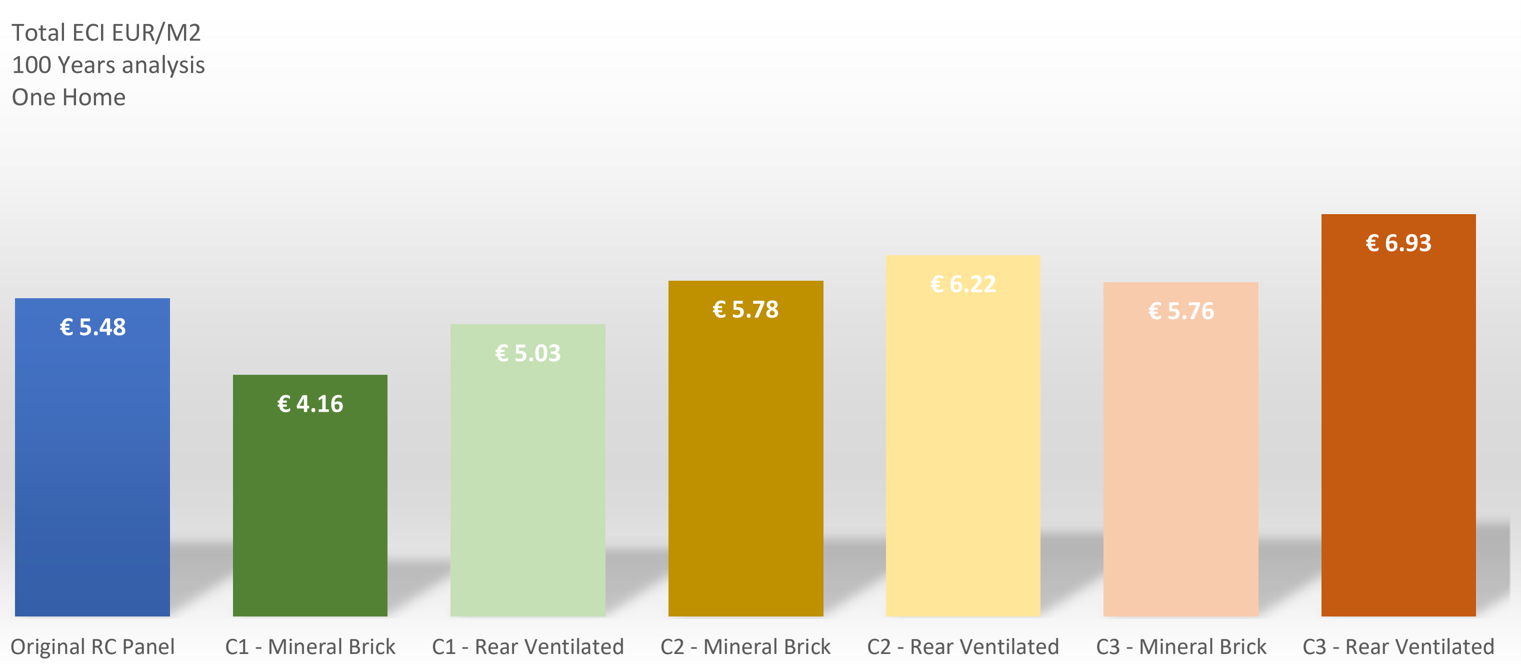


Figure 88 Environmental cost per m2 - First circularity scenario

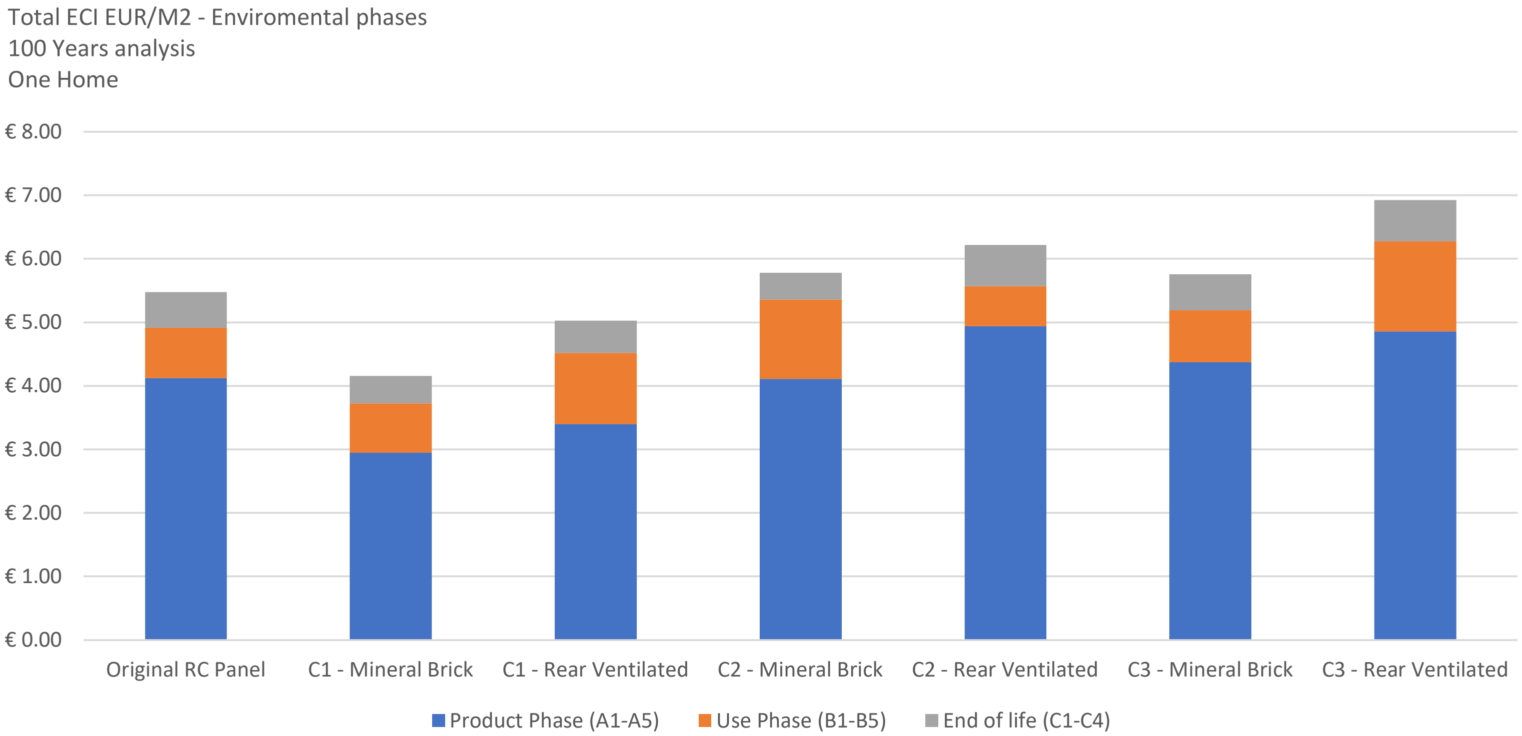


Figure 89Environmental impact per phase - First circularity scenario

Circularity scenarios results and interpretations.

Now, the calculation of the environmental impacts in the 100 years analysis with two homes is presented. The labels of the design options are the same as C1, C2 or C3 for concept one, two and three, respectively. Also, each of them has specified the type of cladding used for the analysis, please refer to Figure 87.

The environmental costs index (ECI) of the resources used for each design concept in the second circularity scenario are presented in Figure 90. As seen in the graph, now three out of the six alternatives generate a better impact than the original design. However, these are now the three options using the Mineral brick cladding. C1-Mineral brick scores 20.5 % better, C2-Mineral brick scores 15.7 % better, and C3-Mineral brick scores 17.5 % better. The fact that the last two options have the possibility to reuse materials in the main thermal panel by avoiding a membrane (in the case of concept 2) and having a frame system (in the case of concept 3) makes them score better than the original panel.

In Figure 91 the environmental effects per phase are shown. Here, it can be noticed how the options with the mineral brick have a lower ECI in the production phase when compare with their “equals” with the rear ventilated façades. Also, in the remaining value (phase D), all the options with the possibility to mechanically detached materials and reuse them for the second home start to have a lower ECI in the remaining value phase (D).

The two biobased sandwich panels have a higher ECI for the 2nd home analysis. This is mainly because most of the materials in these options and in the original design can not be reused in a new home. The only materials that can be extracted from the sandwich panel is the core. The rest of them, due to their chemical bonding, are processed and disposed. In Figure 92 it can be immediately seen how the first home get a higher impact in the options for concept 2 and concept 3; however the second home starts to reduce the amount of materials needed.

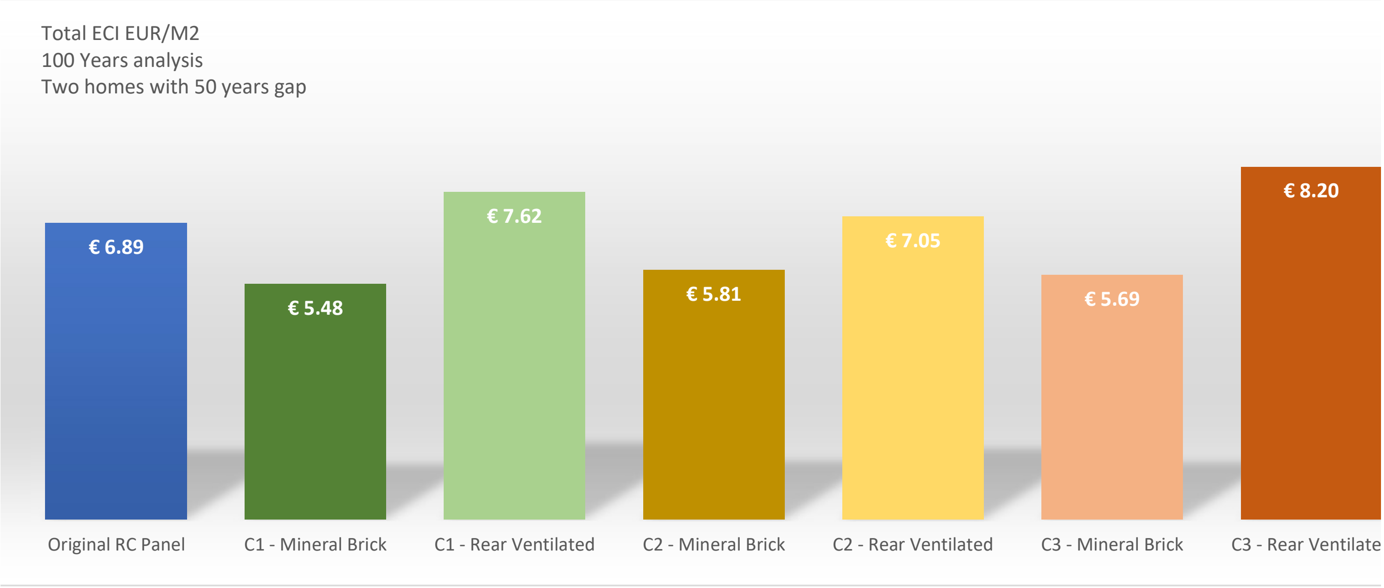
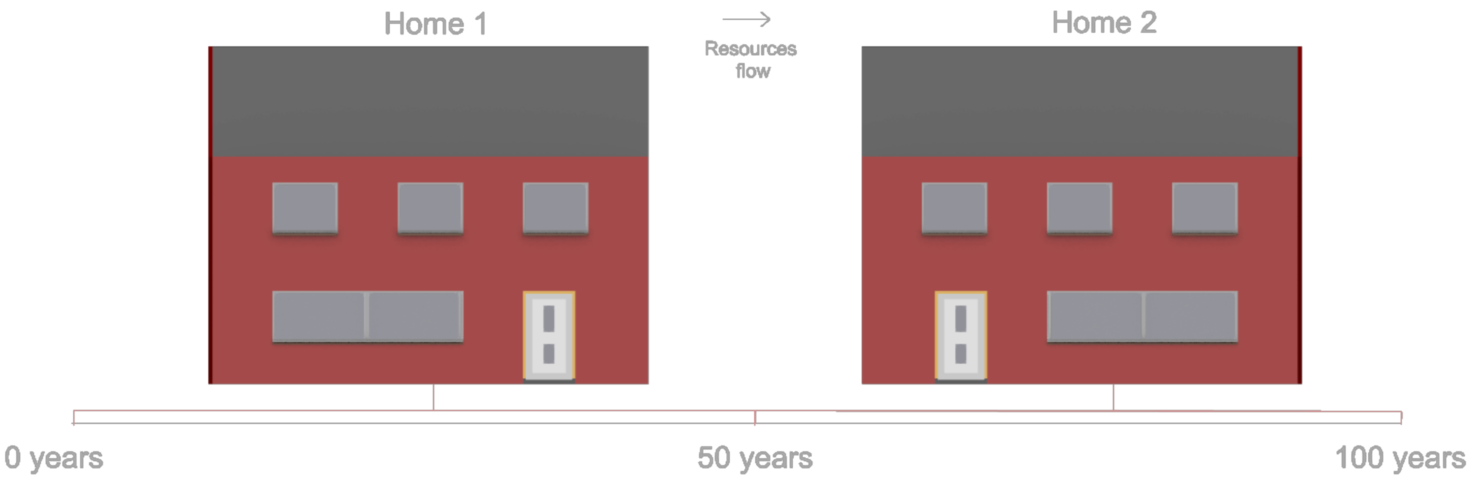


Figure 90 Environmental cost per m2 - Second circularity scenario



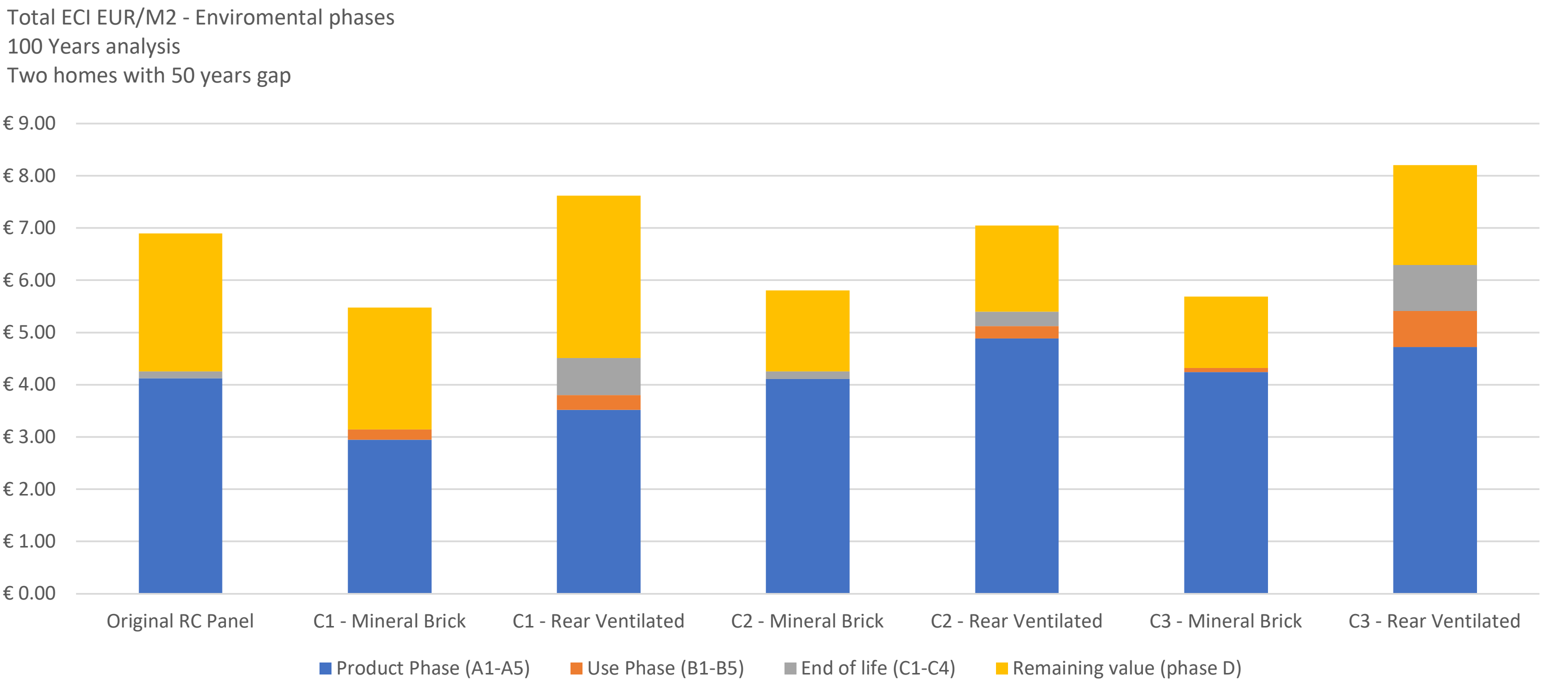


Figure 91 Environmental impact per phase - Second circularity scenario

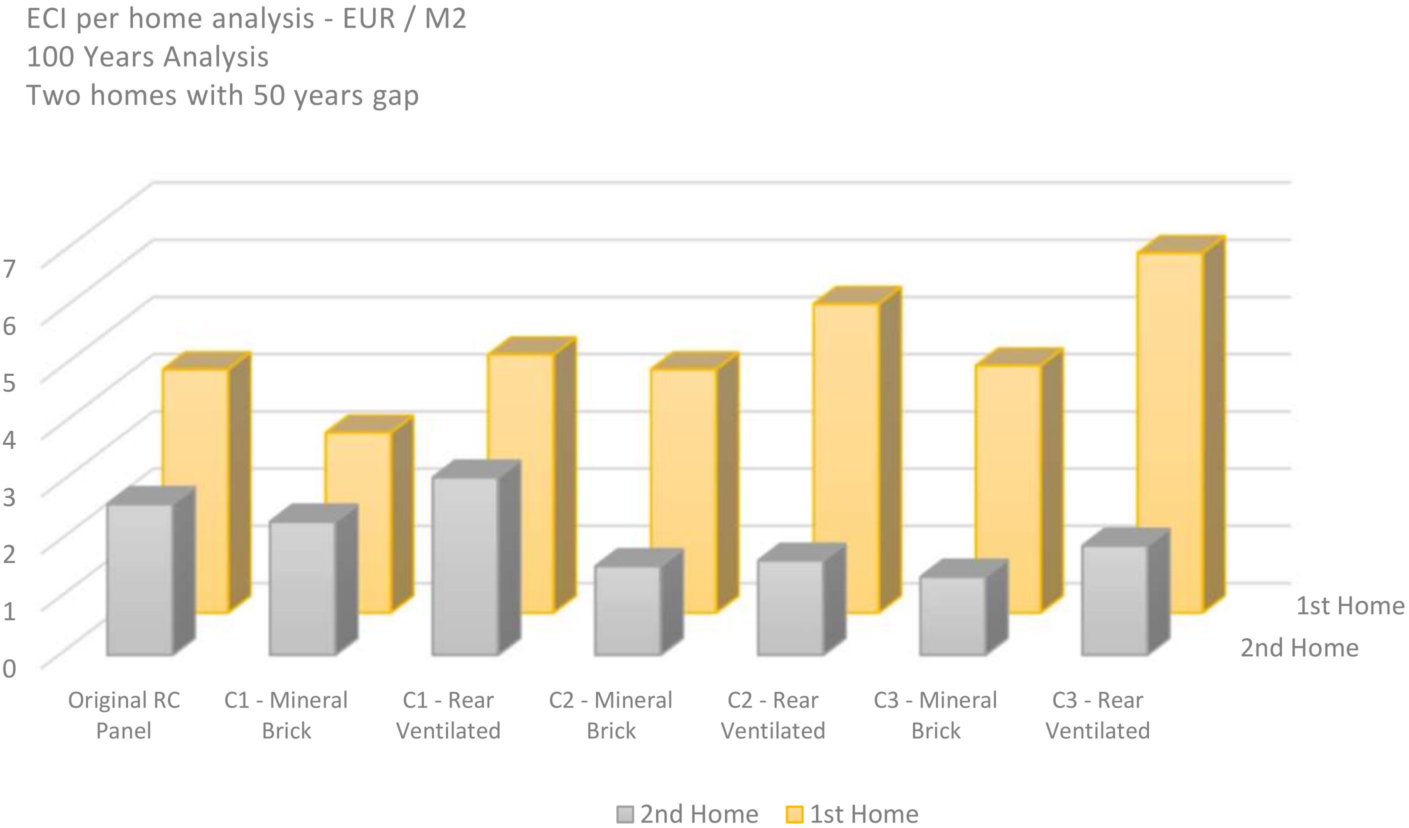


Figure 92 Environmental cost per home - Second Circularity Scenario

Circularity scenarios results and interpretations.

Finally, the calculation of the environmental impacts in the 100 years analysis with four homes is presented. Again, the same labels of the design options are used.

The environmental costs index (ECI) of the resources used for each design concept in the third circularity scenario are presented in Figure 93. As seen in the graph, now all the six new design alternatives generate a better impact than the original design. C1-Mineral brick scores 13.7%, C1- rear ventilated scores 10.8%, C2-mineral brick scores 21.7%, C2-rear ventilated scores 28.4%, C3-Mineral brick scores 30.1%, C3- rear ventilated scores 25.5%,

The best design in this scenario is C3-mineral brick; this option is the hybrid frame/sandwich panel with a stucco finish. As seen in Figure 94, the number of outputs due to the resources used for the following homes is considerably less than the rest of the original panel. Even though, the original panel and concept 1 options use fewer materials in the first home, in the long term, they end up using more due to the impossibility to reuse the panel´s materials. Also, only if the new design options are compared between each other, the two biobased sandwich panel are now the ones with the highest ECI.

In Figure 95 it can be noticed how the designs in concepts two and three have more materials usage when compare with the biobased sandwich panels. However, from the 2nd to the 4th home concepts two and three reduce considerably the use of new materials.

The option with lowest ECI in phase “D” is C2-rear ventilated facade, having 56% less emission than the original panel in the subsequent homes. However, this options still uses more materials than the C3-mineral brick making this option the best alternative with this circularity scenario.

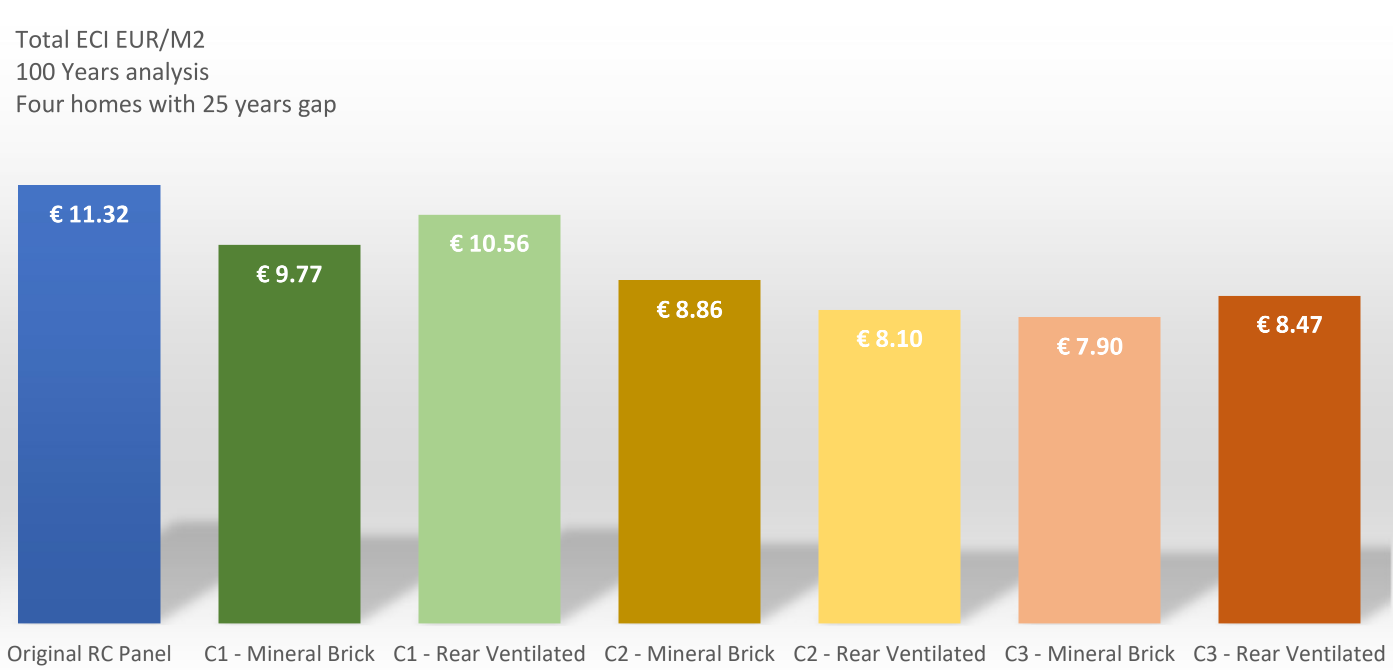
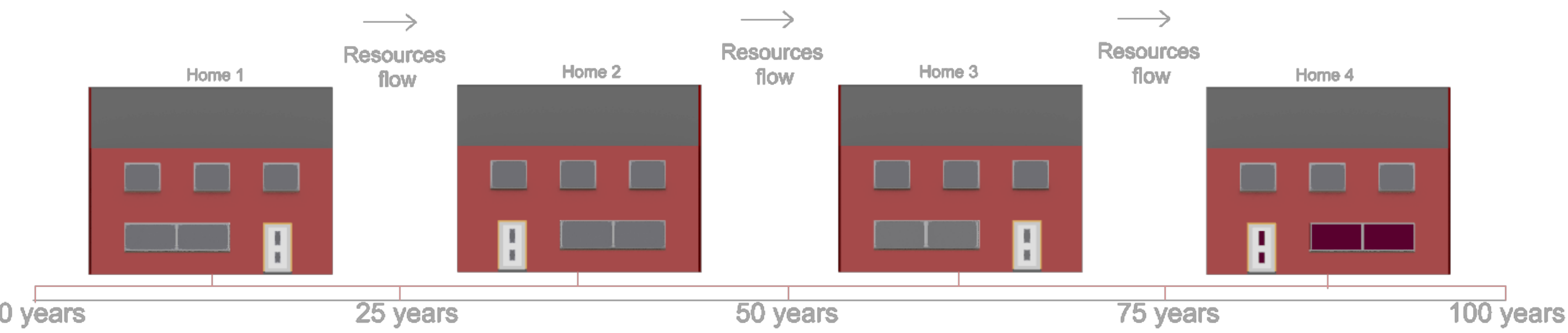


Figure 93 Environmental cost per m2 - Third circularity scenario



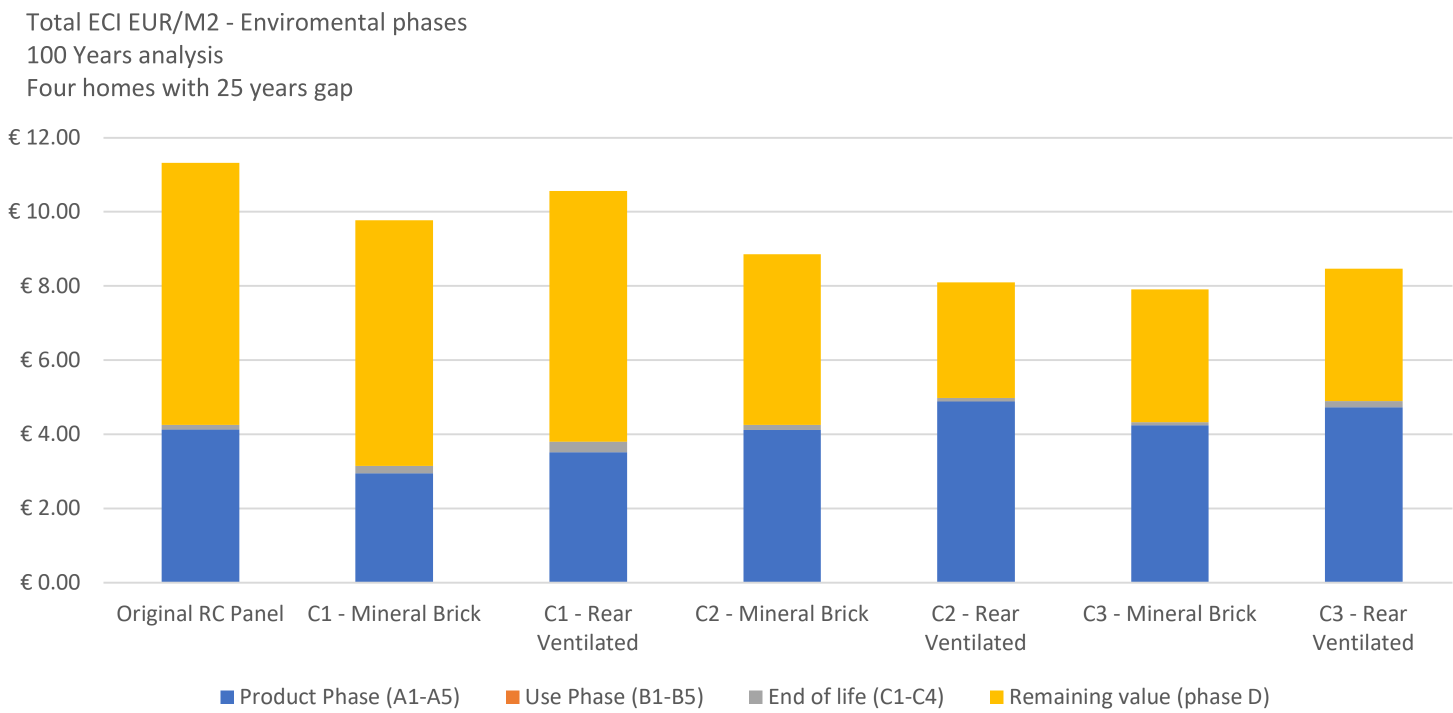


Figure 94 Environmental impact per phase - Third circularity scenario

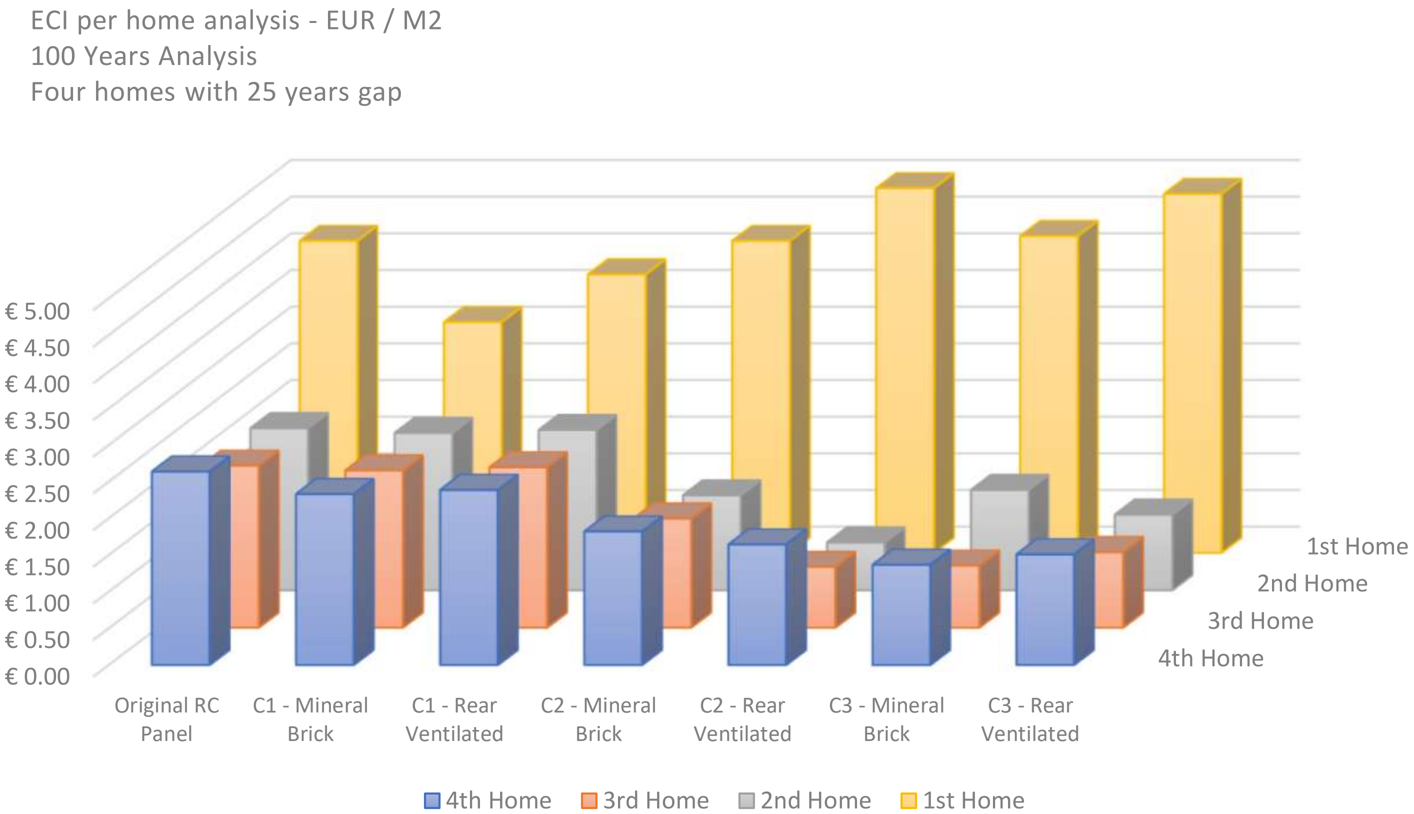


Figure 95 Environmental cost per home - Second Circularity Scenario

Core materials comparison

An LCA will be performed to understand the difference in changing the core between expanded cork and wood fiber. Now that the best design options are known, only design concepts one and three with the mineral brick cladding will be analyzed with an average thickness for each one (Table 8).

To simplify the calculation, only the insulation layer will be reviewed in a cradle to grave basis, including the product phase (A1-A5) and end of life phase (C1-C4). Then a percentage will be obtained to correlate the emission with the previously mentioned design concepts in their different specific circularity scenarios.

Figure 96 and Figure 97 include calculating the environmental cost index of 1 m2 of cork and 1 m2 of wood fibre. For both, an average thickness was considered. Since the insulation core is reused for over 100 years in all the scenarios assuming no damage occurs inside the panel, the use phase was neglected. Also, since the transportation from the factory to the housing will take place in both options and the densities do not represent a significant difference, this parameter was not considered.

The ECI for 1 m2 of expanded cork result is 1.23 EUR/m2 while for 1 m2 of wood fiber is 2.04 EUR/m2. The difference between them is 67% in the product phase and 60% in the end of life. The total difference is 65.8% between both resources.

Once this percentage is calculated, for the best design option in each circularity scenario, wood fibre will be included and compared with the original RC Panel.

Circularity scenario 1
Concept 1 with the mineral brick cladding (Figure 98)

Circularity scenario 2
Concept 1 with the mineral brick cladding (Figure 99)

Circularity scenario 3
Concept 1 with the mineral brick cladding (Figure 100)

Resource	Functional Unit	Density	Average thickness
		Kg/m3	mm
Wood fiber	1 m2	140	288
Cork board	1 m2	130	253

Cork board

A1-A4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Product Manufacturing			kg CO2e	kg SO2e	kg PO4e	kg CFC11e	kg Ethenee	MJ
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
			1.96E+01	**2.52E-03**	**8.53E-04**	**2.94E-08**	**1.44E-04**	**4.29E+00**

C1-C4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
End of life (Deconstruction)			kg CO2e	kg SO2e	kg PO4e	kg CFC11e	kg Ethenee	MJ
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2	1	m2	3.75E+00	5.09E-03	1.11E-03	1.78E-12	4.20E-04	1.35E+01
			3.75E+00	**5.09E-03**	**1.11E-03**	**1.78E-12**	**4.20E-04**	**1.35E+01**

			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
Monetary value (Euros/Emission unit)			EUR 0.05	EUR 4.00	EUR 9.00	EUR 30.00	EUR 30.00	
Product Manufacturing	1	m2	$0.98	$0.01	$0.01	$0.00	$0.00	$1.00
End of life	1	m2	$0.19	$0.02	$0.01	$0.00	$0.01	$0.23
			$1.17	$0.03	$0.02	$0.00	$0.02	$1.23
								$1.23

Figure 96 Cradle to grave analysis
1 m2 of 253 mm of Expanded cork

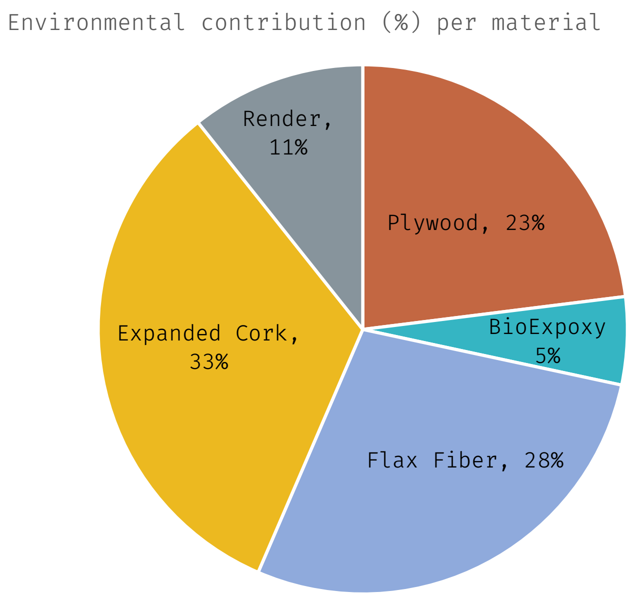


Figure 98 Environmental contribution (%) per materials - C1-Mineral brick 1st circularity scenario

Wood fiber								
A1-A4 Product Manufacturing			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO2e	kg SO2e	kg PO4e	kg CFC11e	kg Ethenee	MJ
Wood fibre insulation panels, L = 0.040 W/mK, 120-160 kg/m³	1	m2	2.67E+01	3.50E-02	7.17E-03	4.57E-13	4.34E-03	4.44E+02
			2.67E+01	**3.50E-02**	**7.17E-03**	**4.57E-13**	**4.34E-03**	**4.44E+02**

C1-C4 End of life (Deconstruction)			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO2e	kg SO2e	kg PO4e	kg CFC11e	kg Ethenee	MJ
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2	1	m2	6.04E+00	8.19E-03	1.79E-03	2.86E-12	6.76E-04	2.18E+01
			6.04E+00	**8.19E-03**	**1.79E-03**	**2.86E-12**	**6.76E-04**	**2.18E+01**

				Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
	Monetary value (Euros/Emission unit)			**EUR 0.05**	**EUR 4.00**	**EUR 9.00**	**EUR 30.00**	**EUR 30.00**	
A1-A5	Product Manufacturing	1	m2	$1.34	$0.14	$0.06	$0.00	$0.13	$1.67
C1-C5	End of life	1	m2	$0.30	$0.03	$0.02	$0.00	$0.02	$0.37
				$1.64	$0.17	$0.08	$0.00	$0.15	$2.04
									$2.04

Figure 97 Cradle to grave analysis
1 m2 of 253 mm of 288 mm of wood fiber

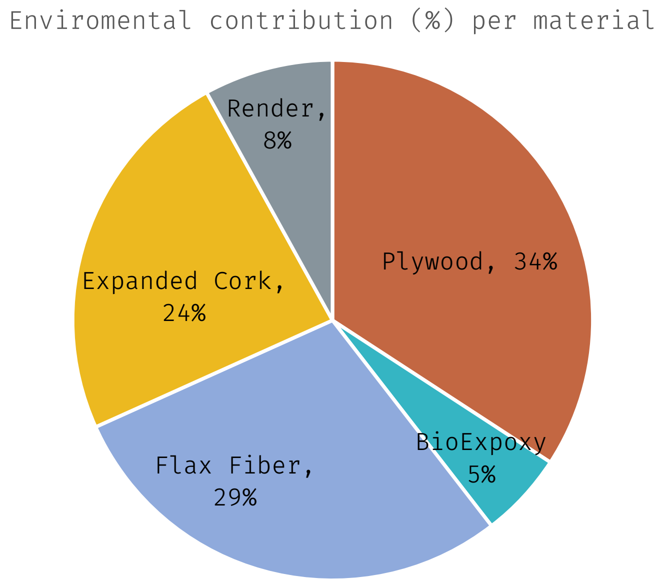


Figure 99 Environmental contribution (%) per materials - C1-Mineral brick 2nd circularity scenario

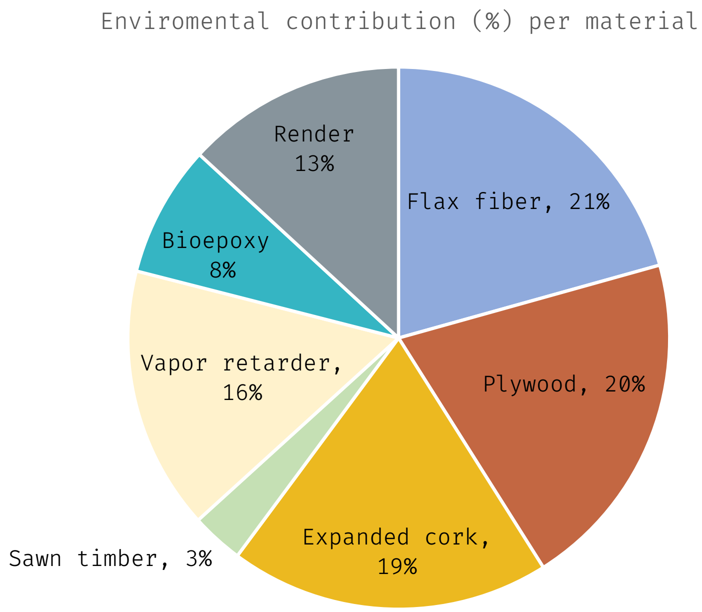


Figure 100 Environmental contribution (%) per materials - C3-Mineral brick 3rd circularity scenario

For the 1st circularity scenario, the best option is C1-mineral brick. The environmental contributions (%) of expanded cork is 33%. For the 2nd circularity scenario, again, the best option was C1-mineral brick, however, the environmental contributions (%) of expanded cork is 24%. Finally, for the 2nd circularity scenario, the best option was C3-mineral brick. The environmental contributions (%) of expanded cork is 19%. By modifying the contribution of the cork core percentages by the ECI difference with wood fibre the new set of options can be obtained.

Further, in Figure 101 the contributions per materials (%) in the 1st circularity scenario of "C1-mineral brick" with a wood fibre core are presented. The impact of the insulation increases from 33% to 45%, this is mainly due to the emissions of manufacturing the wood fibre. Similarly, Figure 102 shows the materials contribution in the 2nd circularity scenario "C1-mineral brick" with wood fiber. Now the insulation impacts change from 24% to 34%. Finally, Figure 103 shows the 3rd circularity scenario for "C3-mineral brick" where the insulation changes from 19% to 28%.

If each insulation core alternative is compared, in their circularity scenario, with the original panel, the three new designs with 288 mm of wood fibre still have lower ECI. Meaning that both insulation cores are likely to improve the sustainability and circularity of RC Panels.

From Figure 104 to Figure 106 the ECI are presented for the original panel, wood fibre and cork for each selected design in their circularity scenarios. As seen in Figure 104, wood fibre is 7.6% lower than the original panel and 21% higher than the expanded cork. Figure 105 shows now for the 2nd circularity scenario that wood fibre has an 8.1% better performance than the original panel and 15.5% higher than the expanded cork option. Finally, the third circularity scenario, wood fibre has 21.3% better performance than the original panel and is 12.65% higher than the expanded cork option.

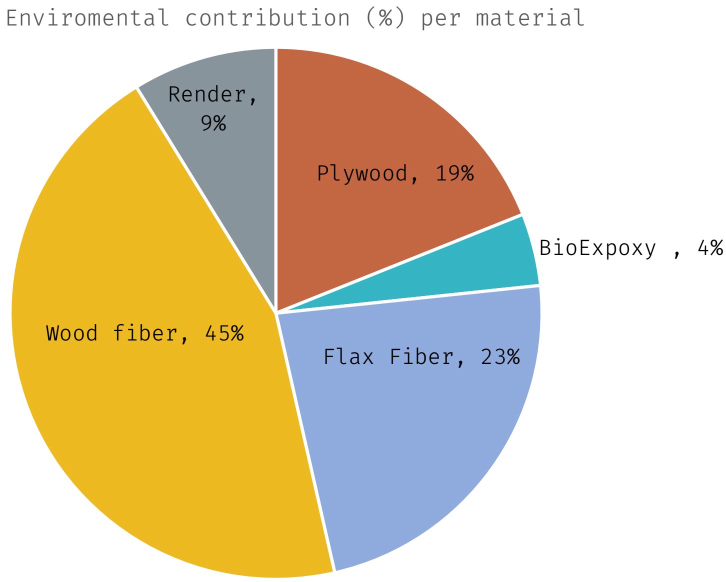


Figure 101 Environmental contribution (%) per materials - C1-Mineral brick 1st circularity scenario

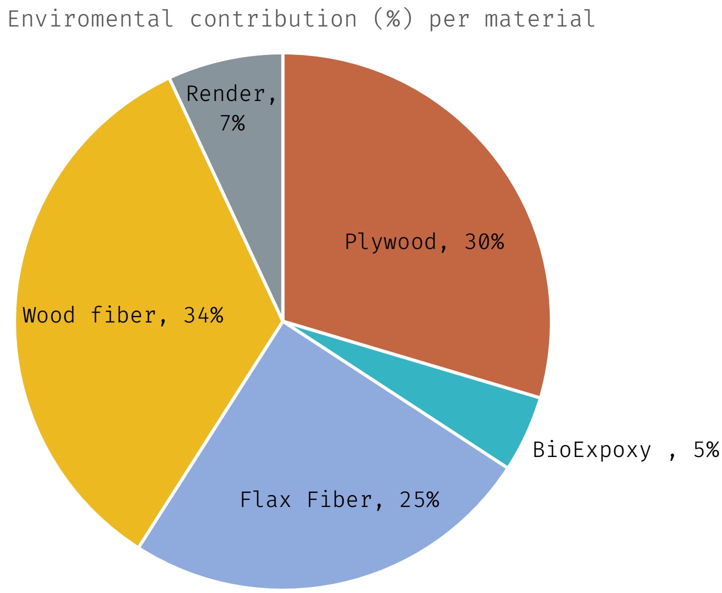


Figure 102 Environmental contribution (%) per materials - C1-Mineral brick 2nd circularity scenario

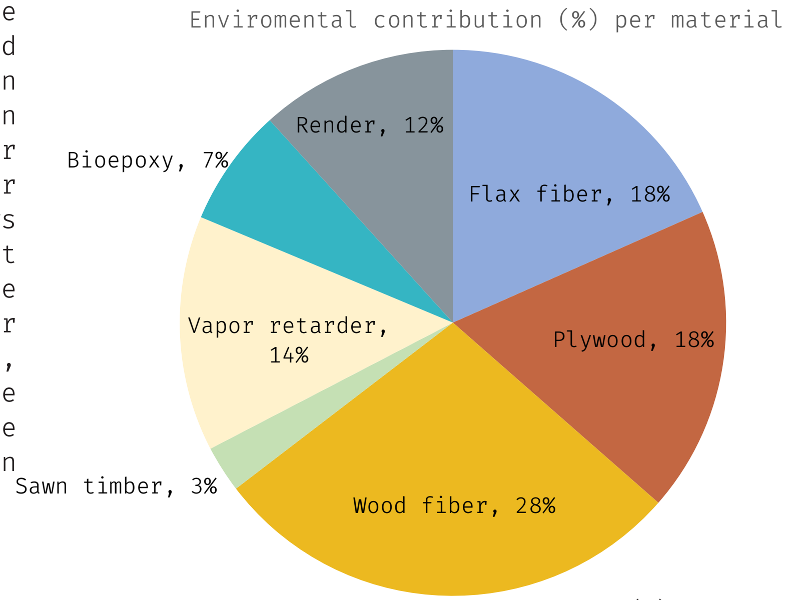


Figure 103 Environmental contribution (%) per materials - C3-Mineral brick 3rd circularity scenario

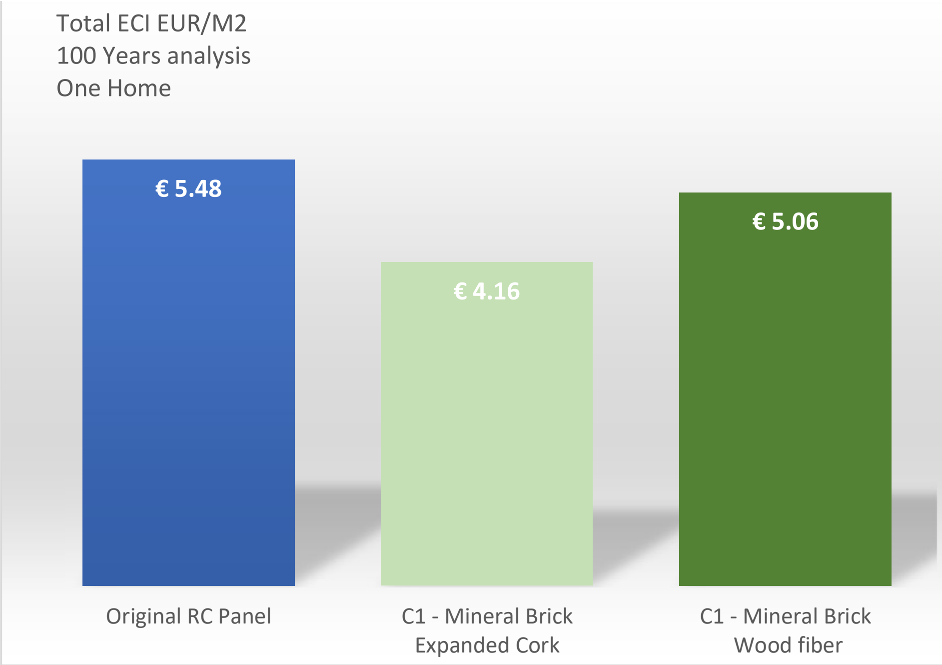


Figure 104 ECI Wood fiber and Expanded Cork - 1st Circularity Scenario

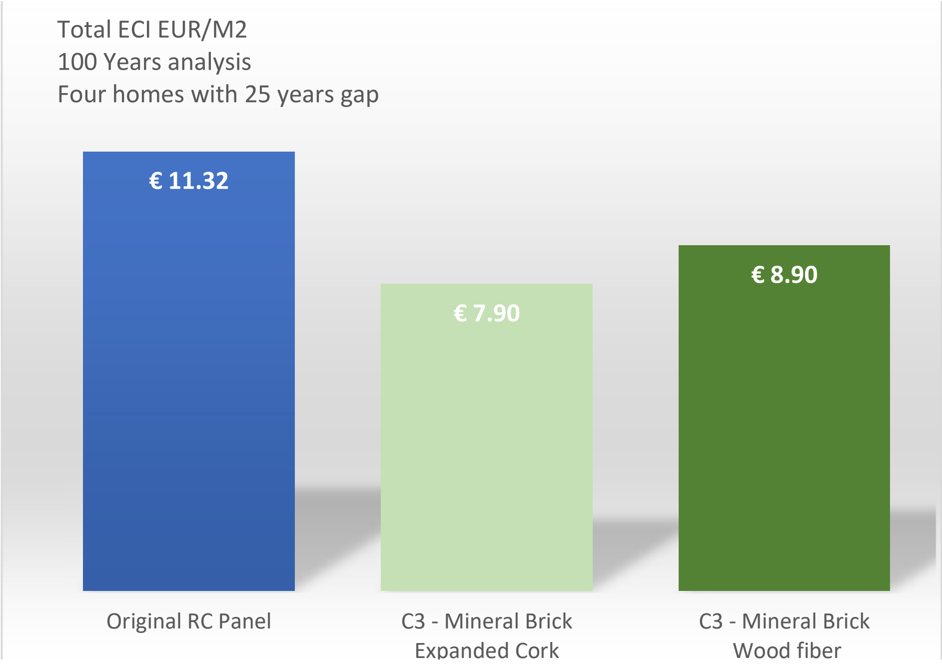


Figure 105 ECI Wood fiber and Expanded Cork - 2nd Circularity Scenario

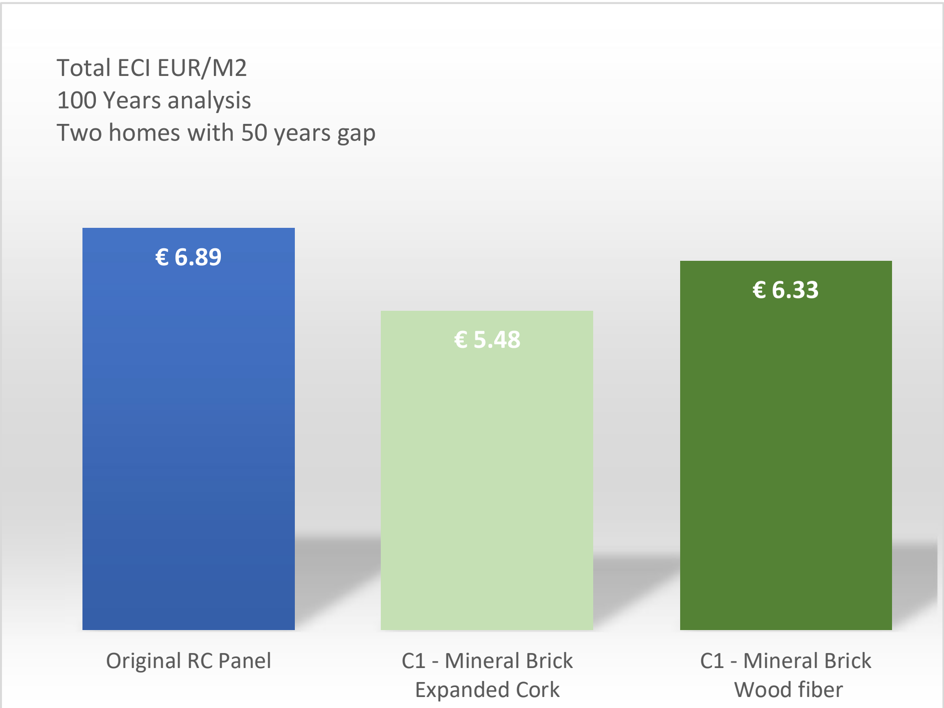


Figure 106 ECI Wood fiber and Expanded Cork - 3rd Circularity Scenario

Cost estimation

As part of the elaboration phase, a rough cost estimation is performed to compare the best designs in their own circularity scenarios. Therefore, for the circularity scenarios number one and two, the cost of the biobased sandwich panel is calculated, and for the third circularity scenario, the hybrid sandwich panel/frame cost is calculated.

These costs are compared with the cost of the original RC Panel. The numbers are analyzed only for the materials cost, hence, these analysis does not include any cost related to labor, equipment, management fees, profits and taxes.

For all materials of the two new designs and the Original RC Panel, the costs are “retail cots”, which means they are prices for a a “non-frequent” customer. The only three components that were not available as retail cost were the woven glass fiber polyester membranes and the Polyurethane adhesive for the original RC Panel. Unfortunately, the suppliers of these materials were not able to provide their current retail price and the estimating team of RC Panels shared the price they normally quote.

First, for the original design the cost and supplier references (all retrieved in June 2021) are presented in Figure 105. The materials cost of 1 m2 of RC Panel is estimated as 55.4 euros. Most of this cost come from the insulation, glass fiber polyester and OSB 3. The cladding is not included in the analysis since it is the same price for all the options.

In Figure 106 and in Figure 107 the materials costs and the suppliers reference are presented for the biobased sandwich panel. The cost with the expanded cork insulation is 128.4 Euros meaning is 2.3 times more expensive than the original design. Also, the wood fiber insulation alternative is 116.8 Euros or 2.1 time more expensive than the original design. Both options represent a considerably higher material cost than the original design. These two higher costs are mainly affected by the insulation. As mentioned in the technical part, one of the best advantages of the RC Panel is the EPS; and here again in an economical review, is also the case with a cost of 22.9 Euros. For 253 mm of expanded cork, the estimated cost is 80.6 or Euros and for 288 mm of wood fiber the estimated cost is 69.0 Euros.

In Figure 108 and in Figure 109 the materials costs and the suppliers reference are presented for hybrid frame/sandwich panel. The cost with the expanded cork insulation is 136.4 Euros meaning

Original - RC Panel

Material	Reference	Unit	Cost/m2
EPS 200 graphite- 220 mm	*DAWO*	m2	€ 22.9
Laminuxplan Woven fabric	*Lamilux*	m2	€ 5.0
Laminuxplan Woven fabric FR	*Lamilux*	m2	€ 12.0
Polyerethane adhesive	*Bostik*	m2	€ 3.8
OSB3 18 mm	Wickes	m2	€ 11.7
			€ 55.4

Figure 105 Original RC Panel cost

Biobased panel - Cork core

Material	Reference	Unit	Cost/m2
Expanded Cork insulation - 253 mm	*Corkribas*	m2	€ 80.6
Flax fiber fabric 200 gr/m2	*Castro Composites*	m2	€ 15.0
Cardolite Biepoxy Resin 2501 A	*Vosschemie Benelux*	kg	€ 15.4
Cardolite Haderner 2401 B 1:10 ratio	*Vosschemie Benelux*	kg	€ 3.0
Plywood - Structural sofwood 18 mm	Wickes	m2	€ 14.5
			€ 128.4

Figure 106 Biobased sandwich panel - Cork Core

Biobased panel - Wood fiber

Material	Reference	Unit	Cost/m
Wood fiber insulation panel - 288 mm	*Gutex*	m2	€ 69.
Flax fiber fabric 200 gr/m2	*Castro Composites*	m2	€ 15.
Cardolite Biepoxy Resin 2501 A	*Vosschemie Benelux*	kg	€ 15.
Cardolite Haderner 2401 B 1:10 ratio	*Vosschemie Benelux*	kg	€ 3.0
Plywood - Structural sofwood 18 mm	Wickes	m2	€ 14.
			€ 116.

Figure 107 Biobased sandwich panel - Wood fiber Core

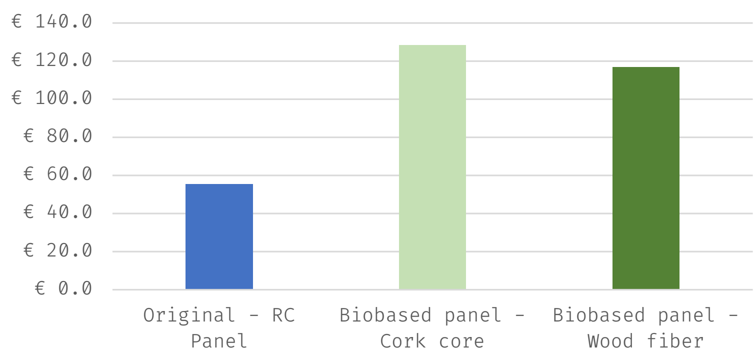


Figure Biobased sandwich panel comparison is almost 2.5 times more expensive than the original design. Also, the wood fiber insulation alternative is 124.6 Euros or 2.1 time more expensive than the original design. Again, both options represent a considerably higher material cost than the original design. These two higher costs are again mainly affected by the insulation and by the framing studs.

Original - RC Panel

Material	Reference	Unit	Cost/m2
EPS 200 graphite- 220 mm	*DAWO*	m2	€ 22.9
Laminuxplan Woven fabric	*Lamilux*	m2	€ 5.0
Laminuxplan Woven fabric FR	*Lamilux*	m2	€ 12.0
Polyerethane adhesive	*Bostik*	m2	€ 3.8
OSB3 18 mm	Wickes	m2	€ 11.7
			€ 55.4

Hybrid frame/panel - Cork core

Material	Reference	Unit	Cost/m2
Expanded Cork insulation - 253 mm	*Corkribas*	m2	€ 80.6
Flax fiber fabric 200 gr/m2	*Castro Composites*	m2	€ 7.5
Cardolite Biepoxy Resin 2501 A	*Vosschemie Benelux*	kg	€ 7.7
Cardolite Haderner 2401 B 1:10 ratio	*Vosschemie Benelux*	kg	€ 1.5
Plywood - Structural sofwood 18 mm	*Wickes*	m2	€ 22.0
Spruce studs - 50.8x10.16x2700 mm	*Hornbach*	m3	€ 15.0
Miofol 125AV - Vaportight foil	*Meuwissen Gerritsen*	m2	€ 2.2
			€ 136.4

Figure 108 Hybrid sandwich/frame panel - Cork core

Hybrid frame/panel - Cork core

Material	Reference	Unit	Cost/m2
Expanded Cork insulation - 253 mm	*Corkribas*	m2	€ 69.0
Flax fiber fabric 200 gr/m2	*Castro Composites*	m2	€ 7.2
Cardolite Biepoxy Resin 2501 A	*Vosschemie Benelux*	kg	€ 7.7
Cardolite Haderner 2401 B 1:10 ratio	*Vosschemie Benelux*	kg	€ 1.5
Plywood - Structural sofwood 18 mm	*Wickes*	m2	€ 22.0
Spruce studs - 50.8x10.16x2700 mm	*Hornbach*	m3	€ 15.0
Miofol 125AV - Vaportight foil	*Meuwissen Gerritsen*	m2	€ 2.2
			€ 124.6

Figure 109 Hybrid sandwich/frame panel - Wood fiber core

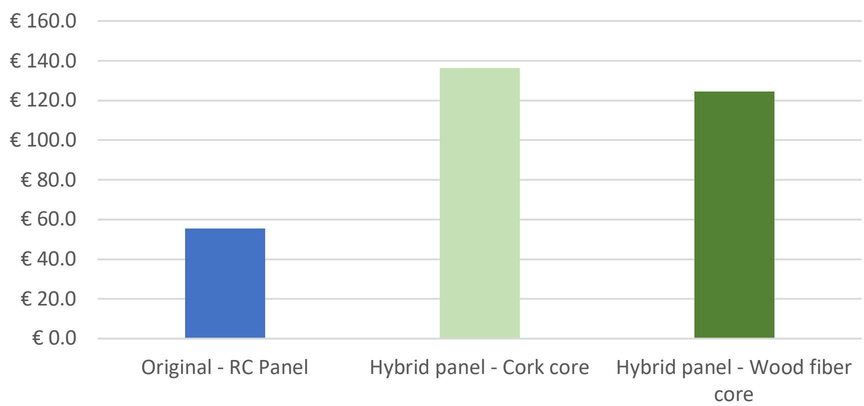


Figure Hybrid sandwich/frame panel comparison

ELABORATION PHASE

Discussion

With the three circularity scenarios analyzed in the research, the findings suggest that by using the existing skeleton of the homes for a prolongated time (100 years and 50 years), the best option is to redesign the RC panel as a biobased sandwich panel with a mineral brick cladding system. However, by reducing the time component to a 25-year analysis, the findings suggest that a hybrid frame/ sandwich system with a mineral brick will represent considerably lower environmental impacts than the original and the biobased sandwich panels.

These results relate to the circularity literature review with the terminologies of slowing (reusing) and narrowing (reducing) resources loops (Bocken et al., 2016). A "cradle-to-cradle" strategy where the resources are taken back to the technical cycle by extending the utilization time of a product, in this case, are the same strategies that use more materials at the earlier stage of the analysis (product phase). The fact that more materials are used to incentivize "assembly and disassembly" in the internal interfaces of the panels and in combination with a scenario where they are never going to be reused in a different home, makes them not an appropriate strategy to follow because they never balance their ECI in time.

By reusing the existing skeleton of the dwelling from periods between 50 and 100 years, the suggested options rely on renewables and materials with low environmental impacts. However, it is essential to remark that not all the materials in the biobased sandwich panel can be recycled or can re-enter into a biological cycle, because they are not 100% biodegradable, which means that this is an efficient "cradle to grave" strategy relying on renewables as much as possible and narrowing resources loops by using as fewer materials as possible.

Further, when more homes are introduced to time analysis (25 years reference), the best option is indeed the one that follows the "cradle to cradle" strategy where the resources are taken back to the technical cycle. However, the cladding system with the lower ECI still has a chemical bonding where none of the resources can be taken back if the home is changed. The mineral brick cladding can not be separated but uses very few materials following a "narrowing resources loop" strategy. This confirms the theory of Bouken that combining narrowing and slowing the loops is a good idea, but in this case, it highly depends on the time the skeletons are reused.

Some of the study's limitations rely on the assumptions made, and these start from the structural design to the durability component and the environmental analysis. Starting from the structural design, the analysis followed in the CLPT is a linear calculation, is does not comprehend a finite element analysis and the joints in between the material inside the factsheets (biocomposite, plywood or GFP) are not considered. Also, the concentration of stresses due to cut-outs is still not reviewed. However, as mentioned in the literature review of RC Panels, the company already reinforces the cutouts by making a reassessed opening with a CNC machine between the wood board and core, allocating a wood frame. Therefore, the cutouts are likely not to present failure whit these new options.

Another limitation is the durability assumptions. Although the biocomposite and the waterproofing membrane (WFM), working as 1st lines of defence, are not the best environmental options, in these cases, it is assumed that no water or moisture will enter the system. Also, it is assuming that the enclosure main connection details keep bugs, fungus, and any degradation mechanism out of the main thermal panel. The STO mineral brick durability does not have a limitation in this sense because it follows the results of SKB-IKOB for RC Panels with a real 1:1 façade mockup. However, the detailing of the cutouts and connections is important to ensure the water is still kept out.

The environmental analysis limitations are that only five out of the eleven environmental categories are considered in the study. The license used in the present research has student permission and does not allow full access to the eleven categories required by the Dutch building decree. Also, as mentioned in the LCA phase, the input brings four different insulation cores from the structural design to the environmental analysis. However, the database did not include two out of the fours cores, making a limited amount of insulation environmentally reviewed.

In terms of the usage of benefits and loads in a LCA. Currently in the EN standards, for the “category D” or “Beyond the 1st life cycle”, items can be included and listed but for now it is not allowed to credit “bonus” for the ECI. The main reason for this is because is not 100% sure that the potential reusable or recycle items will be reused and with renovation this is completely unclear. Even more, in the future new building codes may change in the meantime. However, this type of research challenges the standards and the codes to target and accomplish the environmental challenges we are currently facing.The correct combination with engineering and financial cases is important to account for this “bonus”.

Finally, for future analysis, it is suggested to make further testing for the biobased panels and pursue the possibility of analyzing the environmental impacts of the remaining cores. In terms of mechanical testing, the panels are suggested to be analyzed with the proposed dimensions for both expanded cork and wood fiber. This analysis should be performed with correct loading conditions as a vertical element hanging from anchors or rails and a uniform load acting as the wind. After this test is correlated with the structural theoretical results, developing the connection details with foundation, slabs, windows, and doors is suggested. Then, a durability test like the one performed by SKG-IKOB where meteorological cycles are induced to the panel and its degradations and failure are observed.

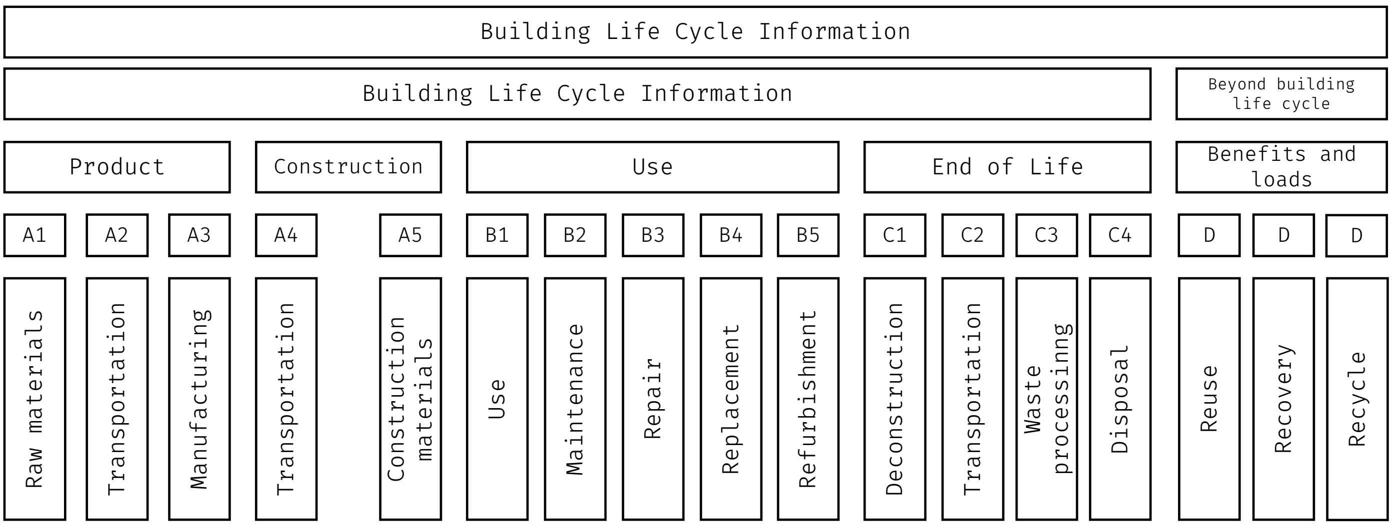


Figure 64 Life cycle stages considered in NEN-EN 15804:2012

Findings

The findings from the research are offered in comparison with the combination of the life cycle assessments and the circularity scenarios proposed.

1) Time component

The findings suggest that the “time component” in terms of the usage of the existing skeletons in combination with scenarios where materials are mined from a first renovated home and reused in a series of subsequent homes, has a close relationship with the environmental impacts of the retrofitting panels.

With renovations it is beforehand unclear for how long the existing stock will be effectively reused in the (far) future. Just in The Netherlands, there are almost 8 million homes that need to be renovated (Ministry of Economic Affairs and Climate Policy, 2019). The findings suggest that a prolongated usage of products in time, has a considerably lower environmental impact and strategies reducing the materials usage will succeed against a combination of designs that allow dis-and-re assembly of the façade interfaces.

A “cradle-to-cradle” strategy only succeeds, based on this research results, if the materials are reused in subsequent homes but not if the first renovated home is kept in usage for prolongated time. The main reason is because a “cradle to cradle” design uses more materials at the product phase. The fact that design is incentivized to have “assembly and disassembly” in the internal interfaces of the panels and with a combination with a scenario where they are never reused in a different home, makes them not an appropriate strategy to follow even if the end-of-life is considered in materials coming from fossil fuels such as EPS, Polyester, polyurea, etc.

2) Residual value

The residual value of the materials is referring as the “beyond the first LCA” benefits and loads of materials. Here is where reusing makes a big difference in the environmental impacts. In case of the second and third circularity scenarios, these loads reduce the ECI of the second, third and fourth renovated home.

Despite the low material usage in the product phase of the original panel and the biobased sandwich panels, the findings suggest that the loads and benefits will likely be improved due to correct return to a technical cycle and thus improved functionality of the resources by not having a linear behavior. However, even in combination with four homes with 25 years span, the residual value of a rear ventilated façade compared with the mineral brick slips does not performed with the lowest ECI. Only when combining “reusing” as a cradle-to-cradle design in the main thermal panel and “reducing” as a cradle-to-grave design in the cladding, the product reaches between 30.2 % and 21.3 % lower Environmental Cost Index (depending on the core selection).

3) Use of bio-based materials

Detaching the sandwich panel from fossil fuels and using biobased materials reduces the ECI of the product in time. The best design strategy for the first and second circularity scenarios is a biobased sandwich panel that relies on renewable materials with low environmental impacts. However, it is essential to investigate and document the modification of this natural resources through the manufacturing of the panel. Not all the biobased products can be recycled or can re-enter into a biological cycle because they are not 100% biodegradable. Meaning that the biobased sandwich panel, in this is research, is therefore an efficient “cradle to grave” strategy using renewables as much as possible and narrowing resources loops by using as fewer materials as possible.

4) Circular principles within sandwich panels framework

One home analysis – 100 years

If the existing stock is used for a prolonged period like 100 years, the best options to improve the sustainability of RC Panels are the two biobased sandwich panels. Regardless of the two core options (expanded cork or wood fibre), both alternatives will have a better environmental performance than the current product developed by RC Panels and the rest of the new design options. The biobased sandwich panel with the mineral brick slips has a 24.1% better performance, whereas the panel with the rear ventilated façade has an 8.2%.

The best advantage of the current design is its durability and efficiency in the material used. When strategies allowing the reentering of resources to a service cycle are compared with the original design, the environmental impacts in the product phase (A1-A5) of such strategies are considerably higher than the current product. Regardless of the efforts to make the internal interfaces of the façade "detachable", the environmental performance of the original panel is still better because the home is never changed in the analysis. Therefore, those "mechanically detachable" resources never really fulfill their purpose because it is just not needed.

Two home analysis – 100 years (50 years gap)

If an existing home is used for 50 years, and a second home receives the mined resources from the first home, the original panel starts to have higher environmental impacts than some of the designs aimed for "detachability". Three out of the six new design concepts perform better than the original design, and all of them using the current cladding of RC Panels. This starts to tell that the actual mineral brick cladding that brings the 50 years durability span is a significant advantage in combination with a double-board panel and a hybrid sandwich/frame panel.

Regardless of the efforts to make the cladding detachable, the concept with a rear ventilated façade do not balance the emissions of the manufacturing of materials at the beginning. Those "mechanically detachable" resources fulfill their purpose one time and are no longer accounted for in the analysis.

Four home analysis – 100 years (25 years gap)

Similarly to the findings analysis but now with four homes with a 25-year gap in between mining resources from one home to another, the original panel has higher environmental impacts than all the new designs. Six out of the six new concepts have better ECI, and both mineral brick slips and a rear ventilated façade now have a better performance. This process shows how products with an internal and external interface allowing "detachability" will reduce the environmental impacts of retrofitting the existing stock.

The best design in this is now a hybrid sandwich/frame panel with mineral brick. Minimizing the use of materials with a clever design allowing the detachability of resources is proved to result in a lower environmental impact. This design combines the "reduce" use materials of a sandwich panel by using few resources for the cladding and exterior factsheet and the "reuse" of materials of a frame by allowing the separation of resources.

Conclusions

The extent of applying a “cradle to cradle” design strategy to improve the circularity and sustainability of RC Panels will depend on the time the existing stock to be renovated is used. By means of what is the strategy to renovate and how many years the buildings will still be used and not demolished. Additionally, it is evident that using renewables materials reduces the environmental impacts of the panels; given a large number of dwellings to be renovated, products relying on biobased resources will have a high demand in the coming years.

The problem stated that the company’s current product is designed and analyzed without its end-of-service life in mind. The hypothesis is that the resources, materials, and energy involved to produce the panel for the first time are lost at the end-of-life phase by detaching the “time component” and not including scenarios where the materials are “processed and disposed” or “mined and reused”. The goals are to find a new design that reduces the environmental impacts, relies on renewables, and incorporates the circular economy as an essential design parameter.

To answer the main research question, “To what extent can a cradle-to-cradle design strategy contribute to optimize the circularity and sustainability of RC Panels?”, first the research sub-questions will be answered:

What does circularity and sustainability mean?

Circularity

Circularity refers to an industrial model that is restorative by intention; it relies mainly on renewables, eliminates the use of toxic chemicals, and eradicates waste through careful design. A “restorative by intention” means to redefine goods beyond the required “needs” of a product/service always acknowledging the time component.
Regardless of the efforts made to improve the use of recourses and materials, any model that relies only on consumption detaching the time component at the end of life, disregards a restorative use of the resources, losing value all along the flow of resources.

Sustainability

Sustainability stands for sustainable development of products and needs. It is a development that meets the needs of the present without compromising the ability of future generations´ availability of natural resources and healthy living conditions. The idea is not compromising the future by putting a burden and emitting harmful components into the environment. Acknowledging that the capacity of the environment to heal the pollution is limited and that there is an economic need to develop technologies to solve pollution caused by human action. Policy makers specifying taxes for the release of harmful compounds and for landfilling waste brings efficiency in the building sector and creates a cyclic process. Only by combining sustainability actions with circular economy stability the environmental challenges can be mitigated

Which are the promising product design models that incentivize a circular economy?

Reusing (slowing loops) resources as much as possible is probably the best model incentivizing circular economy. As mentioned before, a product that already exists will not take natural resources. However, these strategies have different design solutions such as “design for dis and re assembly” or “creating long-life products”. In both the product design should facilitate and controls maintenance and repair.

Reducing the use of resources (narrowing loops) is consider by multiple authors as a desperate design model aiming for resource efficiency. It is not aimed to improve the life cycle of a product but a strategy to reduce the flow of resources used as an eco-efficient cradle-to-grave strategy. As normally, in the current economy these strategies detach the time component by just selling more of a “resource efficient product” a therefore these solutions are thought as not circular. However, this study marks how the success of this strategy depends on how long the products are used, therefore combined with the “reuse” strategy of “creating long-life products” this model enhances circular economy with a renovation project if the home remains the same for the scenarios of 50 and 100 years.

What are the boundary conditions of the current panel that should prevail in a new “cradle to cradle” design?

The current RC Panel offers multiple conditions that need to be considered when a new design is pursed.

- The first one is its thermal resistance, currently the company offers an R-value of 7.0 (m2·K/W) which mainly comes from the use of EPS, all the design options occur to have this same value.
- A second condition is the possibility to detach the panel from the dwellings by not gluing insulation to the existing façade. For this reason, the same anchorage systems used in the current panel are reviewed as the loading conditions in the 24 designs analyzed in the design development stage of the panels.
- A third boundary is to support the same loads the current panel withstands. These are the self-weight and the wind load for a terrace homes height, these parameters are also reviewed in the design development stage.
- A fourth condition is to offer an aesthetical view for the audience in the Netherlands. It is known by RC Panels that clients have a strong alike for bricks, for this reason the product offers the possibility to be quickly manufactured with a render mortar that is installed automatically.

Which are the state-of-the-art materials for the components of a new panel that can contribute to the circularity and sustainability of the panel?

There are different materials for the different layers of the new panels.

(1) Facesheets:
The current research suggests that using a biocomposite reduces the environmental effects caused by the current Glass fiber polyester (GFP). However, the matrixes available for this application are not yet available with 100% biobased resources, making a biocomposite a non-biodegradable material. Also, biocomposite as GFP cannot be reused after the service life due to the chemical bonding between the matrix and the fiber. However, it´s high percentage of renewables makes it a better product when it´s compared with GFP.

(2) Wood boards:

Changing the OSB3 panel for plywood also reduces the total environmental effects. However, due to the reduction of the environmental impacts of the biocomposite instead of GFP, and the expanded cork (or Wood fiber) instead of EPS, the percentage of the contribution of wood board as increases from 13% with the OSB3 to 23% with plywood. However, by reviewing the weighting factors of OSB3 vs Plywood, it can be noticed how the new wood board has lower ECI.

(3) Cores:

This study suggested two new core options: Expanded Cork and high-density wood fiber. The sustainability analysis reveals that both have a better performance than EPS, scoring better than the expanded cork option. Also, in the design development, PLA foam and Hemp mycelium board can potently withstand the same loading conditions, making them replace EPS if a biobased core is a purse. For these two last options, further research must be done for the ECI review and comparison.

Conclusions

(4) Cladding:

After reviewing the comparison between a rear ventilated façade and the cladding currently use by the company, it can be seen how mineral brick slips have a significantly better performance than a rear ventilated façade. This study suggests that the lowest environmental cladding option is the mineral brick in the scenarios proposed where the homes are used 25, 50 and 100 years. However, if a real brick option is desired, and the existing skeleton is expected to be used for 100 years more, a biobased sandwich panel with a rear ventilated façade still offers an 8.2% reduction in the ECI than the original panel.

Which are circularity scenarios are considered in the analysis?

To compare the difference between using the existing stock for a long time and using it for reduced time spans, three scenarios are proposed to evaluate the impacts of the raw materials extraction, transportation, disposal, and reuse of materials. The Netherlands has almost 7.9 million homes, out of which 2.76 million have been used for more than 50 years and 5.2 million happen to be already used between 35 – 50+ years. These homes (5.2 million), comprehend the dwellings with the lowest energy labels. Hence, this group needs to be retrofitted before 2050. However, it is difficult to predict for how long they will be used, and this "time component" affects the environmental performance of the panels. For this reason the scenarios analyzed in this research are:

4) 100 years analysis with one terrace home included.
5) 100 years with two terrace homes included, after the first retrofitted home is used for 50 years, a second home will receive the still "usable" materials and reuse them for next 50 years.
6) 100 years with four terrace homes, after the first retrofitted home is used for 25 years, a second home will receive the still "usable" materials and reuse them for the following 25 years. The process will repeat itself until the panel reaches the 4th home in the 100 years' time frame.

Main research question

To what extent can a cradle-to-cradle design strategy contribute to optimize the circularity and sustainability of RC Panels?

According to the research, a cradle-to-cradle strategy primarily offers the possibility to bring materials back to service cycles. However, the extent of how much this strategy contributes to improving the sustainability and circularity of the current product will depend on how long the existing stock in question will be used.

Based on the potential of reusing the dwellings between 50 and 100 years, the best option is to use as much as possible biobased materials to reduce the environmental impacts of the retrofitting panel even though most of the resources cannot enter into a service cycle.

Further, if the time expectation is reduced to 25 years, a "cradle to cradle" strategy will be the best option. A strategy relying not only on biobased materials but also in enhancing circularity as an ease of disassembling the resources for a correct re-enter into service cycles. However, the combination between a "reuse resources" of the main thermal panel components (Hybrid sandwich/frame panel) and a "reduce resources" of the cladding system (mineral brick slips) is still the best option for the 25-year analysis.

Recommendations

Technical recommendations

It is suggested to test the biobased panels for both wood fiber and expanded cork.

Mechanical and meteorological testing

The panels are suggested to be analyzed with the proposed dimensions for both cores. This analysis is suggested to be performed with correct loading conditions as a vertical element hanging from anchors or rails and a uniform load acting as the wind.

After reviewing multiples tests performed by RC Panels in their lab in Staphorst, it was noticed that the panels are being loadedW with a 4-point bending test where steel beans are located on top of the panel and loaded from the top trying to mimic the wind force. However, this type of testing does not correctly represent the loading conditions of wind suction or pressure, it induces more load concertation and therefore stresses in the panel areas below the beams.

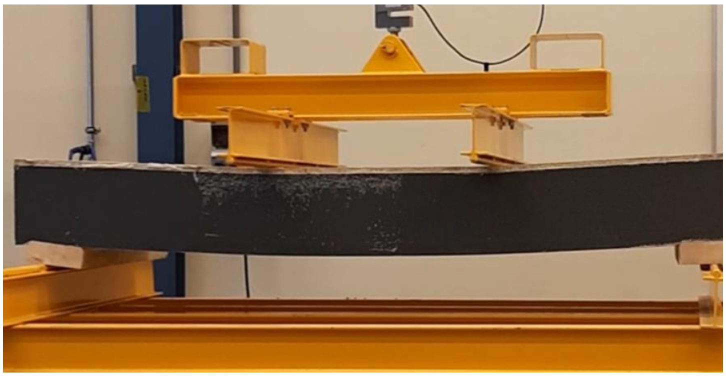


Figure 110 RC Panel - 4 point bending test before failure (picture from report T200007 owned by RC Panels innovation team)

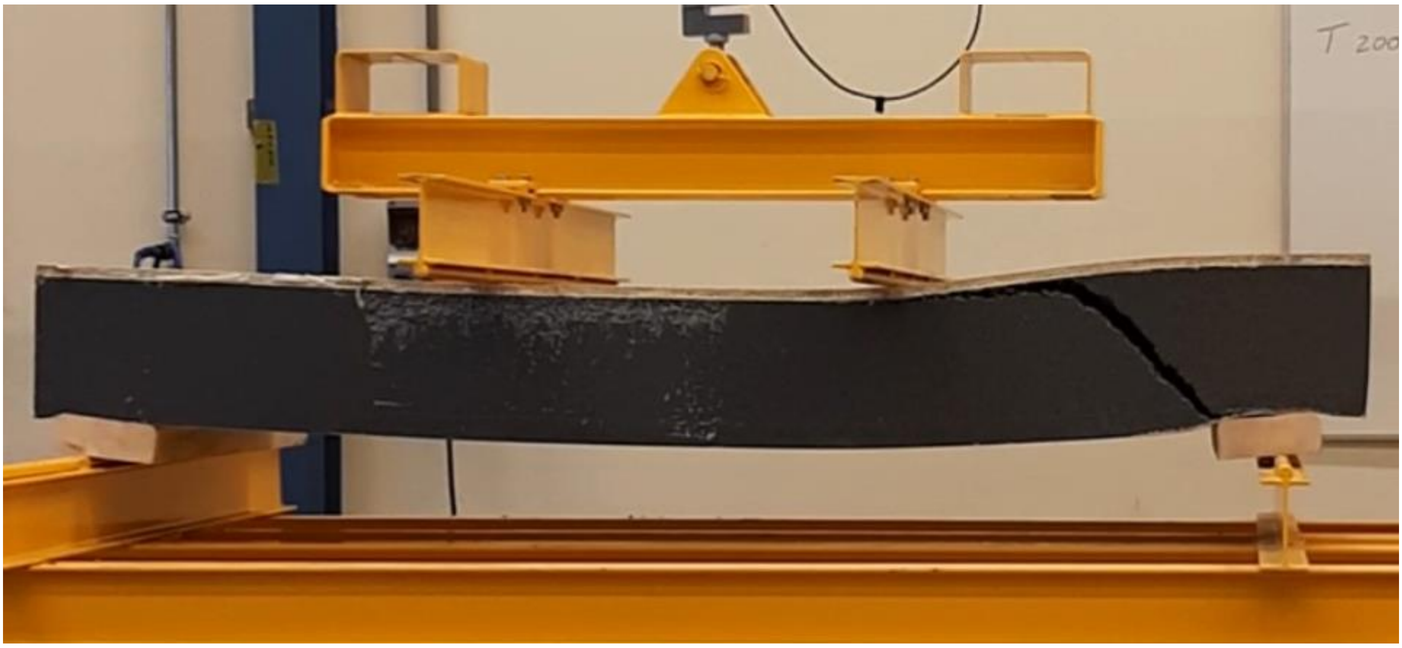


Figure 111 RC Panel - 4 point bending test after failure (picture from report T200007 owned by RC Panels innovation team)

Recommendations

In real life wind will act as a uniform load with possible multiple pressure zone depending on the height of the building. For this reason, a grid of vertical and horizontal pads is suggested working as a "Whiffletree". Each pad with metal circle or tab of a "known" area and with the surface in contact with the panel coated with a silicon or flexible rubber to avoid failure due to punctual load.

A "Whiffletree" set up with a uniform distribution would then represent the wind load acting in the panel. As seen in Figure 107 and in Figure 108 the force "F" represented in kilonewtons is equally divided between the vertical and horizontal rods accommodated on top of the pads. This type of testing could be more representative on a real life scenario where the wind acts at each section of the panel. The optimal number of pads could be a good future research to determine which is the best number in terms of results reliability and cost

After the mechanical testing, the develop the construction details for the foundation, slabs, windows, and doors for the biobased panel is suggested. Here it important to make sure the biocomposite is not exposed to the environment by protecting it completely it with the STO mineral cladding. The durability of the LCA relies on this line of defense and details should avoid any moisture instruction but also any type of degradation coming from sun exposure, bugs or fungus.

After details are developed, perform a durability test like the one performed by SKG-IKOB in 2017. Induced the same meteorological cycles to the biobased panel and observe its degradations and failure. Due to the biobased materials in the core, reviewing internal condensation and water intrusion behind the cladding is important. Also, the bonding test between the bio composite and the brick slips is suggested, since de-lamination of these layers compromises completely the system.

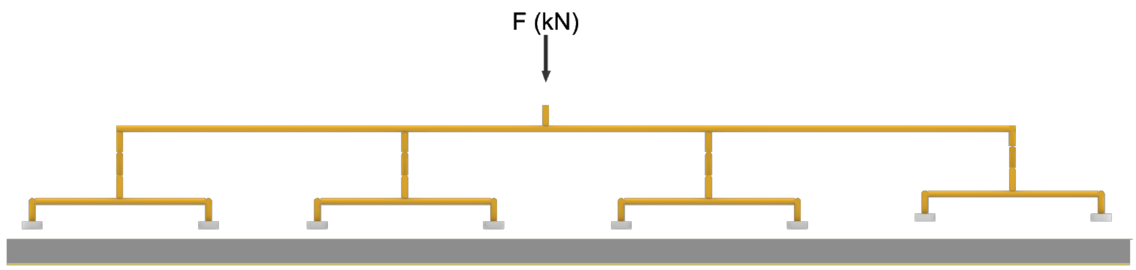


Figure 113 Whiffle tree

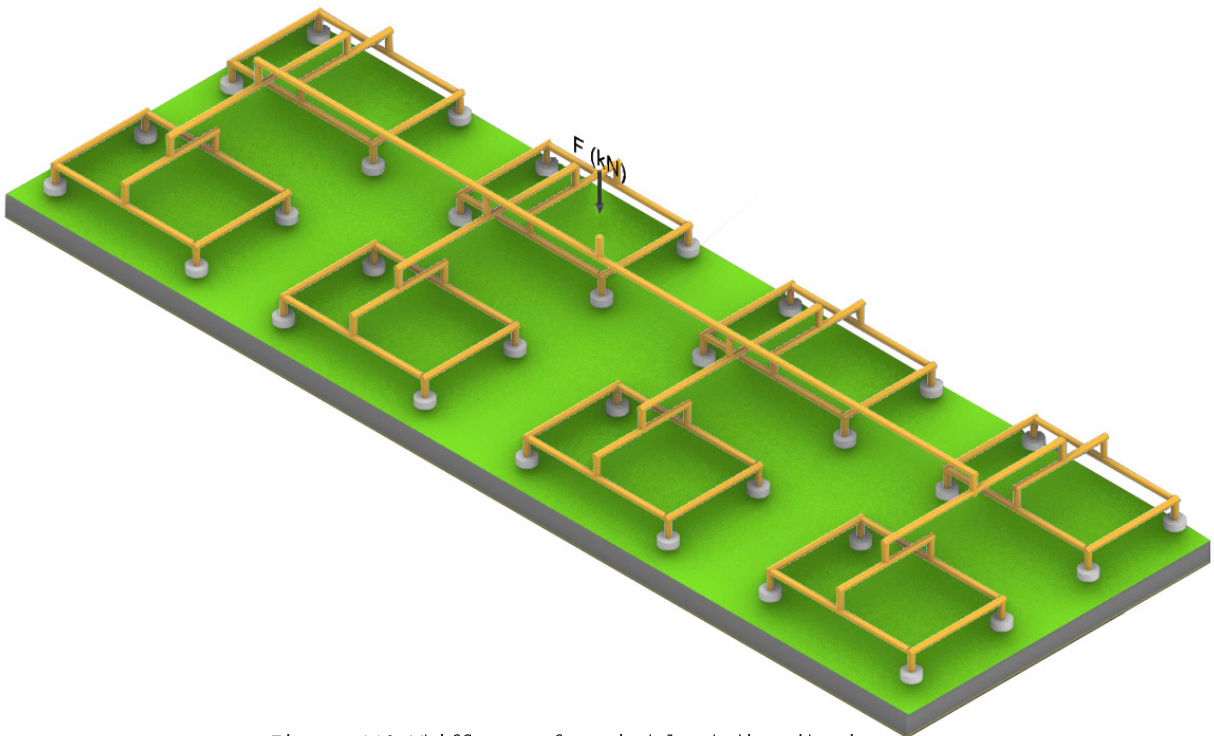


Figure 112 Whiffletree for wind load distribution

Environmental recommendations

Future research in biobased matrix with higher biobased content for a biocomposite is suggested. Ideally a full biobased and biodegradable biocomposite could take the biobased sandwich panel closer to a cradle-to-cradle strategy. In the case of the hybrid frame/sandwich panel, the combination of reducing and reusing resources could be improved by increasing the biobased content of the exterior facesheet, making it circular and bringing back the biocomposite to a biological cycle.

Also, pursue the reduction in thickness of the biocomposite to lower the cost and the material usage. The thickness is 2.5 times more compared with Glass fiber polyester

Future research the environmental impacts of Mycelium boards with multiple fibers and PLA foams. These materials seem a promising solution however the information about all the mechanical, physical and environmental properties is not completely available or at least is not access for free.

Finally, a general research of the availability of biobased materials is important. The environmental impacts of these materials make them an attractive and promising solution to reduce the environmental challenges faced in the world. However, the correct management and availability could be a challenge, the correct analysis of these materials such as Cork and wood fiber in combination with other industries than construction like textiles, food, and packaging is important since now the marketing of their products want to have a "green label" meaning environmentally friendly products.

Additional recommendations – Financial and business case

Keep the mind open to strategies with a "reuse" design. As seen in the circularity scenario 1, a biobased sandwich panel with a ventilated cladding scores slightly better than the original panel. This could be seen as an opportunity to manufacture this panel when designers prefer real stone finish.

Have the flexibility to discuss and collaborate with municipalities in the neighborhoods' planning and offer a multi scenario portfolio that can potentially be freely adjusted. However, at the same time having in mind that these scenarios with shorter time spans (50 and 25 years) would represent a medium to long term involvement from the company and therefore a business model that makes sure the resources can be reused needs further development.

The scenarios where the loads a benefits after the first LCA also represent a larger economical investment and they only work if the materials are actually reused. A possibility to create the materials flow, could be by allocating the liability in one or more of the stakeholders involved in a renovation These to make sure someone brings back the façades to factory. If this liable entity were RC Panels, the economical capacity of the company would get affected since right now RC Panels only manufactures and sells. To introduce the time component to their portfolio, the company could ask for an incentive or loan to bring and offer these scenarios where the façades are traced, mined, reused and correctly disposed (if needed).

In any case, the collaboration of municipalities with urban designers, architects, and developers to determine what´s the most likely scenario of each neighborhood in the cities is needed. Determining if a "reduced usage of material" is better than a "reuse usage of materials" will depend on these decisions. Having that done that, future financial research in creating a business models for the 2nd and 3rd scenarios would be need

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APPENDIX A - STRESS CONCENTRATIONS SELF-WEIGHT + WIND FORCE

WEIGHT + WIND FORCES

Concept 1 *All units in Pascals*

Anchorage system : 3 vertical rails with 12 mm bolts at every 20 cm

Top Coordinates - Local stress

	Concept 1 - Biobased panel			
	Cladding: Rendering mortar			
	Top coordinates stresses			
	Biocomposite	**Birch plywood**	***Cork***	**Biocomposite**
σ_1	-1.01E+04	-5.57E+06	-7.65E+03	9.92E+03
σ_2	-6.98E+03	-4.95E+06	-1.18E+04	6.86E+03
t_{12}	1.51E+03	1.37E+06	7.89E+03	-1.48E+03
	Bottom coordinates stresses			
	Biocomposite	**Birch plywood**	***Cork***	**Biocomposite**
σ_1	-9.92E+03	-4.84E+06	8.79E+03	1.01E+04
σ_2	-6.89E+03	-4.31E+06	1.35E+04	6.96E+03
t_{12}	1.48E+03	1.19E+06	-9.07E+03	-1.51E+03

	Concept 1 - Biobased panel			
	Cladding: Rendering mortar			
	Top coordinates stresses			
	Biocomposite	**Birch plywood**	***Mycelium***	**Biocomposite**
σ_1	-9.36E+03	-5.19E+06	-1.09E+03	9.26E+03
σ_2	-6.50E+03	-4.61E+06	-1.52E+03	6.26E+03
t_{12}	1.40E+03	1.28E+06	2.11E+03	-1.38E+03
	Bottom coordinates stresses			
	Biocomposite	**Birch plywood**	***Mycelium***	**Biocomposite**
σ_1	-9.24E+03	-4.56E+06	1.24E+03	9.38E+03
σ_2	-6.42E+03	-4.06E+06	1.68E+03	6.35E+03
t_{12}	1.38E+03	1.13E+06	-2.40E+03	-1.40E+03

	Concept 1 - Biobased panel			
	Cladding: Rendering mortar			
	Top coordinates stresses			
	Biocomposite	**Birch plywood**	**Wood fiber**	**Biocomposite**
σ_1	-8.88E+03	-4.92E+06	-2.09E+03	8.93E+03
σ_2	-6.15E+03	-4.37E+06	-6.47E+03	6.05E+03
t_{12}	1.33E+03	1.22E+06	1.23E+03	-1.31E+03
	Bottom coordinates stresses			
	Biocomposite	**Birch plywood**	**Wood fiber**	**Biocomposite**
σ_1	-8.76E+03	-4.35E+06	2.35E+03	9.04E+03
σ_2	-6.08E+03	-3.87E+06	7.26E+03	6.12E+03
t_{12}	1.31E+03	1.07E+06	-1.39E+03	-1.33E+03

	Concept 1 - Biobased panel			
	Cladding: Rendering mortar			
	Top coordinates stresses			
	Biocomposite	**Birch plywood**	**PLA**	**Biocomposite**
σ_1	-2.51E+03	-1.41E+06	-2.79E+05	2.48E+03
σ_2	-1.56E+03	-1.10E+06	-4.02E+05	1.55E+03
t_{12}	3.55E+02	3.25E+05	1.31E+05	-3.51E+02
	Bottom coordinates stresses			
	Biocomposite	**Birch plywood**	**PLA**	**Biocomposite**
σ_1	-2.48E+03	-1.27E+06	3.10E+05	2.51E+03
σ_2	-1.55E+03	-9.88E+05	4.47E+05	1.56E+03
t_{12}	3.51E+02	2.92E+05	-1.45E+05	-3.55E+02

Bottom Coordinates - Local stress

	Concept 1 - Biobased panel			
	Cladding: Rear ventilated facade			
	Top coordinates stresses			
	Biocomposite	**Birch plywood**	***Cork***	**Biocomposite**
σ_1	-1.01E+04	-5.57E+06	-7.65E+03	9.93E+03
σ_2	-6.98E+03	-4.95E+06	-1.18E+04	6.84E+03
t_{12}	1.51E+03	1.37E+06	7.89E+03	-1.48E+03
	Bottom coordinates stresses			
	Biocomposite	**Birch plywood**	***Cork***	**Biocomposite**
σ_1	-9.92E+03	-4.84E+06	8.79E+03	1.01E+04
σ_2	-6.89E+03	-4.31E+06	1.34E+04	6.94E+03
t_{12}	1.48E+03	1.19E+06	-9.07E+03	-1.51E+03

	Concept 1 - Biobased panel			
	Cladding: Rear ventilated facade			
	Top coordinates stresses			
	Biocomposite	**Birch plywood**	**Mycelium**	**Biocomposite**
σ_1	-9.36E+03	-5.19E+06	-1.09E+03	9.28E+03
σ_2	-6.50E+03	-4.61E+06	-1.52E+03	6.12E+03
t_{12}	1.40E+03	1.28E+06	2.11E+03	-1.38E+03
	Bottom coordinates stresses			
	Biocomposite	**Birch plywood**	**Mycelium**	**Biocomposite**
σ_1	-9.24E+03	-4.56E+06	1.23E+03	9.40E+03
σ_2	-6.41E+03	-4.07E+06	1.64E+03	6.20E+03
t_{12}	1.38E+03	1.13E+06	-2.40E+03	-1.40E+03

	Concept 1 - Biobased panel			
	Cladding: Rear ventilated facade			
	Top coordinates stresses			
	Biocomposite	**Birch plywood**	**Wood fiber**	**Biocomposite**
σ_1	-8.88E+03	-4.92E+06	-2.09E+03	9.07E+03
σ_2	-6.15E+03	-4.37E+06	-6.48E+03	6.02E+03
t_{12}	1.33E+03	1.22E+06	1.23E+03	-1.31E+03
	Bottom coordinates stresses			
	Biocomposite	**Birch plywood**	**Wood fiber**	**Biocomposite**
σ_1	-8.77E+03	-4.34E+06	2.35E+03	9.18E+03
σ_2	-6.08E+03	-3.87E+06	7.21E+03	6.10E+03
t_{12}	1.31E+03	1.07E+06	-1.39E+03	-1.33E+03

	Concept 1 - Biobased panel			
	Cladding: Rear ventilated facade			
	Top coordinates stresses			
	Biocomposite	**Birch plywood**	**PLA**	**Biocomposite**
σ_1	-2.51E+03	-1.41E+06	-2.79E+05	2.48E+03
σ_2	-1.56E+03	-1.10E+06	-4.02E+05	1.55E+03
t_{12}	3.55E+02	3.25E+05	1.31E+05	-3.51E+02
	Bottom coordinates stresses			
	Biocomposite	**Birch plywood**	**PLA**	**Biocomposite**
σ_1	-2.48E+03	-1.27E+06	3.10E+05	2.51E+03
σ_2	-1.55E+03	-9.88E+05	4.47E+05	1.56E+03
t_{12}	3.51E+02	2.92E+05	-1.45E+05	-3.55E+02

Concept 2 *All units in Pascals*

Anchorage system : 3 vertical rails with 12 mm bolts at every 20 cm

Top Coordinates - Local stress

	Concept 2 - Double board panel		
	Cladding: Rendering mortar		
	Birch plywood	***Cork***	**Birch plywood**
σ_1	-1.47E+06	-2.00E+03	1.29E+06
σ_2	-1.20E+06	-2.89E+03	1.06E+06
t_{12}	3.26E+05	1.89E+03	-2.86E+05
	Birch plywood	***Cork***	**Birch plywood**
σ_1	-1.29E+06	2.00E+03	1.47E+06
σ_2	-1.06E+06	2.89E+03	1.20E+06
t_{12}	2.86E+05	-1.89E+03	-3.26E+05

	Concept 2 - Double board panel		
	Cladding: Rendering mortar		
	Birch plywood	**Mycelium**	**Birch plywood**
σ_1	-1.37E+06	-2.85E+02	1.21E+06
σ_2	-1.12E+06	-3.71E+02	9.92E+05
t_{12}	3.03E+05	5.04E+02	-2.69E+05
	Birch plywood	**Mycelium**	**Birch plywood**
σ_1	-1.21E+06	2.85E+02	1.37E+06
σ_2	-9.93E+05	3.71E+02	1.12E+06
t_{12}	2.69E+05	-5.04E+02	-3.03E+05

	Concept 2 - Double board panel		
	Cladding: Rendering mortar		
	Birch plywood	**Wood fiber**	**Birch plywood**
σ_1	-1.30E+06	-5.20E+02	1.16E+06
σ_2	-1.07E+06	-1.59E+03	9.49E+05
t_{12}	2.89E+05	2.95E+02	-2.57E+05
	Birch plywood	**Wood fiber**	**Birch plywood**
σ_1	-1.16E+06	5.19E+02	1.30E+06
σ_2	-9.50E+05	1.59E+03	1.07E+06
t_{12}	2.57E+05	-2.95E+02	-2.89E+05

	Concept 2 - Double board panel		
	Cladding: Rendering mortar		
	Birch plywood	**PLA**	**Birch plywood**
σ_1	-5.94E+05	-1.17E+05	5.38E+05
σ_2	-4.41E+05	-1.63E+05	3.99E+05
t_{12}	1.26E+05	5.11E+04	-1.14E+05
	Birch plywood	**PLA**	**Birch plywood**
σ_1	-5.38E+05	1.17E+05	5.94E+05
σ_2	-3.99E+05	1.63E+05	4.41E+05
t_{12}	1.14E+05	-5.11E+04	-1.26E+05

Bottom Coordinates - Local stress

	Concept 2 - Double board panel		
	Cladding: Rear ventilated facade		
	Birch plywood	***Cork***	**Birch plywood**
σ_1	-1.47E+06	-2.00E+03	1.29E+06
σ_2	-1.20E+06	-2.89E+03	1.06E+06
t_{12}	3.26E+05	1.89E+03	-2.86E+05
	Birch plywood	***Cork***	**Birch plywood**
σ_1	-1.29E+06	2.00E+03	1.47E+06
σ_2	-1.06E+06	2.89E+03	1.20E+06
t_{12}	2.86E+05	-1.89E+03	-3.26E+05

	Concept 2 - Double board panel		
	Cladding: Rear ventilated facade		
	Birch plywood	**Mycelium**	**Birch plywood**
σ_1	-1.37E+06	-2.85E+02	1.21E+06
σ_2	-1.12E+06	-3.71E+02	9.92E+05
t_{12}	3.03E+05	5.04E+02	-2.69E+05
	Birch plywood	**Mycelium**	**Birch plywood**
σ_1	-1.21E+06	2.85E+02	1.37E+06
σ_2	-9.93E+05	3.71E+02	1.12E+06
t_{12}	2.69E+05	-5.04E+02	-3.03E+05

	Concept 2 - Double board panel		
	Cladding: Rear ventilated facade		
	Birch plywood	**Wood fiber**	**Birch plywood**
σ_1	-1.30E+06	-5.20E+02	1.16E+06
σ_2	-1.07E+06	-1.59E+03	9.49E+05
t_{12}	2.89E+05	2.95E+02	-2.57E+05
	Birch plywood	**Wood fiber**	**Birch plywood**
σ_1	-1.16E+06	5.19E+02	1.30E+06
σ_2	-9.50E+05	1.59E+03	1.07E+06
t_{12}	2.57E+05	-2.95E+02	-2.89E+05

	Concept 2 - Double board panel		
	Cladding: Rear ventilated facade		
	Birch plywood	**PLA**	**Birch plywood**
σ_1	-5.94E+05	-1.17E+05	5.38E+05
σ_2	-4.41E+05	-1.63E+05	3.99E+05
t_{12}	1.26E+05	5.11E+04	-1.14E+05
	Birch plywood	**PLA**	**Birch plywood**
σ_1	-5.38E+05	1.17E+05	5.94E+05
σ_2	-3.99E+05	1.63E+05	4.41E+05
t_{12}	1.14E+05	-5.11E+04	-1.26E+05

Concept 3 *All units in Pascals*

Anchorage system : 3 vertical rails with 12 mm bolts at every 20 cm

Top Coordinates - Local stress

	Concept 3 - Hybrid/frame panel		
	Cladding: Rendering mortar		
	Birch plywood	***Cork***	**Biocomposite**
σ_1	-5.52E+06	-7.60E+03	9.71E+03
σ_2	-4.91E+06	-1.17E+04	6.70E+03
t_{12}	1.36E+06	7.84E+03	-1.45E+03
	Birch plywood	***Cork***	**Biocomposite**
σ_1	-4.81E+06	8.60E+03	9.85E+03
σ_2	-4.28E+06	1.32E+04	6.79E+03
t_{12}	1.19E+06	-8.87E+03	-1.47E+03

	Concept 3 - Hybrid/frame panel		
	Cladding: Rendering mortar		
	Birch plywood	**Mycelium**	**Biocomposite**
σ_1	-5.15E+06	-1.08E+03	9.08E+03
σ_2	-4.58E+06	-1.51E+03	6.05E+03
t_{12}	1.27E+06	2.10E+03	-1.36E+03
	Birch plywood	**Mycelium**	**Biocomposite**
σ_1	-4.53E+06	1.21E+03	9.20E+03
σ_2	-4.04E+06	1.62E+03	6.13E+03
t_{12}	1.12E+06	-2.35E+03	-1.37E+03

	Concept 3 - Hybrid/frame panel		
	Cladding: Rendering mortar		
	Birch plywood	**Wood fiber**	**Biocomposite**
σ_1	-4.89E+06	-2.08E+03	8.84E+03
σ_2	-4.34E+06	-6.44E+03	5.91E+03
t_{12}	1.21E+06	1.23E+03	-1.29E+03
	Birch plywood	**Wood fiber**	**Biocomposite**
σ_1	-4.32E+06	2.30E+03	8.95E+03
σ_2	-3.84E+06	7.09E+03	5.99E+03
t_{12}	1.07E+06	-1.37E+03	-1.30E+03

	Concept 3 - Hybrid/frame panel		
	Cladding: Rendering mortar		
	Birch plywood	**PLA**	**Biocomposite**
σ_1	-1.41E+06	-2.80E+05	2.46E+03
σ_2	-1.10E+06	-4.04E+05	1.53E+03
t_{12}	3.26E+05	1.31E+05	-3.48E+02
	Birch plywood	**PLA**	**Biocomposite**
σ_1	-1.27E+06	3.08E+05	2.49E+03
σ_2	-9.92E+05	4.43E+05	1.55E+03
t_{12}	2.93E+05	-1.44E+05	-3.52E+02

Bottom Coordinates - Local stress

	Concept 3 - Hybrid/frame panel		
	Cladding: Rear ventilated facade		
	Birch plywood	***Cork***	**Biocomposite**
σ_1	-5.52E+06	-7.60E+03	9.72E+03
σ_2	-4.91E+06	-1.17E+04	6.68E+03
t_{12}	1.36E+06	7.84E+03	-1.45E+03
	Birch plywood	***Cork***	**Biocomposite**
σ_1	-4.81E+06	8.60E+03	9.86E+03
σ_2	-4.28E+06	1.31E+04	6.78E+03

	Concept 3 - Hybrid/frame panel		
	Cladding: Rear ventilated facade		
	Birch plywood	**Mycelium**	**Biocomposite**
σ_1	-5.15E+06	-1.08E+03	9.09E+03
σ_2	-4.58E+06	-1.51E+03	5.95E+03
t_{12}	1.27E+06	2.10E+03	-1.36E+03
	Birch plywood	**Mycelium**	**Biocomposite**
σ_1	-4.53E+06	1.21E+03	9.22E+03
σ_2	-4.04E+06	1.59E+03	6.03E+03

	Concept 3 - Hybrid/frame panel		
	Cladding: Rear ventilated facade		
	Birch plywood	**Wood fiber**	**Biocomposite**
σ_1	-4.89E+06	-2.08E+03	8.94E+03
σ_2	-4.34E+06	-6.44E+03	5.89E+03
t_{12}	1.21E+06	1.23E+03	-1.29E+03
	Birch plywood	**Wood fiber**	**Biocomposite**
σ_1	-4.32E+06	2.30E+03	9.05E+03
σ_2	-3.84E+06	7.05E+03	5.97E+03

	Concept 3 - Hybrid/frame panel		
	Cladding: Rear ventilated facade		
	Birch plywood	**PLA**	**Biocomposite**
σ_1	-1.41E+06	-2.80E+05	2.46E+03
σ_2	-1.10E+06	-4.04E+05	1.53E+03
t_{12}	3.26E+05	1.31E+05	-3.48E+02
	Birch plywood	**PLA**	**Biocomposite**
σ_1	-1.27E+06	3.08E+05	2.49E+03
σ_2	-9.92E+05	4.43E+05	1.55E+03

APPENDIX B - STRESS CONCENTRATIONS HOISTING

Concept 1

All units in Pascals

Hoisting system : 2 vertical rails with 12 mm bolts at every 20 cm

Concept 1 - Biobased panel

Cladding: Rendering mortar

	Biocomposite	Birch plywood	Cork	Biocomposite
σ_1	-1.01E+04	-5.57E+06	-7.65E+03	9.96E+03
σ_2	-6.98E+03	-4.95E+06	-1.18E+04	6.77E+03
t_12	1.51E+03	1.37E+06	7.89E+03	-1.48E+03

	Biocomposite	Birch plywood	Cork	Biocomposite
σ_1	-9.92E+03	-4.84E+06	8.79E+03	1.01E+04
σ_2	-6.88E+03	-4.31E+06	1.33E+04	6.87E+03
t_12	1.48E+03	1.19E+06	-9.07E+03	-1.51E+03

Concept 1 - Biobased panel

Cladding: Rear ventilated facade

	Biocomposite	Birch plywood	Cork	Biocomposite
σ_1	-1.01E+04	-5.57E+06	-7.65E+03	1.00E+04
σ_2	-6.98E+03	-4.95E+06	-1.18E+04	6.66E+03
t_12	1.51E+03	1.37E+06	7.89E+03	-1.48E+03

	Biocomposite	Birch plywood	Cork	Biocomposite
σ_1	-9.92E+03	-4.84E+06	8.78E+03	1.01E+04
σ_2	-6.88E+03	-4.32E+06	1.30E+04	6.76E+03
t_12	1.48E+03	1.19E+06	-9.07E+03	-1.51E+03

Concept 1 - Biobased panel

Cladding: Rendering mortar

	Biocomposite	Birch plywood	Mycelium	Biocomposite
σ_1	-9.37E+03	-5.19E+06	-1.09E+03	9.33E+03
σ_2	-6.48E+03	-4.60E+06	-1.53E+03	5.71E+03
t_12	1.40E+03	1.28E+06	2.11E+03	-1.38E+03

	Biocomposite	Birch plywood	Mycelium	Biocomposite
σ_1	-9.24E+03	-4.55E+06	1.23E+03	9.46E+03
σ_2	-6.40E+03	-4.08E+06	1.51E+03	5.79E+03
t_12	1.38E+03	1.13E+06	-2.40E+03	-1.40E+03

Concept 1 - Biobased panel

Cladding: Rear ventilated facade

	Biocomposite	Birch plywood	Mycelium	Biocomposite
σ_1	-9.37E+03	-5.19E+06	-1.09E+03	9.42E+03
σ_2	-6.46E+03	-4.59E+06	-1.53E+03	5.06E+03
t_12	1.40E+03	1.28E+06	2.11E+03	-1.38E+03

	Biocomposite	Birch plywood	Mycelium	Biocomposite
σ_1	-9.24E+03	-4.55E+06	1.22E+03	9.54E+03
σ_2	-6.38E+03	-4.10E+06	1.32E+03	5.14E+03
t_12	1.38E+03	1.13E+06	-2.40E+03	-1.40E+03

Concept 1 - Biobased panel

Cladding: Rendering mortar

	Biocomposite	Birch plywood	Wood fiber	Biocomposite
σ_1	-8.90E+03	-4.93E+06	-2.09E+03	9.51E+03
σ_2	-6.15E+03	-4.37E+06	-6.48E+03	5.94E+03
t_12	1.33E+03	1.22E+06	1.23E+03	-1.31E+03

	Biocomposite	Birch plywood	Wood fiber	Biocomposite
σ_1	-8.78E+03	-4.34E+06	2.32E+03	9.63E+03
σ_2	-6.07E+03	-3.87E+06	7.06E+03	6.02E+03
t_12	1.31E+03	1.07E+06	-1.39E+03	-1.33E+03

Concept 1 - Biobased panel

Cladding: Rear ventilated facade

	Biocomposite	Birch plywood	Wood fiber	Biocomposite
σ_1	-8.92E+03	-4.94E+06	-2.09E+03	1.01E+04
σ_2	-6.15E+03	-4.36E+06	-6.49E+03	5.82E+03
t_12	1.33E+03	1.22E+06	1.23E+03	-1.31E+03

	Biocomposite	Birch plywood	Wood fiber	Biocomposite
σ_1	-8.80E+03	-4.32E+06	2.29E+03	1.03E+04
σ_2	-6.07E+03	-3.88E+06	6.84E+03	5.90E+03
t_12	1.31E+03	1.07E+06	-1.39E+03	-1.33E+03

Concept 1 - Biobased panel

Cladding: Rendering mortar

	Biocomposite	Birch plywood	PLA	Biocomposite
σ_1	-2.51E+03	-1.41E+06	-2.79E+05	2.48E+03
σ_2	-1.56E+03	-1.10E+06	-4.02E+05	1.54E+03
t_12	3.55E+02	3.25E+05	1.31E+05	-3.51E+02

	Biocomposite	Birch plywood	PLA	Biocomposite
σ_1	-2.48E+03	-1.27E+06	3.10E+05	2.51E+03
σ_2	-1.55E+03	-9.88E+05	4.46E+05	1.56E+03
t_12	3.51E+02	2.92E+05	-1.45E+05	-3.55E+02

Concept 1 - Biobased panel

Cladding: Rear ventilated facade

	Biocomposite	Birch plywood	PLA	Biocomposite
σ_1	-2.51E+03	-1.41E+06	-2.79E+05	2.48E+03
σ_2	-1.56E+03	-1.10E+06	-4.02E+05	1.54E+03
t_12	3.55E+02	3.25E+05	1.31E+05	-3.51E+02

	Biocomposite	Birch plywood	PLA	Biocomposite
σ_1	-2.48E+03	-1.27E+06	3.10E+05	2.51E+03
σ_2	-1.55E+03	-9.89E+05	4.46E+05	1.56E+03
t_12	3.51E+02	2.92E+05	-1.45E+05	-3.55E+02

Concept 2

All units in Pascals

Hoisting system : 2 vertical rails with 12 mm bolts at every 20 cm

Concept 2 - Double board panel

Cladding: Rendering mortar

	Birch plywood	Cork	Birch plywood
σ_1	-1.47E+06	-2.00E+03	1.29E+06
σ_2	-1.20E+06	-2.89E+03	1.06E+06
t_12	3.26E+05	1.89E+03	-2.86E+05

	Birch plywood	Cork	Birch plywood
σ_1	-1.29E+06	2.00E+03	1.47E+06
σ_2	-1.06E+06	2.89E+03	1.20E+06
t_12	2.86E+05	-1.89E+03	-3.26E+05

Concept 2 - Double board panel

Cladding: Rear ventilated facade

	Birch plywood	Cork	Birch plywood
σ_1	-1.37E+06	-2.85E+02	1.21E+06
σ_2	-1.12E+06	-3.72E+02	9.92E+05
t_12	3.03E+05	5.04E+02	-2.69E+05

	Birch plywood	Cork	Birch plywood
σ_1	-1.21E+06	2.85E+02	1.37E+06
σ_2	-9.93E+05	3.71E+02	1.12E+06
t_12	2.69E+05	-5.04E+02	-3.03E+05

Concept 2 - Double board panel

Cladding: Rendering mortar

	Birch plywood	Mycelium	Birch plywood
σ_1	-1.37E+06	-2.85E+02	1.21E+06
σ_2	-1.12E+06	-3.71E+02	9.92E+05
t_12	3.03E+05	5.04E+02	-2.69E+05

	Birch plywood	Mycelium	Birch plywood
σ_1	-1.21E+06	2.85E+02	1.37E+06
σ_2	-9.93E+05	3.71E+02	1.12E+06
t_12	2.69E+05	-5.04E+02	-3.03E+05

Concept 2 - Double board panel

Cladding: Rear ventilated facade

	Birch plywood	Mycelium	Birch plywood
σ_1	-1.37E+06	-2.85E+02	1.21E+06
σ_2	-1.12E+06	-3.72E+02	9.91E+05
t_12	3.03E+05	5.04E+02	-2.69E+05

	Birch plywood	Mycelium	Birch plywood
σ_1	-1.21E+06	2.85E+02	1.37E+06
σ_2	-9.94E+05	3.71E+02	1.12E+06
t_12	2.69E+05	-5.04E+02	-3.03E+05

Concept 2 - Double board panel

Cladding: Rendering mortar

	Birch plywood	Wood fiber	Birch plywood
σ_1	-1.30E+06	-5.20E+02	1.16E+06
σ_2	-1.07E+06	-1.59E+03	9.48E+05
t_12	2.89E+05	2.95E+02	-2.57E+05

	Birch plywood	Wood fiber	Birch plywood
σ_1	-1.16E+06	5.19E+02	1.30E+06
σ_2	-9.50E+05	1.59E+03	1.06E+06
t_12	2.57E+05	-2.95E+02	-2.89E+05

Concept 2 - Double board panel

Cladding: Rear ventilated facade

	Birch plywood	Wood fiber	Birch plywood
σ_1	-1.30E+06	-5.20E+02	1.16E+06
σ_2	-1.07E+06	-1.59E+03	9.48E+05
t_12	2.89E+05	2.95E+02	-2.57E+05

	Birch plywood	Wood fiber	Birch plywood
σ_1	-1.16E+06	5.19E+02	1.30E+06
σ_2	-9.51E+05	1.59E+03	1.06E+06
t_12	2.57E+05	-2.95E+02	-2.89E+05

Concept 2 - Double board panel

Cladding: Rendering mortar

	Birch plywood	PLA	Birch plywood
σ_1	-5.94E+05	-1.17E+05	5.38E+05
σ_2	-4.41E+05	-1.63E+05	3.99E+05
t_12	1.26E+05	5.11E+04	-1.14E+05

	Birch plywood	PLA	Birch plywood
σ_1	-5.38E+05	1.17E+05	5.94E+05
σ_2	-3.99E+05	1.63E+05	4.41E+05
t_12	1.14E+05	-5.11E+04	-1.26E+05

Concept 2 - Double board panel

Cladding: Rear ventilated facade

	Birch plywood	PLA	Birch plywood
σ_1	-5.94E+05	-1.17E+05	5.38E+05
σ_2	-4.41E+05	-1.63E+05	3.99E+05
t_12	1.26E+05	5.11E+04	-1.14E+05

	Birch plywood	PLA	Birch plywood
σ_1	-5.38E+05	1.17E+05	5.94E+05
σ_2	-4.00E+05	1.62E+05	4.41E+05
t_12	1.14E+05	-5.11E+04	-1.26E+05

Concept 3

All units in Pascals

Hoisting system : 2 vertical rails with 12 mm bolts at every 20 cm

Concept 3 - Hybrid/frame panel

Cladding: Rendering mortar

	Birch plywood	Cork	Biocomposite
σ_1	-5.52E+06	-7.60E+03	9.74E+03
σ_2	-4.91E+06	-1.17E+04	6.61E+03
t_12	1.36E+06	7.84E+03	-1.45E+03

	Birch plywood	Cork	Biocomposite
σ_1	-4.81E+06	8.59E+03	9.88E+03
σ_2	-4.28E+06	1.30E+04	6.71E+03
t_12	1.19E+06	-8.87E+03	-1.47E+03

Concept 3 - Hybrid/frame panel

Cladding: Rear ventilated facade

	Birch plywood	Cork	Biocomposite
σ_1	-5.52E+06	-7.60E+03	9.77E+03
σ_2	-4.91E+06	-1.17E+04	6.54E+03
t_12	1.36E+06	7.84E+03	-1.45E+03

	Birch plywood	Cork	Biocomposite
σ_1	-4.81E+06	8.59E+03	9.91E+03
σ_2	-4.29E+06	1.28E+04	6.63E+03
t_12	1.19E+06	-8.87E+03	-1.47E+03

Concept 3 - Hybrid/frame panel

Cladding: Rendering mortar

	Birch plywood	Mycelium	Biocomposite
σ_1	-5.15E+06	-1.08E+03	9.19E+03
σ_2	-4.56E+06	-1.52E+03	5.19E+03
t_12	1.27E+06	2.10E+03	-1.36E+03

	Birch plywood	Mycelium	Biocomposite
σ_1	-4.52E+06	1.20E+03	9.32E+03
σ_2	-4.06E+06	1.36E+03	5.27E+03
t_12	1.12E+06	-2.35E+03	-1.37E+03

Concept 3 - Hybrid/frame panel

Cladding: Rear ventilated facade

	Birch plywood	Mycelium	Biocomposite
σ_1	-5.16E+06	-1.08E+03	9.25E+03
σ_2	-4.55E+06	-1.52E+03	4.75E+03
t_12	1.27E+06	2.10E+03	-1.36E+03

	Birch plywood	Mycelium	Biocomposite
σ_1	-4.52E+06	1.19E+03	9.38E+03
σ_2	-4.08E+06	1.23E+03	4.82E+03
t_12	1.12E+06	-2.35E+03	-1.37E+03

Concept 3 - Hybrid/frame panel

Cladding: Rendering mortar

	Birch plywood	Wood fiber	Biocomposite
σ_1	-4.90E+06	-2.08E+03	9.72E+03
σ_2	-4.33E+06	-6.45E+03	5.75E+03
t_12	1.21E+06	1.23E+03	-1.29E+03

	Birch plywood	Wood fiber	Biocomposite
σ_1	-4.30E+06	2.26E+03	9.84E+03
σ_2	-3.85E+06	6.78E+03	5.83E+03
t_12	1.07E+06	-1.37E+03	-1.30E+03

Concept 3 - Hybrid/frame panel

Cladding: Rear ventilated facade

	Birch plywood	Wood fiber	Biocomposite
σ_1	-4.91E+06	-2.08E+03	1.02E+04
σ_2	-4.33E+06	-6.45E+03	5.67E+03
t_12	1.21E+06	1.23E+03	-1.29E+03

	Birch plywood	Wood fiber	Biocomposite
σ_1	-4.29E+06	2.23E+03	1.03E+04
σ_2	-3.85E+06	6.63E+03	5.74E+03
t_12	1.07E+06	-1.37E+03	-1.30E+03

Concept 3 - Hybrid/frame panel

Cladding: Rendering mortar

	Birch plywood	PLA	Biocomposite
σ_1	-1.41E+06	-2.80E+05	2.46E+03
σ_2	-1.10E+06	-4.04E+05	1.53E+03
t_12	3.26E+05	1.31E+05	-3.48E+02

	Birch plywood	PLA	Biocomposite
σ_1	-1.27E+06	3.08E+05	2.49E+03
σ_2	-9.92E+05	4.43E+05	1.55E+03
t_12	2.93E+05	-1.44E+05	-3.52E+02

Concept 3 - Hybrid/frame panel

Cladding: Rear ventilated facade

	Birch plywood	PLA	Biocomposite
σ_1	-1.41E+06	-2.80E+05	2.46E+03
σ_2	-1.10E+06	-4.04E+05	1.53E+03
t_12	3.26E+05	1.31E+05	-3.48E+02

	Birch plywood	PLA	Biocomposite
σ_1	-1.27E+06	3.08E+05	2.49E+03
σ_2	-9.92E+05	4.43E+05	1.55E+03
t_12	2.93E+05	-1.44E+05	-3.52E+02

APPENDIX C –SELF WEIGHT CONCEPT 1

Concept 1

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
		Concept 1 - Biobased panel *Cladding: Rendering mortar*		
Inside	*Composite: flax + bioepoxy*	2	1,350	2.70
	Birch Plywood	18	500	9.00
	Cork insulation panels	253	130	32.89
	Composite: flax + bioepoxy	2	1,350	2.70
Outside	*Mineral brick slip*	6	1,800	9.00
			Total	56.29

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
		Concept 1 - Biobased panel *Cladding: Rendering mortar*		
Inside	*Composite: flax +*	2	1,350	2.70
	Birch Plywood	18	500	9.00
	Mycelium insulation boa	274	133	36.31
	bioepoxy	2	1,350	2.70
Outside	*Mineral brick slip*	6	1,800	9.00
			Total	59.71

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
		Concept 1 - Biobased panel *Cladding: Rendering mortar*		
Inside	*Composite: flax +*	2	1,350	2.70
	Birch Plywood	18	500	9.00
	Wood fiber panels	288	140	40.32
	bioepoxy	2	1,350	2.70
Outside	*Mineral brick slip*	6	1,800	9.00
			Total	63.72

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
		Concept 1 - Biobased panel *Cladding: Rendering mortar*		
Inside	*Composite: flax +*	2	1,350	2.70
	Birch Plywood	18	500	9.00
	PLA Foam	336	215	72.07
	bioepoxy	2	1,350	2.70
Outside	*Mineral brick slip*	6	1,800	9.00
			Total	95.47

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
		Concept 1 - Biobased panel *Cladding: Rear ventilated facade*		
Inside	*Composite: flax + bioepoxy*	2	1,350	2.70
	Birch Plywood	18	500	9.00
	Cork insulation panels	253	130	32.89
	Composite: flax + bioepoxy	2	1,350	2.70
	Sawn wood studs	n.a	350	17.35
	Alumnimun stud	n.a	2,700	4.48
Outside	*Mechslip think brick claddin*	n.a	n.a	42.00
			Total	111.12

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
		Concept 1 - Biobased panel *Cladding: Rear ventilated facade*		
Inside	*Composite: flax + bioepoxy*	2	1,350	2.70
	Birch Plywood	18	500	9.00
	Mycelium insulation boa	274	133	36.31
	Composite: flax + bioepoxy	2	1,350	2.70
	Sawn wood studs	n.a	350	17.35
	Alumnimun stud	n.a	2,700	4.48
Outside	*Mineral brick slip*	n.a	n.a	42.00
			Total	114.54

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
		Concept 1 - Biobased panel *Cladding: Rear ventilated facade*		
Inside	*Composite: flax + bioepoxy*	2	1,350	2.70
	Birch Plywood	18	500	9.00
	Wood fiber panels	288	140	40.32
	Composite: flax + bioepoxy	2	1,350	2.70
	Sawn wood studs	n.a	350	17.35
	Alumnimun stud	n.a	2,700	4.48
Outside	*Mineral brick slip*	n.a	n.a	42.00
			Total	118.55

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
		Concept 1 - Biobased panel *Cladding: Rear ventilated facade*		
Inside	*Composite: flax + bioepoxy*	2	1,350	2.70
	Birch Plywood	18	500	9.00
	PLA Foam	336	215	72.07
	Composite: flax + bioepoxy	2	1,350	2.70
	Sawn wood studs	n.a	350	17.35
	Alumnimun stud	n.a	2,700	4.48
Outside	*Mineral brick slip*	n.a	n.a	42.00
			Total	150.30

APPENDIX D - SELF WEIGHT CONCEPT 2

Concept 2

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
		Concept 2 - Double board panel		
		Cladding: Rendering mortar		
Inside	Birch Plywood	18	500	9.00
	Cork insulation panels	248	130	32.24
	Birch Plywood	18	500	9.00
Outside	Mineral brick slip	6	1,800	9.00
			Total	59.24

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
		Concept 2 - Double board panel		
		Cladding: Rendering mortar		
Inside	Birch Plywood	18	500	9.00
	Mycelium insulation boa	268	133	35.51
	Birch Plywood	18	500	9.00
Outside	Mineral brick slip	6	1,800	9.00
			Total	62.51

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
		Concept 2 - Double board panel		
		Cladding: Rendering mortar		
Inside	Birch Plywood	18	500	9.00
	Wood fiber panels	282	140	39.48
	Birch Plywood	18	500	9.00
Outside	Mineral brick slip	6	1,800	9.00
			Total	66.48

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
		Concept 2 - Double board panel		
		Cladding: Rendering mortar		
Inside	Birch Plywood	18	500	9.00
	PLA Foam	329	215	70.57
	Birch Plywood	18	500	9.00
Outside	Mineral brick slip	6	1,800	9.00
			Total	97.57

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
		Concept 2 - Double board panel		
		Cladding: Rear ventilated facade		
Inside	Birch Plywood	18	500	9.00
	Cork insulation panels	248	130	32.24
	Birch Plywood	18	500	9.00
	Alumnimun stud	n.a	2,700	4.48
Outside	Mechslip think brick claddin	n.a	n.a	42.00
			Total	96.72

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
		Concept 2 - Double board panel		
		Cladding: Rear ventilated facade		
Inside	Birch Plywood	18	500	9.00
	Mycelium insulation boa	268	133	35.51
	Birch Plywood	18	500	9.00
	Alumnimun stud	n.a	2,700	4.48
Outside	Mineral brick slip	n.a	n.a	42.00
			Total	99.99

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
		Concept 2 - Double board panel		
		Cladding: Rear ventilated facade		
Inside	Birch Plywood	18	500	9.00
	Wood fiber panels	282	140	39.48
	Birch Plywood	18	500	9.00
	Alumnimun stud	n.a	2,700	4.48
Outside	Mineral brick slip	n.a	n.a	42.00
			Total	103.96

	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
		Concept 2 - Double board panel		
		Cladding: Rear ventilated facade		
Inside	Birch Plywood	18	500	9.00
	PLA Foam	329	215	70.57
	Birch Plywood	18	500	9.00
	Alumnimun stud	n.a	2,700	4.48
Outside	Mineral brick slip	n.a	n.a	42.00
			Total	135.05

APPENDIX E -SELF WEIGHT CONCEPT 3

Concept 3

	Concept 3 - Hybrid/frame panel Cladding: Rendering mortar			
	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
Inside	Birch Plywood	18	500	9.00
	Sawn wood studs	n.a	350	17.35
	Cork insulation panels	254	130	33.02
	Sawn wood studs	n.a	350	17.35
	Composite: flax + bioepoxy	2	1,350	2.70
Outside	Mineral brick slip	6	1,800	9.00
			Total	88.42

	Concept 3 - Hybrid/frame panel Cladding: Rendering mortar			
	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
Inside	Birch Plywood	18	500	9.00
	Sawn wood studs	n.a	350	17.35
	Mycelium insulation boa	274	133	36.31
	Sawn wood studs	n.a	350	17.35
	Composite: flax + bioep	2	1,350	2.70
Outside	Mineral brick slip	6	1,800	9.00
			Total	91.71

	Concept 3 - Hybrid/frame panel Cladding: Rendering mortar			
	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
Inside	Birch Plywood	18	500	9.00
	Sawn wood studs	n.a	350	17.35
	Wood fiber panels	288	140	40.32
	Sawn wood studs	n.a	350	17.35
	Composite: flax + bioepo	2	1,350	2.70
Outside	Mineral brick slip	6	1,800	9.00
			Total	95.72

	Concept 3 - Hybrid/frame panel Cladding: Rendering mortar			
	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
Inside	Birch Plywood	18	500	9.00
	Sawn wood studs	n.a	350	17.35
	PLA Foam	336	215	72.07
	Sawn wood studs	n.a	350	17.35
	Composite: flax + bioepox	2	1,350	2.70
Outside	Mineral brick slip	6	1,800	9.00
			Total	127.47

	Concept 3 - Hybrid/frame panel Cladding: Rendering mortar			
	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
Inside	Birch Plywood	18	500	9.00
	Sawn wood studs	n.a	350	17.35
	Cork insulation panels	254	130	33.02
	Sawn wood studs	n.a	350	17.35
	Composite: flax + bioepoxy	2	1,350	2.70
	Alumnimun stud	n.a	2,700	4.48
Outside	Mechslip think brick claddin	n.a	n.a	42.00
			Total	125.90

	Concept 3 - Hybrid/frame panel Cladding: Rendering mortar			
	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
Inside	Birch Plywood	18	500	9.00
	Sawn wood studs	n.a	350	17.35
	Mycelium insulation boa	274	133	36.31
	Sawn wood studs	n.a	350	17.35
	Composite: flax + bioep	2	1,350	2.70
	Alumnimun stud	n.a	2,700	4.48
Outside	Mechslip think brick cl	n.a	n.a	42.00
			Total	129.19

	Concept 3 - Hybrid/frame panel Cladding: Rendering mortar			
	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
Inside	Birch Plywood	18	500	9.00
	Sawn wood studs	n.a	350	17.35
	Birch Plywood	288	140	40.32
	Sawn wood studs	n.a	350	17.35
	Composite: flax + bioepo	2	1,350	2.70
	Alumnimun stud	n.a	2,700	4.48
Outside	Mechslip think brick cla	n.a	n.a	42.00
			Total	133.20

	Concept 3 - Hybrid/frame panel Cladding: Rendering mortar			
	Panel Structure	Thickness (mm)	Density (kg/m3)	Weight/m2
Inside	Birch Plywood	18	500	9.00
	Sawn wood studs	n.a	350	17.35
	PLA Foam	336	215	72.07
	Sawn wood studs	n.a	350	17.35
	Composite: flax + bioepox	2	1,350	2.70
	Alumnimun stud	n.a	2,700	4.48
Outside	Mechslip think brick clad	n.a	n.a	42.00
			Total	164.95

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APPENDIX F - WEIGHTING FACTOR ORIGINAL PANEL 1ST CIRCULARITY SCENARIO

A1-A3 Product Manufacturing			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Parquet glue, 0.6 kg/m2, BOSTIK PU 456 (BOSTIK SA)	3.7	kg	5.60	2.40E-02	1.41E-02	4.18E-06	2.03E-03	9.29E+01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	m2	3.08	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
EPS insulation, grey, 15 kg/m3 (STYBENEX)	0.22	m3	13.20	3.96E-02	4.29E-03	3.30E-07	3.96E-02	3.31E+02
Polyester resin laminated part (GFRP, 30% glass fibres), 140...	0.002	m3	10.70	1.42E-02	1.41E-03	1.32E-13	1.34E-03	2.49E+02
OSB panels, biogenic CO2 not substracted, 617 kg/m3, EPD cov...	1	m2	7.70	2.13E-02	2.95E-03	2.91E-06	3.23E-03	9.31E+01
			40.28	**1.06E-01**	**2.34E-02**	**7.46E-06**	**4.68E-02**	**7.98E+02**

A4 Materials Transportation to the factory			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Parquet glue, 0.6 kg/m2, BOSTIK PU 456 (BOSTIK SA)	3.7	kg	1.61E-01	6.51E-04	1.40E-04	3.10E-08	1.34E-05	4.49E+00
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	m2	3.29E-02	1.51E-04	3.30E-05	6.49E-09	1.85E-06	9.35E-01
EPS insulation, grey, 15 kg/m3 (STYBENEX)	0.22	m3	5.43E-02	2.50E-04	5.45E-05	1.07E-08	3.06E-06	1.55E+00
Polyester resin laminated part (GFRP, 30% glass fibres), 140...	0.002	m3	4.61E-02	2.12E-04	4.63E-05	9.11E-09	2.60E-06	1.31E+00
OSB panels, biogenic CO2 not substracted, 617 kg/m3, EPD cov...	1	m2	1.45E-01	6.66E-04	1.45E-04	2.86E-08	8.15E-06	4.12E+00
			4.39E-01	**1.93E-03**	**4.19E-04**	**8.59E-08**	**2.91E-05**	**1.24E+01**

A4 Panel transportation to the Housing site			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	29.21	kg	4.72E-01	2.18E-03	4.73E-04	9.32E-08	2.66E-05	1.34E+01
			4.72E-01	**2.18E-03**	**4.73E-04**	**9.32E-08**	**2.66E-05**	**1.34E+01**

B1-B5 Maintenance and material replacement			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Parquet glue, 0.6 kg/m2, BOSTIK PU 456 (BOSTIK SA)	1.23	kg	1.87E+00	8.00E-03	4.70E-03	1.39E-06	6.77E-04	3.10E+01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	1.1	m2	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
Polyester resin laminated part (GFRP, 30% glass fibres), 140...	0.001	m3	5.35E+00	7.10E-03	7.05E-04	6.60E-14	6.70E-04	1.25E+02
			1.03E+01	**2.17E-02**	**6.07E-03**	**1.43E-06**	**1.91E-03**	**1.88E+02**

C1-C4 End of life (Deconstruction)			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Parquet glue, 0.6 kg/m2, BOSTIK PU 456 (BOSTIK SA)	3.7	kg	5.00E-02	3.09E-04	4.46E-05	7.71E-13	3.00E-05	7.45E-01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	m2	2.13E-02	1.67E-04	3.46E-05	1.70E-14	1.65E-05	4.44E-01
EPS insulation, grey, 15 kg/m3 (STYBENEX)	0.22	m3	8.34E+00	1.95E-03	1.63E-04	6.71E-13	8.93E-05	4.53E+00
Polyester resin laminated part (GFRP, 30% glass fibres), 140...	0.002	m3	2.45E-02	1.72E-04	2.41E-05	3.31E-09	8.36E-06	6.69E-01
OSB panels, biogenic CO2 not substracted, 617 kg/m3, EPD cov...	1	m2	1.39E+00	1.89E-03	4.14E-04	6.61E-13	1.56E-04	5.03E+00
			9.83E+00	**4.49E-03**	**6.80E-04**	**3.31E-09**	**3.00E-04**	**1.14E+01**

				Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
	Monetary value (Euros/Emission unit)			**EUR 0.05**	**EUR 4.00**	**EUR 9.00**	**EUR 30.00**	**EUR 30.00**	
A1-A3	Product Manufacturing	1	m2	$2.01	$0.42	$0.21	$0.00	$1.40	$4.12
	Materials Transportation to the factory	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	
A5	Panel transportation to the Housing site	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	
B1 - B5	Panel Transportation to the factory	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	$0.79
	Product Maintenance	1	m2	$0.51	$0.09	$0.05	$0.00	$0.06	
	End of life (Deconstruction) of parts maintained	1	m2	$0.00	$0.00	$0.00	$0.00	$0.00	
	Panel transportation to the Housing site	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	
C1-C4	Panel Transportation for deconstruction process	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	$0.56
	End of life (Deconstruction)	1	m2	$0.49	$0.02	$0.01	$0.00	$0.01	
				$3.14	$0.57	$0.29	$0.00	$1.47	$5.48
									$5.48

APPENDIX G - WEIGHTING FACTOR ORIGINAL PANEL 2ND CIRCULARITY SCENARIO

A1-A3 Product Manufacturing			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Parquet glue, 0.6 kg/m2, BOSTIK PU 456 (BOSTIK SA)	3.7	kg	5.60E+00	2.40E-02	1.41E-02	4.18E-06	2.03E-03	9.29E+01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	m2	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
EPS insulation, grey, 15 kg/m3 (STYBENEX)	0.22	m3	1.32E+01	3.96E-02	4.29E-03	3.30E-07	3.96E-02	3.31E+02
Polyester resin laminated part (GFRP, 30% glass fibres), 140...	0.002	m3	1.07E+01	1.42E-02	1.41E-03	1.32E-13	1.34E-03	2.49E+02
OSB panels, biogenic CO2 not substracted, 617 kg/m3, EPD cov...	1	m2	7.70E+00	2.13E-02	2.95E-03	2.91E-06	3.23E-03	9.31E+01
			4.03E+01	**1.06E-01**	**2.34E-02**	**7.46E-06**	**4.68E-02**	**7.98E+02**

A4 Materials Transportation to the factory			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Parquet glue, 0.6 kg/m2, BOSTIK PU 456 (BOSTIK SA)	3.7	kg	1.61E-01	6.51E-04	1.40E-04	3.10E-08	1.34E-05	4.49E+00
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	m2	3.29E-02	1.51E-04	3.30E-05	6.49E-09	1.85E-06	9.35E-01
EPS insulation, grey, 15 kg/m3 (STYBENEX)	0.22	m3	5.43E-02	2.50E-04	5.45E-05	1.07E-08	3.06E-06	1.55E+00
Polyester resin laminated part (GFRP, 30% glass fibres), 140...	0.002	m3	4.61E-02	2.12E-04	4.63E-05	9.11E-09	2.60E-06	1.31E+00
OSB panels, biogenic CO2 not substracted, 617 kg/m3, EPD cov...	1	m2	1.45E-01	6.66E-04	1.45E-04	2.86E-08	8.15E-06	4.12E+00
			4.39E-01	**1.93E-03**	**4.19E-04**	**8.59E-08**	**2.91E-05**	**1.24E+01**

A4 Panel transportation to the Housing site			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	29.21	kg-km	4.72E-01	2.18E-03	4.73E-04	9.32E-08	2.66E-05	1.34E+01
			4.72E-01	**2.18E-03**	**4.73E-04**	**9.32E-08**	**2.66E-05**	**1.34E+01**

C1-C4 End of life (Deconstruction)			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Parquet glue, 0.6 kg/m2, BOSTIK PU 456 (BOSTIK SA)	3.7	kg	5.00E-02	3.09E-04	4.46E-05	7.71E-13	3.00E-05	7.45E-01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	m2	2.13E-02	1.67E-04	3.46E-05	1.70E-14	1.65E-05	4.44E-01
EPS insulation, grey, 15 kg/m3 (STYBENEX)	0.22	m3	8.34E+00	1.95E-03	1.63E-04	6.71E-13	8.93E-05	4.53E+00
Polyester resin laminated part (GFRP, 30% glass fibres), 140...	0.002	m3	2.45E-02	1.72E-04	2.41E-05	3.31E-09	8.36E-06	6.69E-01
OSB panels, biogenic CO2 not substracted, 617 kg/m3, EPD cov...	1	m2	1.39E+00	1.89E-03	4.14E-04	6.61E-13	1.56E-04	5.03E+00
			9.83E+00	**4.49E-03**	**6.80E-04**	**3.31E-09**	**3.00E-04**	**1.14E+01**

D Product Manufacturing			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Parquet glue, 0.6 kg/m2, BOSTIK PU 456 (BOSTIK SA)	3.7	kg	5.60E+00	2.40E-02	1.41E-02	4.18E-06	2.03E-03	9.29E+01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	m2	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
Polyester resin laminated part (GFRP, 30% glass fibres), 140...	0.002	m3	1.07E+01	1.42E-02	1.41E-03	1.32E-13	1.34E-03	2.49E+02
OSB panels, biogenic CO2 not substracted, 617 kg/m3, EPD cov...	1	m2	7.70E+00	2.13E-02	2.95E-03	2.91E-06	3.23E-03	9.31E+01
			27.08	**6.61E-02**	**1.91E-02**	**7.13E-06**	**7.16E-03**	**4.67E+02**

D End of life (Deconstruction)			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Parquet glue, 0.6 kg/m2, BOSTIK PU 456 (BOSTIK SA)	3.7	kg	5.00E-02	3.09E-04	4.46E-05	7.71E-13	3.00E-05	7.45E-01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	m2	2.13E-02	1.67E-04	3.46E-05	1.70E-14	1.65E-05	4.44E-01
Polyester resin laminated part (GFRP, 30% glass fibres), 140...	0.002	m3	2.45E-02	1.72E-04	2.41E-05	3.31E-09	8.36E-06	6.69E-01
OSB panels, biogenic CO2 not substracted, 617 kg/m3, EPD cov...	1	m2	1.39E+00	1.89E-03	4.14E-04	6.61E-13	1.56E-04	5.03E+00
			1.49E+00	**2.54E-03**	**5.17E-04**	**3.31E-09**	**2.11E-04**	**6.89E+00**

					Global warming	Acidification	Eutrophication	Ozone depletion potential		
		Monetary value (Euros/Emission unit)			EUR 0.05	EUR 4.00	EUR 9.00	EUR 30.00	EUR 30.00	
HOME 1	A1-A3	Product Manufacturing	1	m2	$2.01	$0.42	$0.21	$0.00	$1.40	$4.12
		Materials Transportation to the factory	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	
	A5	Panel transportation to the Housing site	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	$0.13
		End of life (Deconstruction)	1	m2	$0.07	$0.01	$0.00	$0.00	$0.01	
HOME 2	D	Product Manufacturing	1	m2	$1.35	$0.26	$0.17	$0.00	$0.21	$2.08
		Materials Transportation to the factory	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	
	D	Panel transportation to the Housing site	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	
	D	Panel Transportation for deconstruction process	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	$0.56
		End of life (Deconstruction)	1	m2	$0.49	$0.02	$0.01	$0.00	$0.01	
					$4.07	$0.77	$0.42	$0.00	$1.64	$6.89
										$6.89

APPENDIX H - WEIGHTING FACTOR ORIGINAL PANEL 3RD CIRCULARITY SCENARIO

A1-A3 Product Manufacturing			Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
Parquet glue, 0.6 kg/m2, BOSTIK PU 456 (BOSTIK SA)	3.7	kg	5.60E+00	2.40E-02	1.41E-02	4.18E-06	2.03E-03	9.29E+01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	m2	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
EPS insulation, grey, 15 kg/m3 (STYBENEX)	0.22	m3	1.32E+01	3.96E-02	4.29E-03	3.30E-07	3.96E-02	3.31E+02
Polyester resin laminated part (GFRP, 30% glass fibres), 140...	0.002	m3	1.07E+01	1.42E-02	1.41E-03	1.32E-13	1.34E-03	2.49E+02
OSB panels, biogenic CO2 not substracted, 617 kg/m3, EPD cov...	1	m2	7.70E+00	2.13E-02	2.95E-03	2.91E-06	3.23E-03	9.31E+01
			4.03E+01	**1.06E-01**	**2.34E-02**	**7.46E-06**	**4.68E-02**	**7.98E+02**

A4 Materials Transportation to the factory			Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
Parquet glue, 0.6 kg/m2, BOSTIK PU 456 (BOSTIK SA)	3.7	kg	1.61E-01	6.51E-04	1.40E-04	3.10E-08	1.34E-05	4.49E+00
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	m2	3.29E-02	1.51E-04	3.30E-05	6.49E-09	1.85E-06	9.35E-01
EPS insulation, grey, 15 kg/m3 (STYBENEX)	0.22	m3	5.43E-02	2.50E-04	5.45E-05	1.07E-08	3.06E-06	1.55E+00
Polyester resin laminated part (GFRP, 30% glass fibres), 140...	0.002	m3	4.61E-02	2.12E-04	4.63E-05	9.11E-09	2.60E-06	1.31E+00
OSB panels, biogenic CO2 not substracted, 617 kg/m3, EPD cov...	1	m2	1.45E-01	6.66E-04	1.45E-04	2.86E-08	8.15E-06	4.12E+00
			4.39E-01	**1.93E-03**	**4.19E-04**	**8.59E-08**	**2.91E-05**	**1.24E+01**

A4 Panel transportation to the Housing site			Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
Trailer combination. 40 ton capacity	29.21	kg-km	4.72E-01	2.18E-03	4.73E-04	9.32E-08	2.66E-05	1.34E+01
			4.72E-01	**2.18E-03**	**4.73E-04**	**9.32E-08**	**2.66E-05**	**1.34E+01**

C1-C4 End of life (Deconstruction)			Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
Parquet glue, 0.6 kg/m2, BOSTIK PU 456 (BOSTIK SA)	3.7	kg	5.00E-02	3.09E-04	4.46E-05	7.71E-13	3.00E-05	7.45E-01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	m2	2.13E-02	1.67E-04	3.46E-05	1.70E-14	1.65E-05	4.44E-01
EPS insulation, grey, 15 kg/m3 (STYBENEX)	0.22	m3	8.34E+00	1.95E-03	1.63E-04	6.71E-13	8.93E-05	4.53E+00
Polyester resin laminated part (GFRP, 30% glass fibres), 140...	0.002	m3	2.45E-02	1.72E-04	2.41E-05	3.31E-09	8.36E-06	6.69E-01
OSB panels, biogenic CO2 not substracted, 617 kg/m3, EPD cov...	1	m2	1.39E+00	1.89E-03	4.14E-04	6.61E-13	1.56E-04	5.03E+00
			9.83E+00	**4.49E-03**	**6.80E-04**	**3.31E-09**	**3.00E-04**	**1.14E+01**

D Product Manufacturing			Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
Parquet glue, 0.6 kg/m2, BOSTIK PU 456 (BOSTIK SA)	3.7	kg	5.60E+00	2.40E-02	1.41E-02	4.18E-06	2.03E-03	9.29E+01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	m2	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
Polyester resin laminated part (GFRP, 30% glass fibres), 140...	0.002	m3	1.07E+01	1.42E-02	1.41E-03	1.32E-13	1.34E-03	2.49E+02
OSB panels, biogenic CO2 not substracted, 617 kg/m3, EPD cov...	1	m2	7.70E+00	2.13E-02	2.95E-03	2.91E-06	3.23E-03	9.31E+01
			27.08	**6.61E-02**	**1.91E-02**	**7.13E-06**	**7.16E-03**	**4.67E+02**

D End of life (Deconstruction)			Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
Parquet glue, 0.6 kg/m2, BOSTIK PU 456 (BOSTIK SA)	3.7	kg	5.00E-02	3.09E-04	4.46E-05	7.71E-13	3.00E-05	7.45E-01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	m2	2.13E-02	1.67E-04	3.46E-05	1.70E-14	1.65E-05	4.44E-01
Polyester resin laminated part (GFRP, 30% glass fibres), 140...	0.002	m3	2.45E-02	1.72E-04	2.41E-05	3.31E-09	8.36E-06	6.69E-01
OSB panels, biogenic CO2 not substracted, 617 kg/m3, EPD cov...	1	m2	1.39E+00	1.89E-03	4.14E-04	6.61E-13	1.56E-04	5.03E+00
			1.49E+00	**2.54E-03**	**5.17E-04**	**3.31E-09**	**2.11E-04**	**6.89E+00**

					Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
		Monetary value (Euros/Emission unit)			EUR 0.05	EUR 4.00	EUR 9.00	EUR 30.00	EUR 30.00	
HOME 1	A1-A3	Product Manufacturing	1	m2	$2.01	$0.42	$0.21	$0.00	$1.40	$4.12
		Materials Transportation to the factory	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	
	A5	Panel transportation to the Housing site	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	$0.13
		End of life (Deconstruction)	1	m2	$0.07	$0.01	$0.00	$0.00	$0.01	
HOME 2	A1-A3	Product Manufacturing	1	m2	$1.35	$0.26	$0.17	$0.00	$0.21	$2.08
		Materials Transportation to the factory	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	
	A5	Panel transportation to the Housing site	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	$0.13
		End of life (Deconstruction)	1	m2	$0.07	$0.01	$0.00	$0.00	$0.01	
HOME 3	A1-A3	Product Manufacturing	1	m2	$1.35	$0.26	$0.17	$0.00	$0.21	$2.08
		Materials Transportation to the factory	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	
	A5	Panel transportation to the Housing site	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	$0.13
		End of life (Deconstruction)	1	m2	$0.07	$0.01	$0.00	$0.00	$0.01	
HOME 4	A1-A3	Product Manufacturing	1	m2	$1.35	$0.26	$0.17	$0.00	$0.21	$2.08
		Materials Transportation to the factory	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	
	A5	Panel transportation to the Housing site	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	$0.02	$0.01	$0.00	$0.00	$0.00	$0.56
		End of life (Deconstruction)	1	m2	$0.49	$0.02	$0.01	$0.00	$0.01	

APPENDIX I - WEIGHTING FACTOR CONCEPT 1 1ST CIRCULARITY SCENARIO STUCCO CLADDING

A1-A3			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Product Manufacturing			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	1.88E+00	4.18E-03	6.96E-04	3.66E-08	5.62E-04	2.82E+01
Flax fibre fleece. 38 kg/m3	1.1	kg	9.45E+00	1.93E-02	2.46E-03	1.35E-09	3.70E-03	2.06E+02
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
Rendering mortar – normal / finishing render	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			4.16E+01	**9.19E-02**	**1.43E-02**	**1.03E-06**	**8.26E-03**	**4.90E+02**

A4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Materials Transportation to the factory			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Rendering mortar – normal / finishing render. 1300 - 1800 kg...	1.6	kg	3.29E-02	1.51E-04	3.30E-05	6.49E-09	1.85E-06	9.35E-01
Epoxy resin. EU avg.. 1-1.25 kg/l. solvent-free. low content...	1.1	kg	7.06E-02	2.86E-04	6.14E-05	1.36E-08	5.90E-06	1.97E+00
Flax fibre fleece. 38 kg/m3	1	m2	1.78E-02	8.19E-05	1.78E-05	3.51E-09	1.00E-06	5.06E-01
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2...	7.8	kg	4.01E-01	1.85E-03	4.02E-04	7.92E-08	2.26E-05	1.14E+01
			6.44E-01	**2.93E-03**	**6.36E-04**	**1.27E-07**	**3.82E-05**	**1.83E+01**

A5			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Panel transportation to the Housing site			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	53.65	kg	8.67E-01	4.00E-03	8.69E-04	1.71E-07	4.89E-05	2.46E+01
			8.67E-01	**4.00E-03**	**8.69E-04**	**1.71E-07**	**4.89E-05**	**2.46E+01**

B1-B5			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Maintenance and material replacement			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	9.39E-01	2.09E-03	3.48E-04	1.83E-08	2.81E-04	1.41E+01
Flax fibre fleece. 38 kg/m3	0.55	kg	4.73E+00	9.65E-03	1.23E-03	6.75E-10	1.85E-03	1.03E+02
Rendering mortar – normal / finishing render	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			8.74E+00	**1.84E-02**	**2.25E-03**	**5.56E-08**	**2.69E-03**	**1.49E+02**

C1-C4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
End of life (Deconstruction)			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
Rendering mortar – normal / finishing render. 1300 - 1800 kg...	1.6	kg	2.13E-02	1.67E-04	3.46E-05	1.70E-14	1.65E-05	4.44E-01
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.1	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Flax fibre fleece. 38 kg/m3	1.1	kg	8.05E-01	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2...	7.8	kg	3.75E+00	5.09E-03	1.11E-03	1.78E-12	4.20E-04	1.35E+01
			5.75E+00	**8.96E-03**	**2.37E-03**	**1.48E-08**	**5.98E-04**	**1.97E+01**

				Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
	Monetary value (Euros/Emission unit)			0.05	4	9	30	30	
A1-A3	Product Manufacturing	1	m2	€ 2.08	€ 0.37	€ 0.13	€ 0.00	€ 0.25	€ 2.95
	Materials Transportation to the factory	1	m2	€ 0.03	€ 0.01	€ 0.01	€ 0.00	€ 0.00	
A5	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
B1 - B5	Panel Transportation to the factory	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.78
	Product Maintenance	1	m2	€ 0.44	€ 0.07	€ 0.02	€ 0.00	€ 0.08	
	End of life (Deconstruction) of parts maintained	1	m2	€ 0.02	€ 0.00	€ 0.00	€ 0.00	€ 0.00	
	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.43
	End of life (Deconstruction)	1	m2	€ 0.29	€ 0.04	€ 0.02	€ 0.00	€ 0.02	
				€ 3.03	€ 0.56	€ 0.21	€ 0.00	€ 0.35	€ 4.16
									€ 4.16

APPENDIX J - WEIGHTING FACTOR CONCEPT 1 1ST CIRCULARITY SCENARIO REAR VENTILATED CLADDING

A1-A3			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex.
Product Manufacturing			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	1.88E+00	4.18E-03	6.96E-04	3.66E-08	5.62E-04	2.82E+01
Flax fibre fleece. 38 kg/m3	1.1	kg	9.45E+00	1.93E-02	2.46E-03	1.35E-09	3.70E-03	2.06E+02
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
Threaded reinforcement bolts, 1.7 kg/unit	0.2	kg	1.45E-01	7.16E-04	1.34E-04	6.61E-09	3.79E-05	3.13E+00
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	1.09E+00	5.76E-03	2.81E-04	6.99E-11	3.31E-04	1.95E+01
Bricks (KNB)	42	kg	7.88E+00	1.09E-02	1.89E-03	9.91E-07	1.75E-03	1.44E+02
			4.77E+01	**1.03E-01**	**1.60E-02**	**1.99E-06**	**9.81E-03**	**6.24E+02**

A4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex.
Materials Transportation to the factory			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	3.29E-02	1.51E-04	3.30E-05	6.49E-09	1.85E-06	9.35E-01
Flax fibre fleece. 38 kg/m3	1.1	kg	7.06E-02	2.86E-04	6.14E-05	1.36E-08	5.90E-06	1.97E+00
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2	1	m2	1.78E-02	8.19E-05	1.78E-05	3.51E-09	1.00E-06	5.06E-01
Threaded reinforcement bolts, 1.7 kg/unit	0.2	kg	2.83E-03	1.31E-05	2.84E-06	5.60E-10	1.60E-07	8.07E-02
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	3.42E-03	1.57E-05	3.43E-06	6.75E-10	1.93E-07	9.73E-02
Bricks (KNB)	42	kg	9.65E-02	4.44E-04	9.68E-05	1.91E-08	5.44E-06	2.75E+00
			3.46E-01	**1.55E-03**	**3.37E-04**	**6.80E-08**	**2.14E-05**	**9.81E+00**

A5			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Panel transportation to the Housing site			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	108.77	kg	1.76E+00	8.11E-03	1.76E-03	3.47E-07	9.90E-05	5.00E+01
			1.76E+00	**8.11E-03**	**1.76E-03**	**3.47E-07**	**9.90E-05**	**5.00E+01**

B1-B5			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Maintenance and material replacement			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	9.39E-01	2.09E-03	3.48E-04	1.83E-08	2.81E-04	1.41E+01
Flax fibre fleece. 38 kg/m3	1.1	kg	4.73E+00	9.65E-03	1.23E-03	6.75E-10	1.85E-03	1.03E+02
			5.66E+00	**1.17E-02**	**1.58E-03**	**1.90E-08**	**2.13E-03**	**1.17E+02**

C1-C4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
End of life (Deconstruction)			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Flax fibre fleece. 38 kg/m3	1.1	kg	8.05E-01	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2	1	m2	3.75E+00	5.09E-03	1.11E-03	1.78E-12	4.20E-04	1.35E+01
Threaded reinforcement bolts, 1.7 kg/unit	0.2	kg	1.61E-04	9.54E-07	1.30E-07	1.52E-16	7.60E-08	2.41E-03
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	1.47E-03	5.85E-06	1.22E-06	2.87E-10	1.98E-07	4.19E-02
Bricks (KNB)	42	kg	1.15E-01	8.99E-04	1.86E-04	9.16E-14	8.88E-05	2.39E+00
			5.85E+00	**9.70E-03**	**2.52E-03**	**1.51E-08**	**6.71E-04**	**2.17E+01**

				Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
	Monetary value (Euros/Emission unit)			0.05	4	9	30	30	
A1-A3	Product Manufacturing	1	m2	€ 2.384	€ 0.411	€ 0.144	€ 0.000	€ 0.294	€ 3.400
	Materials Transportation to the factory	1	m2	€ 0.017	€ 0.006	€ 0.003	€ 0.000	€ 0.001	
A5	Panel transportation to the Housing site	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	
B1 - B5	Panel Transportation to the factory	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	€ 0.744
	Product Maintenance	1	m2	€ 0.283	€ 0.047	€ 0.014	€ 0.000	€ 0.064	
	End of life (Deconstruction) of parts maintained	1	m2	€ 0.040	€ 0.008	€ 0.008	€ 0.000	€ 0.001	
	Panel transportation to the Housing site	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	
B1 - B5	Panel Transportation to the factory	1	m2	€ 0.044	€ 0.016	€ 0.008	€ 0.000	€ 0.001	€ 0.372
	Product Maintenance	1	m2	€ 0.142	€ 0.023	€ 0.007	€ 0.000	€ 0.032	
	End of life (Deconstruction) of parts maintained	1	m2	€ 0.020	€ 0.004	€ 0.004	€ 0.000	€ 0.000	
	Panel transportation to the Housing site	1	m2	€ 0.044	€ 0.016	€ 0.008	€ 0.000	€ 0.001	
C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	€ 0.513
	End of life (Deconstruction)	1	m2	€ 0.292	€ 0.039	€ 0.023	€ 0.000	€ 0.020	
				€ 3.62	€ 0.70	€ 0.28	€ 0.00	€ 0.43	€ 5.03
									€ 5.03

APPENDIX K - WEIGHTING FACTOR CONCEPT 1 2ND CIRCULARITY SCENARIO STUCCO CLADDING

A1-A3			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Product Manufacturing			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	1.88E+00	4.18E-03	6.96E-04	3.66E-08	5.62E-04	2.82E+01
Flax fibre fleece. 38 kg/m3	1.1	kg	9.45E+00	1.93E-02	2.46E-03	1.35E-09	3.70E-03	2.06E+02
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
Rendering mortar – normal / finishing render	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			4.16E+01	**9.19E-02**	**1.43E-02**	**1.03E-06**	**8.26E-03**	**4.90E+02**

A4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Materials Transportation to the factory			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Rendering mortar – normal / finishing render. 1300 - 1800 kg...	1.6	kg	3.29E-02	1.51E-04	3.30E-05	6.49E-09	1.85E-06	9.35E-01
Epoxy resin. EU avg.. 1-1.25 kg/l. solvent-free. low content...	1.1	kg	7.06E-02	2.86E-04	6.14E-05	1.36E-08	5.90E-06	1.97E+00
Flax fibre fleece. 38 kg/m3	1	m2	1.78E-02	8.19E-05	1.78E-05	3.51E-09	1.00E-06	5.06E-01
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2...	7.8	kg	4.01E-01	1.85E-03	4.02E-04	7.92E-08	2.26E-05	1.14E+01
			6.44E-01	**2.93E-03**	**6.36E-04**	**1.27E-07**	**3.82E-05**	**1.83E+01**

A5			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Panel transportation to the Housing site			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	53.65	kg	8.67E-01	4.00E-03	8.69E-04	1.71E-07	4.89E-05	2.46E+01
			8.67E-01	**4.00E-03**	**8.69E-04**	**1.71E-07**	**4.89E-05**	**2.46E+01**

B1-B5			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Maintenance and material replacement			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	9.39E-01	2.09E-03	3.48E-04	1.83E-08	2.81E-04	1.41E+01
Flax fibre fleece. 38 kg/m3	1.1	kg	4.73E+00	9.65E-03	1.23E-03	6.75E-10	1.85E-03	1.03E+02
Rendering mortar – normal / finishing render	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			8.74E+00	**1.84E-02**	**2.25E-03**	**5.56E-08**	**2.69E-03**	**1.49E+02**

C1-C4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
End of life (Deconstruction)			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
Rendering mortar – normal / finishing render. 1300 - 1800 kg...	1.6	kg	2.13E-02	1.67E-04	3.46E-05	1.70E-14	1.65E-05	4.44E-01
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.1	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Flax fibre fleece. 38 kg/m3	1.1	kg	8.05E-01	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2...	7.8	kg	3.75E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.35E+01
			5.75E+00	**3.87E-03**	**1.26E-03**	**1.48E-08**	**1.78E-04**	**1.97E+01**

D			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Product Manufacturing			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	1.88E+00	4.18E-03	6.96E-04	3.66E-08	5.62E-04	2.82E+01
Flax fibre fleece. 38 kg/m3	1.1	kg	9.45E+00	1.93E-02	2.46E-03	1.35E-09	3.70E-03	2.06E+02
Rendering mortar – normal / finishing render	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			2.20E+01	**8.94E-02**	**1.35E-02**	**9.99E-07**	**8.11E-03**	**4.85E+02**

D			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
End of life (Deconstruction)			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
Rendering mortar – normal / finishing render. 1300 - 1800 kg...	1.6	kg	2.13E-02	1.67E-04	3.46E-05	1.70E-14	1.65E-05	4.44E-01
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.1	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Flax fibre fleece. 38 kg/m3	1.1	kg	8.05E-01	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
			2.00E+00	**3.87E-03**	**1.26E-03**	**1.48E-08**	**1.78E-04**	**6.23E+00**

					Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
		Monetary value (Euros/Emission unit)			0.05	4	9	30	30	
HOME 1	A1-A3	Product Manufacturing	1	m2	€ 2.08	€ 0.37	€ 0.13	€ 0.00	€ 0.25	€ 2.95
		Materials Transportation to the factory	1	m2	€ 0.03	€ 0.01	€ 0.01	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.20
		End of life (Deconstruction)	1	m2	€ 0.10	€ 0.02	€ 0.01	€ 0.00	€ 0.01	
HOME 2	D	Product Manufacturing	1	m2	€ 1.10	€ 0.36	€ 0.12	€ 0.00	€ 0.24	€ 1.94
		Materials Transportation to the factory	1	m2	€ 0.03	€ 0.01	€ 0.01	€ 0.00	€ 0.00	
	D	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	D	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.39
		End of life (Deconstruction)	1	m2	€ 0.29	€ 0.02	€ 0.01	€ 0.00	€ 0.01	
					€ 3.81	€ 0.84	€ 0.32	€ 0.00	€ 0.51	€ 5.48
										€ 5.48
									% vs Original	79.5%

APPENDIX L- WEIGHTING FACTOR CONCEPT 1 2ND CIRCULARITY SCENARIO REAR VENTILATED CLADDING

A1-A3			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Product Manufacturing			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	1.88E+00	4.18E-03	6.96E-04	3.66E-08	5.62E-04	2.82E+01
Flax fibre fleece. 38 kg/m3	1.1	kg	9.45E+00	1.93E-02	2.46E-03	1.35E-09	3.70E-03	2.06E+02
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	3.35E-01	2.65E-03	9.54E-03	3.25E-12	1.39E-04	1.09E+01
Threaded reinforcement bolts, 1.7 kg/unit	0.2	kg	1.45E-01	7.16E-04	1.34E-04	6.61E-09	3.79E-05	3.13E+00
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	1.09E+00	5.76E-03	2.81E-04	6.99E-11	3.31E-04	1.95E+01
Bricks (KNB)	42	kg	7.88E+00	1.09E-02	1.89E-03	9.91E-07	1.75E-03	1.44E+02
			4.80E+01	**1.05E-01**	**2.55E-02**	**1.99E-06**	**9.95E-03**	**6.35E+02**

A4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Materials Transportation to the factory			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	3.29E-02	1.51E-04	3.30E-05	6.49E-09	1.85E-06	9.35E-01
Flax fibre fleece. 38 kg/m3	1.1	kg	7.06E-02	2.86E-04	6.14E-05	1.36E-08	5.90E-06	1.97E+00
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2	1	m2	1.78E-02	8.19E-05	1.78E-05	3.51E-09	1.00E-06	5.06E-01
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	1.65E-03	7.58E-06	1.65E-06	3.25E-10	9.28E-08	4.69E-02
Threaded reinforcement bolts, 1.7 kg/unit	0.2	kg	2.83E-03	1.31E-05	2.84E-06	5.60E-10	1.60E-07	8.07E-02
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	3.42E-03	1.57E-05	3.43E-06	6.75E-10	1.93E-07	9.73E-02
Bricks (KNB)	42	kg	9.65E-02	4.44E-04	9.68E-05	1.91E-08	5.44E-06	2.75E+00
			3.48E-01	**1.56E-03**	**3.39E-04**	**6.84E-08**	**2.15E-05**	**9.86E+00**

A5			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Panel transportation to the Housing site			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	108.77	kg-km	1.76E+00	8.11E-03	1.76E-03	3.47E-07	9.90E-05	5.00E+01
			1.76E+00	**8.11E-03**	**1.76E-03**	**3.47E-07**	**9.90E-05**	**5.00E+01**

C1-C4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
End of life (Deconstruction)			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Flax fibre fleece. 38 kg/m3	1.1	kg	8.05E-01	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2	1	m2	3.75E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.35E+01
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	2.53E-01	5.91E-05	4.93E-06	2.03E-14	2.71E-06	1.37E-01
Threaded reinforcement bolts, 1.7 kg/unit	0.2	kg	1.61E-04	9.54E-07	1.30E-07	1.52E-16	7.60E-08	2.41E-03
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	1.47E-03	5.85E-06	1.22E-06	2.87E-10	1.98E-07	4.19E-02
Bricks (KNB)	42	kg	1.15E-01	8.99E-04	1.86E-04	9.16E-14	8.88E-05	2.39E+00
			6.10E+00	**4.67E-03**	**1.41E-03**	**1.51E-08**	**2.53E-04**	**2.19E+01**

D1-D3			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Product Manufacturing			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	1.88E+00	4.18E-03	6.96E-04	3.66E-08	5.62E-04	2.82E+01
Flax fibre fleece. 38 kg/m3	1.1	kg	9.45E+00	1.93E-02	2.46E-03	1.35E-09	3.70E-03	2.06E+02
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	3.35E-01	2.65E-03	9.54E-03	3.25E-12	1.39E-04	1.09E+01
			1.93E+01	**8.54E-02**	**2.24E-02**	**9.62E-07**	**7.69E-03**	**4.64E+02**

D1-D3			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
End of life (Deconstruction)			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Flax fibre fleece. 38 kg/m3	1.1	kg	8.05E-01	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	2.53E-01	5.91E-05	4.93E-06	2.03E-14	2.71E-06	1.37E-01
			2.23E+00	**3.76E-03**	**1.23E-03**	**1.48E-08**	**1.64E-04**	**5.92E+00**

					Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
		Monetary value (Euros/Emission unit)			0.05	4	9	30	30	
HOME 1	A1-A3	Product Manufacturing	1	m2	€ 2.401	€ 0.421	€ 0.230	€ 0.000	€ 0.299	€ 3.517
		Materials Transportation to the factory	1	m2	€ 0.017	€ 0.006	€ 0.003	€ 0.000	€ 0.001	
	A5	Panel transportation to the Housing site	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	
	B1 - B5	Panel Transportation to the factory	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	€ 0.715
		Product Maintenance	1	m2	€ 0.283	€ 0.047	€ 0.014	€ 0.000	€ 0.064	
		End of life (Deconstruction) of parts maintained	1	m2	€ 0.020	€ 0.004	€ 0.004	€ 0.000	€ 0.000	
		Panel transportation to the Housing site	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	€ 0.282
		End of life (Deconstruction)	1	m2	€ 0.112	€ 0.015	€ 0.011	€ 0.000	€ 0.005	
HOME 2	D	Product Manufacturing	1	m2	€ 0.965	€ 0.342	€ 0.201	€ 0.000	€ 0.231	€ 1.905
		Materials Transportation to the factory	1	m2	€ 0.017	€ 0.006	€ 0.003	€ 0.000	€ 0.001	
	D	Panel transportation to the Housing site	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	
	D	Panel Transportation to the factory	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	€ 0.715
		Product Maintenance	1	m2	€ 0.283	€ 0.047	€ 0.014	€ 0.000	€ 0.064	
		End of life (Deconstruction) of parts maintained	1	m2	€ 0.020	€ 0.004	€ 0.004	€ 0.000	€ 0.000	
		Panel transportation to the Housing site	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	
	D	Panel Transportation for deconstruction process	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	€ 0.483
		End of life (Deconstruction)	1	m2	€ 0.305	€ 0.019	€ 0.013	€ 0.000	€ 0.008	
					€ 5.13	€ 1.17	€ 0.62	€ 0.00	€ 0.70	€ 7.62

APPENDIX M - WEIGHTING FACTOR
CONCEPT 1
3RD CIRCULARITY SCENARIO
STUCCO CLADDING

A1-A3 Product Manufacturing			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	1.88E+00	4.18E-03	6.96E-04	3.66E-08	5.62E-04	2.82E+01
Flax fibre fleece. 38 kg/m3	1.1	kg	9.45E+00	1.93E-02	2.46E-03	1.35E-09	3.70E-03	2.06E+02
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
Rendering mortar – normal / finishing render	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			4.16E+01	**9.19E-02**	**1.43E-02**	**1.03E-06**	**8.26E-03**	**4.90E+02**

A4 Materials Transportation to the factory			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Rendering mortar – normal / finishing render. 1300 - 1800 kg...	1.6	kg	3.29E-02	1.51E-04	3.30E-05	6.49E-09	1.85E-06	9.35E-01
Epoxy resin. EU avg.. 1-1.25 kg/l. solvent-free. low content...	1.1	kg	7.06E-02	2.86E-04	6.14E-05	1.36E-08	5.90E-06	1.97E+00
Flax fibre fleece. 38 kg/m3	1	m2	1.78E-02	8.19E-05	1.78E-05	3.51E-09	1.00E-06	5.06E-01
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2...	7.8	kg	4.01E-01	1.85E-03	4.02E-04	7.92E-08	2.26E-05	1.14E+01
			6.44E-01	**2.93E-03**	**6.36E-04**	**1.27E-07**	**3.82E-05**	**1.83E+01**

A5 Panel transportation to the Housing site			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	53.65	kg	8.67E-01	4.00E-03	8.69E-04	1.71E-07	4.89E-05	2.46E+01
			8.67E-01	**4.00E-03**	**8.69E-04**	**1.71E-07**	**4.89E-05**	**2.46E+01**

B1-B5 Maintenance and material replacement			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	9.39E-01	2.09E-03	3.48E-04	1.83E-08	2.81E-04	1.41E+01
Flax fibre fleece. 38 kg/m3	1.1	kg	4.73E+00	9.65E-03	1.23E-03	6.75E-10	1.85E-03	1.03E+02
Rendering mortar – normal / finishing render	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			8.74E+00	**1.84E-02**	**2.25E-03**	**5.56E-08**	**2.69E-03**	**1.49E+02**

C1-C4 End of life (Deconstruction)			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
Rendering mortar – normal / finishing render. 1300 - 1800 kg...	1.6	kg	2.13E-02	1.67E-04	3.46E-05	1.70E-14	1.65E-05	4.44E-01
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.1	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Flax fibre fleece. 38 kg/m3	1.1	kg	8.05E-01	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2...	7.8	kg	3.75E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.35E+01
			5.75E+00	**3.87E-03**	**1.26E-03**	**1.48E-08**	**1.78E-04**	**1.97E+01**

D Product Manufacturing			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	1.88E+00	4.18E-03	6.96E-04	3.66E-08	5.62E-04	2.82E+01
Flax fibre fleece. 38 kg/m3	1.1	kg	9.45E+00	1.93E-02	2.46E-03	1.35E-09	3.70E-03	2.06E+02
Rendering mortar – normal / finishing render	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			2.20E+01	**8.94E-02**	**1.35E-02**	**9.99E-07**	**8.11E-03**	**4.85E+02**

D End of life (Deconstruction)			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
Rendering mortar – normal / finishing render. 1300 - 1800 kg...	1.6	kg	2.13E-02	1.67E-04	3.46E-05	1.70E-14	1.65E-05	4.44E-01
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.1	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Flax fibre fleece. 38 kg/m3	1.1	kg	8.05E-01	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
			2.00E+00	**3.87E-03**	**1.26E-03**	**1.48E-08**	**1.78E-04**	**6.23E+00**

					Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
		Monetary value (Euros/Emission unit)			0.05	4	9	30	30	
HOME 1	A1-A3	Product Manufacturing	1	m2	€ 2.08	€ 0.37	€ 0.13	€ 0.00	€ 0.25	€ 2.95
HOME 1	A1-A3	Materials Transportation to the factory	1	m2	€ 0.03	€ 0.01	€ 0.01	€ 0.00	€ 0.00	
HOME 1	A5	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
HOME 1	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.20
HOME 1	C1-C4	End of life (Deconstruction)	1	m2	€ 0.10	€ 0.02	€ 0.01	€ 0.00	€ 0.01	
HOME 2	A1-A3	Product Manufacturing	1	m2	€ 1.10	€ 0.36	€ 0.12	€ 0.00	€ 0.24	€ 1.94
HOME 2	A1-A3	Materials Transportation to the factory	1	m2	€ 0.03	€ 0.01	€ 0.01	€ 0.00	€ 0.00	
HOME 2	A5	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
HOME 2	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.20
HOME 2	C1-C4	End of life (Deconstruction)	1	m2	€ 0.10	€ 0.02	€ 0.01	€ 0.00	€ 0.01	
HOME 3	A1-A3	Product Manufacturing	1	m2	€ 1.10	€ 0.36	€ 0.12	€ 0.00	€ 0.24	€ 1.94
HOME 3	A1-A3	Materials Transportation to the factory	1	m2	€ 0.03	€ 0.01	€ 0.01	€ 0.00	€ 0.00	
HOME 3	A5	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
HOME 3	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.20
HOME 3	C1-C4	End of life (Deconstruction)	1	m2	€ 0.10	€ 0.02	€ 0.01	€ 0.00	€ 0.01	
HOME 4	A1-A3	Product Manufacturing	1	m2	€ 1.10	€ 0.36	€ 0.12	€ 0.00	€ 0.24	€ 1.94
HOME 4	A1-A3	Materials Transportation to the factory	1	m2	€ 0.03	€ 0.01	€ 0.01	€ 0.00	€ 0.00	
HOME 4	A5	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
HOME 4	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.39
HOME 4	C1-C4	End of life (Deconstruction)	1	m2	€ 0.29	€ 0.02	€ 0.01	€ 0.00	€ 0.01	
					€ 6.45	€ 1.68	€ 0.62	€ 0.00	€ 1.02	€ 9.77
										€ 9.77

APPENDIX N - WEIGHTING FACTOR CONCEPT 1 3RD CIRCULARITY SCENARIO REAR VENTILATED

A1-A3			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Product Manufacturing			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	1.88E+00	4.18E-03	6.96E-04	3.66E-08	5.62E-04	2.82E+01
Flax fibre fleece. 38 kg/m3	1.1	kg	9.45E+00	1.93E-02	2.46E-03	1.35E-09	3.70E-03	2.06E+02
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
Threaded reinforcement bolts, 1.7 kg/unit	0.2	kg	1.45E-01	7.16E-04	1.34E-04	6.61E-09	3.79E-05	3.13E+00
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	1.09E+00	5.76E-03	2.81E-04	6.99E-11	3.31E-04	1.95E+01
Bricks (KNB)	42	kg	7.88E+00	1.09E-02	1.89E-03	9.91E-07	1.75E-03	1.44E+02
			4.77E+01	**1.03E-01**	**1.60E-02**	**1.99E-06**	**9.81E-03**	**6.24E+02**

A4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Materials Transportation to the factory			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	3.29E-02	1.51E-04	3.30E-05	6.49E-09	1.85E-06	9.35E-01
Flax fibre fleece. 38 kg/m3	1.1	kg	7.06E-02	2.86E-04	6.14E-05	1.36E-08	5.90E-06	1.97E+00
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2	1	m2	1.78E-02	8.19E-05	1.78E-05	3.51E-09	1.00E-06	5.06E-01
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	1.65E-03	7.58E-06	1.65E-06	3.25E-10	9.28E-08	4.69E-02
Threaded reinforcement bolts, 1.7 kg/unit	0.2	kg	2.83E-03	1.31E-05	2.84E-06	5.60E-10	1.60E-07	8.07E-02
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	3.42E-03	1.57E-05	3.43E-06	6.75E-10	1.93E-07	9.73E-02
Bricks (KNB)	42	kg	9.65E-02	4.44E-04	9.68E-05	1.91E-08	5.44E-06	2.75E+00
			3.48E-01	**1.56E-03**	**3.39E-04**	**6.84E-08**	**2.15E-05**	**9.86E+00**

A5			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Panel transportation to the Housing site			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	108.77	kg-km	1.76E+00	8.11E-03	1.76E-03	3.47E-07	9.90E-05	5.00E+01
			1.76E+00	**8.11E-03**	**1.76E-03**	**3.47E-07**	**9.90E-05**	**5.00E+01**

C1-C4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
End of life (Deconstruction)			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Flax fibre fleece. 38 kg/m3	1.1	kg	8.05E-01	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
Insulation from expanded corkboard (ICB). > 50 mm. 115 kg/m2	1	m2	3.75E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.35E+01
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	2.53E-01	5.91E-05	4.93E-06	2.03E-14	2.71E-06	1.37E-01
Threaded reinforcement bolts, 1.7 kg/unit	0.2	kg	1.61E-04	9.54E-07	1.30E-07	1.52E-16	7.60E-08	2.41E-03
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	1.47E-03	5.85E-06	1.22E-06	2.87E-10	1.98E-07	4.19E-02
Bricks (KNB)	42	kg	1.15E-01	8.99E-04	1.86E-04	9.16E-14	8.88E-05	2.39E+00
			6.10E+00	**4.67E-03**	**1.41E-03**	**1.51E-08**	**2.53E-04**	**2.19E+01**

D			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Product Manufacturing			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	1.88E+00	4.18E-03	6.96E-04	3.66E-08	5.62E-04	2.82E+01
Flax fibre fleece. 38 kg/m3	1.1	kg	9.45E+00	1.93E-02	2.46E-03	1.35E-09	3.70E-03	2.06E+02
			1.90E+01	**8.28E-02**	**1.28E-02**	**9.62E-07**	**7.55E-03**	**4.53E+02**

D			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
End of life (Deconstruction)			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Flax fibre fleece. 38 kg/m3	1.1	kg	8.05E-01	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	2.53E-01	5.91E-05	4.93E-06	2.03E-14	2.71E-06	1.37E-01
			2.23E+00	**3.76E-03**	**1.23E-03**	**1.48E-08**	**1.64E-04**	**5.92E+00**

					Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
		Monetary value (Euros/Emission unit)			0.05	4	9	30	30	
HOME 1	A1-A3	Product Manufacturing	1	m2	€ 2.384	€ 0.411	€ 0.144	€ 0.000	€ 0.294	€ 3.400
		Materials Transportation to the factory	1	m2	€ 0.017	€ 0.006	€ 0.003	€ 0.000	€ 0.001	
	A5	Panel transportation to the Housing site	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	€ 0.282
		End of life (Deconstruction)	1	m2	€ 0.112	€ 0.015	€ 0.011	€ 0.000	€ 0.005	
HOME 2	A1-A3	Product Manufacturing	1	m2	€ 0.948	€ 0.331	€ 0.115	€ 0.000	€ 0.227	€ 1.788
		Materials Transportation to the factory	1	m2	€ 0.017	€ 0.006	€ 0.003	€ 0.000	€ 0.001	
	A5	Panel transportation to the Housing site	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	€ 0.282
		End of life (Deconstruction)	1	m2	€ 0.112	€ 0.015	€ 0.011	€ 0.000	€ 0.005	
HOME 3	A1-A3	Product Manufacturing	1	m2	€ 0.948	€ 0.331	€ 0.115	€ 0.000	€ 0.227	€ 1.788
		Materials Transportation to the factory	1	m2	€ 0.017	€ 0.006	€ 0.003	€ 0.000	€ 0.001	
	A5	Panel transportation to the Housing site	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	€ 0.282
		End of life (Deconstruction)	1	m2	€ 0.112	€ 0.015	€ 0.011	€ 0.000	€ 0.005	
HOME 4	A1-A3	Product Manufacturing	1	m2	€ 0.948	€ 0.331	€ 0.115	€ 0.000	€ 0.227	€ 1.788
		Materials Transportation to the factory	1	m2	€ 0.017	€ 0.006	€ 0.003	€ 0.000	€ 0.001	
	A5	Panel transportation to the Housing site	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.088	€ 0.032	€ 0.016	€ 0.000	€ 0.003	€ 0.483
		End of life (Deconstruction)	1	m2	€ 0.305	€ 0.019	€ 0.013	€ 0.000	€ 0.008	
					€ 6.64	€ 1.75	€ 0.67	€ 0.00	€ 1.02	€ 10.09
										€ 10.09

APPENDIX O - WEIGHTING FACTOR CONCEPT 2 1ST CIRCULARITY SCENARIO STUCCO CLADDING

A1-A3 Product Manufacturing			Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	1.59E+01	3.39E-02	2.72E-03	2.07E-13	2.58E-03	2.79E+02
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	1.88E+00	4.18E-03	6.96E-04	3.66E-08	5.62E-04	2.82E+01
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			5.57E+01	**1.66E-01**	**2.43E-02**	**1.95E-06**	**1.04E-02**	**7.82E+02**

A4 Materials Transportation to the factory			Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m3	2.52E-02	1.16E-04	2.53E-05	4.98E-09	1.42E-06	7.17E-01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, high conten...	1.1	kg	6.98E-02	2.82E-04	6.06E-05	1.34E-08	5.82E-06	1.95E+00
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	4.01E-01	1.85E-03	4.02E-04	7.92E-08	2.26E-05	1.14E+01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	3.29E-02	1.51E-04	3.30E-05	6.49E-09	1.85E-06	9.35E-01
			7.73E-01	**3.52E-03**	**7.65E-04**	**1.52E-07**	**4.54E-05**	**2.19E+01**

Panel transportation to the Housing site			Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
Trailer combination. 40 ton capacity	1.00	kg	1.47E-04	6.78E-07	1.47E-07	2.90E-11	8.28E-09	4.18E-03

A5 Panel transportation to the Housing site			Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
Trailer combination. 40 ton capacity	53.65	kg	8.67E-01	4.00E-03	8.69E-04	1.71E-07	4.89E-05	2.46E+01
			8.67E-01	**4.00E-03**	**8.69E-04**	**1.71E-07**	**4.89E-05**	**2.46E+01**

B1-B5 Maintenance and material replacement			Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, high conten...	1.6	kg	9.39E-01	2.09E-03	3.48E-04	1.83E-08	2.81E-04	1.41E+01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			1.17E+01	**6.80E-02**	**1.07E-02**	**9.79E-07**	**4.13E-03**	**2.65E+02**

C1-C4 End of life (Deconstruction)			Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	2.93E-03	2,05E-5	2,91E-6	3,94E-10	9,95E-7	7,99E-2
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	3.75E+00	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	2.13E-02	1.67E-04	3.46E-05	1.70E-14	1.65E-05	4.44E-01
			6.12E+00	**5.46E-03**	**1.61E-03**	**1.48E-08**	**3.10E-04**	**1.05E+01**

				Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
	Monetary value (Euros/Emission unit)			0.05	4	9	30	30	
A1-A3	Product Manufacturing	1	m2	€ 2.79	€ 0.66	€ 0.22	€ 0.00	€ 0.31	€ 4.11
	Materials Transportation to the factory	1	m2	€ 0.04	€ 0.01	€ 0.01	€ 0.00	€ 0.00	
A5	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
B1 - B5	Panel Transportation to the factory	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 1.25
	Product Maintenance	1	m2	€ 0.58	€ 0.27	€ 0.10	€ 0.00	€ 0.12	
	End of life (Deconstruction) of parts maintained	1	m2	€ 0.030	€ 0.004	€ 0.002	€ 0.000	€ 0.003	
	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.42
	End of life (Deconstruction)	1	m2	€ 0.31	€ 0.02	€ 0.01	€ 0.00	€ 0.01	
				€ 3.92	€ 1.04	€ 0.37	€ 0.00	€ 0.46	€ 5.78
									€ 5.78

APPENDIX P - WEIGHTING FACTOR CONCEPT 2 1ST CIRCULARITY SCENARIO REAR VENTILATED CLADDING

A1-A3 Product Manufacturing			Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	1.59E+01	3.39E-02	2.72E-03	2.07E-13	2.58E-03	2.79E+02
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, low content...	1.6	kg	1.88E+00	4.18E-03	6.96E-04	3.66E-08	5.62E-04	2.82E+01
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
Butyl waterproofing membrane, 0.9 mm, 1.15 kg/m2, 1250 kg/m3...	1	m2	3.79E+00	5.93E-03	6.97E-04	4.61E-07	6.84E-04	5.70E+01
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	3.35E-01	2.65E-03	9.54E-03	3.25E-12	1.39E-04	1.09E+01
Threaded reinforcement steel bar (rebar) bolts, 1.7 kg/unit,...	0.2	kg	1.45E-01	7.16E-04	1.34E-04	6.61E-09	3.79E-05	3.13E+00
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	1.09E+00	5.76E-03	2.81E-04	6.99E-11	3.31E-04	1.95E+01
Bricks (KNB)	42	kg	7.88E+00	1.09E-02	1.89E-03	9.91E-07	1.75E-03	1.44E+02
			6.59E+01	**1.85E-01**	**3.61E-02**	**3.37E-06**	**1.28E-02**	**9.84E+02**

A4 Materials Transportation to the factory			Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	2.52E-02	1.16E-04	2.53E-05	4.98E-09	1.42E-06	7.17E-01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, low content...	1.6	kg	7.06E-02	2.86E-04	6.14E-05	1.36E-08	5.90E-06	1.97E+00
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	4.01E-01	1.85E-03	4.02E-04	7.92E-08	2.26E-05	1.14E+01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Butyl waterproofing membrane, 0.9 mm, 1.15 kg/m2, 1250 kg/m3...	1	m2	1.89E-02	8.72E-05	1.90E-05	3.74E-09	1.07E-06	5.39E-01
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	1.65E-03	7.58E-06	1.65E-06	3.25E-10	9.28E-08	4.69E-02
Threaded reinforcement steel bar (rebar) bolts, 1.7 kg/unit,...	0.2	kg	2.83E-03	1.31E-05	2.84E-06	5.60E-10	1.60E-07	8.07E-02
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	3.42E-03	1.57E-05	3.43E-06	6.75E-10	1.93E-07	9.73E-02
Bricks (KNB)	42	kg	9.65E-02	4.44E-04	9.68E-05	1.91E-08	5.44E-06	2.75E+00
			8.64E-01	**3.94E-03**	**8.56E-04**	**1.70E-07**	**5.06E-05**	**2.45E+01**

Panel transportation to the Housing site			Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
Trailer combination. 40 ton capacity	1.00	kg	1.47E-04	6.78E-07	1.47E-07	2.90E-11	8.28E-09	4.18E-03

A5 Panel transportation to the Housing site			Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
Trailer combination. 40 ton capacity	99.55	kg	1.61E+00	7.42E-03	1.61E-03	3.18E-07	9.07E-05	4.57E+01
			1.61E+00	**7.42E-03**	**1.61E-03**	**3.18E-07**	**9.07E-05**	**4.57E+01**

B1-B5 Maintenance and material replacement			Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
Butyl waterproofing membrane, 0.9 mm, 1.15 kg/m2, 1250 kg/m3...	1	m2	1.89E-02	8.72E-05	1.90E-05	3.74E-09	1.07E-06	5.39E-01
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	1.65E-03	7.58E-06	1.65E-06	3.25E-10	9.28E-08	4.69E-02
			2.06E-02	**9.48E-05**	**2.07E-05**	**4.07E-09**	**1.16E-06**	**5.86E-01**

C1-C4 End of life (Deconstruction)			Global warming kg CO_2e	Acidification kg SO_2e	Eutrophication kg PO_4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	2.93E-03	2.05E-05	2.91E-06	3.94E-10	9.95E-07	7.99E-02
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, low content...	1.6	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	3.75E+00	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
Butyl waterproofing membrane, 0.9 mm, 1.15 kg/m2, 1250 kg/m3...	1	m2	2.90E+00	6.79E-04	5.67E-05	2.34E-13	3.11E-05	1.58E+00
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	2.53E-01	5.91E-05	4.93E-06	2.03E-14	2.71E-06	1.37E-01
Threaded reinforcement steel bar (rebar) bolts, 1.7 kg/unit,...	0.2	kg	1.61E-04	9.54E-07	1.30E-07	1.52E-16	7.60E-08	2.41E-03
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	1.47E-03	5.85E-06	1.22E-06	2.87E-10	1.98E-07	4.19E-02
Bricks (KNB)	42	kg	1.15E-01	8.99E-04	1.86E-04	9.16E-14	8.88E-05	2.39E+00
			9.37E+00	**6.96E-03**	**1.82E-03**	**1.55E-08**	**4.18E-04**	**1.43E+01**

				Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
	Monetary value (Euros/Emission unit)			**0.05**	**4**	**9**	**30**	**30**	
A1-A3	Product Manufacturing	1	m2	€ 3.29	€ 0.74	€ 0.33	€ 0.00	€ 0.38	€ 4.94
	Materials Transportation to the factory	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
A5	Panel transportation to the Housing site	1	m2	€ 0.08	€ 0.03	€ 0.01	€ 0.00	€ 0.00	
B1 - B5	Panel Transportation to the factory	1	m2	€ 0.08	€ 0.03	€ 0.01	€ 0.00	€ 0.00	€ 0.42
	Product Maintenance	1	m2	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00	
	End of life (Deconstruction) of parts maintained	1	m2	€ 0.158	€ 0.003	€ 0.001	€ 0.000	€ 0.001	
	Panel transportation to the Housing site	1	m2	€ 0.08	€ 0.03	€ 0.01	€ 0.00	€ 0.00	
B1 - B5	Panel Transportation to the factory	1	m2	€ 0.04	€ 0.01	€ 0.01	€ 0.00	€ 0.00	€ 0.21
	Product Maintenance	1	m2	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00	
	End of life (Deconstruction) of parts maintained	1	m2	€ 0.079	€ 0.001	€ 0.000	€ 0.000	€ 0.001	
	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.01	€ 0.01	€ 0.00	€ 0.00	
C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.08	€ 0.03	€ 0.01	€ 0.00	€ 0.00	€ 0.65
	End of life (Deconstruction)	1	m2	€ 0.47	€ 0.03	€ 0.02	€ 0.00	€ 0.01	
				€ 4.45	€ 0.94	€ 0.42	€ 0.00	€ 0.41	€ 6.22
									€ 6.22

APPENDIX Q - WEIGHTING FACTOR CONCEPT 2 2D CIRCULARITY SCENARIO STUCCO CLADDING

A1-A3			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Product Manufacturing			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	1.59E+01	3.39E-02	2.72E-03	2.07E-13	2.58E-03	2.79E+02
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	M3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	1.88E+00	4.18E-03	6.96E-04	3.66E-08	5.62E-04	2.82E+01
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	M3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			5.57E+01	**1.66E-01**	**2.43E-02**	**1.95E-06**	**1.04E-02**	**7.82E+02**

A4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Materials Transportation to the factory			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m3	2.52E-02	1.16E-04	2.53E-05	4.98E-09	1.42E-06	7.17E-01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, high conten...	1.1	kg	6.98E-02	2.82E-04	6.06E-05	1.34E-08	5.82E-06	1.95E+00
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	4.01E-01	1.85E-03	4.02E-04	7.92E-08	2.26E-05	1.14E+01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	3.29E-02	1.51E-04	3.30E-05	6.49E-09	1.85E-06	9.35E-01
			7.73E-01	**3.52E-03**	**7.65E-04**	**1.52E-07**	**4.54E-05**	**2.19E+01**

			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Panel transportation to the Housing site			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	1.00	kg	1.47E-04	6.78E-07	1.47E-07	2.90E-11	8.28E-09	4.18E-03

A5			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Panel transportation to the Housing site			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	53.65	kg	8.67E-01	4.00E-03	8.69E-04	1.71E-07	4.89E-05	2.46E+01
			8.67E-01	**4.00E-03**	**8.69E-04**	**1.71E-07**	**4.89E-05**	**2.46E+01**

C1-C4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
End of life (Deconstruction)			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	2.93E-03	2,05E-5	2,91E-6	3,94E-10	9,95E-7	7,99E-2
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	3.75E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	2.13E-02	1.67E-04	3.46E-05	1.70E-14	1.65E-05	4.44E-01
			6.12E+00	**3.38E-03**	**7.40E-04**	**1.13E-12**	**2.84E-04**	**9.02E+00**

D1-D3			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Product Manufacturing			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	M3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	2.53E-01	5.91E-05	4.93E-06	2.03E-14	2.71E-06	1.37E-01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			1.10E+01	**6.60E-02**	**1.03E-02**	**9.61E-07**	**3.85E-03**	**2.51E+02**

D1-D3			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
End of life (Deconstruction)			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	2.13E-02	1.67E-04	3.46E-05	1.70E-14	1.65E-05	4.44E-01
			1.20E+00	**1.79E-03**	**3.91E-04**	**5.78E-13**	**1.52E-04**	**4.78E+00**

					Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
		Monetary value (Euros/Emission unit)			0.05	4	9	30	30	
HOME 1	A1-A3	Product Manufacturing	1	m2	€ 2.79	€ 0.66	€ 0.22	€ 0.00	€ 0.31	€ 4.11
HOME 1	A1-A3	Materials Transportation to the factory	1	m2	€ 0.04	€ 0.01	€ 0.01	€ 0.00	€ 0.00	
HOME 1	A5	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
HOME 1	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.14
HOME 1	C1-C4	End of life (Deconstruction)	1	m2	€ 0.06	€ 0.01	€ 0.00	€ 0.00	€ 0.00	
HOME 2	D	Product Manufacturing	1	m2	€ 0.55	€ 0.26	€ 0.09	€ 0.00	€ 0.12	€ 1.15
HOME 2	D	Materials Transportation to the factory	1	m2	€ 0.04	€ 0.01	€ 0.01	€ 0.00	€ 0.00	
HOME 2	D	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
HOME 2	D	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.40
HOME 2	D	End of life (Deconstruction)	1	m2	€ 0.31	€ 0.01	€ 0.01	€ 0.00	€ 0.01	
					€ 3.95	€ 1.04	€ 0.37	€ 0.00	€ 0.45	€ 5.81
										€ 5.81

APPENDIX R - WEIGHTING FACTOR CONCEPT 2 2D CIRCULARITY SCENARIO REAR VENTILATED CLADDING

A1-A3 Product Manufacturing			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	1.59E+01	3.39E-02	2.72E-03	2.07E-13	2.58E-03	2.79E+02
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, low content...	1.6	kg	1.88E+00	4.18E-03	6.96E-04	3.66E-08	5.62E-04	2.82E+01
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
Butyl waterproofing membrane, 0.9 mm, 1.15 kg/m2, 1250 kg/m3...	1	m2	3.79E+00	5.93E-03	6.97E-04	4.61E-07	6.84E-04	5.70E+01
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	3.35E-01	2.65E-03	9.54E-03	3.25E-12	1.39E-04	1.09E+01
Threaded reinforcement steel bar (rebar) bolts, 1.7 kg/unit,...	0.2	kg	1.45E-01	7.16E-04	1.34E-04	6.61E-09	3.79E-05	3.13E+00
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	1.09E+00	5.76E-03	2.81E-04	6.99E-11	3.31E-04	1.95E+01
Bricks (KNB)	42	kg	7.88E+00	1.09E-02	1.89E-03	9.91E-07	1.75E-03	1.44E+02
			6.59E+01	**1.85E-01**	**3.61E-02**	**3.37E-06**	**1.28E-02**	**9.84E+02**

A4 Materials Transportation to the factory			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	2.52E-02	1.16E-04	2.53E-05	4.98E-09	1.42E-06	7.17E-01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, low content...	1.6	kg	7.06E-02	2.86E-04	6.14E-05	1.36E-08	5.90E-06	1.97E+00
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	4.01E-01	1.85E-03	4.02E-04	7.92E-08	2.26E-05	1.14E+01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Butyl waterproofing membrane, 0.9 mm, 1.15 kg/m2, 1250 kg/m3...	1	m2	1.89E-02	8.72E-05	1.90E-05	3.74E-09	1.07E-06	5.39E-01
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	1.65E-03	7.58E-06	1.65E-06	3.25E-10	9.28E-08	4.69E-02
Threaded reinforcement steel bar (rebar) bolts, 1.7 kg/unit,...	0.2	kg	2.83E-03	1.31E-05	2.84E-06	5.60E-10	1.60E-07	8.07E-02
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	3.42E-03	1.57E-05	3.43E-06	6.75E-10	1.93E-07	9.73E-02
Bricks (KNB)	42	kg	9.65E-02	4.44E-04	9.68E-05	1.91E-08	5.44E-06	2.75E+00
			8.64E-01	**3.94E-03**	**8.56E-04**	**1.70E-07**	**5.06E-05**	**2.45E+01**

Panel transportation to the Housing site			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	1.00	kg	1.47E-04	6.78E-07	1.47E-07	2.90E-11	8.28E-09	4.18E-03

A5 Panel transportation to the Housing site			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	57.55	kg	9.30E-01	4.29E-03	9.32E-04	1.84E-07	5.24E-05	2.64E+01
			9.30E-01	**4.29E-03**	**9.32E-04**	**1.84E-07**	**5.24E-05**	**2.64E+01**

C1-C4 End of life (Deconstruction)			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	2.93E-03	2.05E-05	2.91E-06	3.94E-10	9.95E-07	7.99E-02
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, low content...	1.6	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	3.75E+00	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
Butyl waterproofing membrane, 0.9 mm, 1.15 kg/m2, 1250 kg/m3...	1	m2	2.90E+00	6.79E-04	5.67E-05	2.34E-13	3.11E-05	1.58E+00
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	2.53E-01	5.91E-05	4.93E-06	2.03E-14	2.71E-06	1.37E-01
Threaded reinforcement steel bar (rebar) bolts, 1.7 kg/unit,...	0.2	kg	1.61E-04	9.54E-07	1.30E-07	1.52E-16	7.60E-08	2.41E-03
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	1.47E-03	5.85E-06	1.22E-06	2.87E-10	1.98E-07	4.19E-02
Bricks (KNB)	42	kg	1.15E-01	8.99E-04	1.86E-04	9.16E-14	8.88E-05	2.39E+00
			9.37E+00	**6.96E-03**	**1.82E-03**	**1.55E-08**	**4.18E-04**	**1.43E+01**

D1-D3 Product Manufacturing			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Butyl waterproofing membrane, 0.9 mm, 1.15 kg/m2, 1250 kg/m3...	1	m2	5.69E+00	8.90E-03	1.05E-03	6.92E-07	1.03E-03	8.55E+01
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	3.35E-01	2.65E-03	9.54E-03	3.25E-12	1.39E-04	1.09E+01
			6.02E+00	**1.15E-02**	**1.06E-02**	**6.92E-07**	**1.17E-03**	**9.64E+01**

D1-D3 End of life (Deconstruction)			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Butyl waterproofing membrane, 0.9 mm, 1.15 kg/m2, 1250 kg/m3...	1	m2	2.90E+00	6.79E-04	5.67E-05	2.34E-13	3.11E-05	1.58E+00
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	2.53E-01	5.91E-05	4.93E-06	2.03E-14	2.71E-06	1.37E-01
			3.15E+00	**7.38E-04**	**6.16E-05**	**2.54E-13**	**3.38E-05**	**1.72E+00**

					Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
		Monetary value (Euros/Emission unit)			0.05	4	9	30	30	
HOME 1	A1-A3	Product Manufacturing	1	m2	€ 3.29	€ 0.74	€ 0.33	€ 0.00	€ 0.38	€ 4.89
		Materials Transportation to the factory	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	1 - B	Panel Transportation to the factory	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.28
		Product Maintenance	1	m2	€ 0.06	€ 0.01	€ 0.02	€ 0.00	€ 0.01	
		End of life (Deconstruction) of parts maintained	1	m2	€ 0.03	€ 0.00	€ 0.00	€ 0.00	€ 0.00	
		Panel transportation to the Housing site	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.24
		End of life (Deconstruction)	1	m2	€ 0.16	€ 0.00	€ 0.00	€ 0.00	€ 0.00	
HOME 2	D	Product Manufacturing	1	m2	€ 0.11	€ 0.03	€ 0.09	€ 0.00	€ 0.02	€ 0.39
		Materials Transportation to the factory	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	D	Panel transportation to the Housing site	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	D	Panel Transportation to the factory	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.66
		Product Maintenance	1	m2	€ 0.24	€ 0.04	€ 0.08	€ 0.00	€ 0.03	
		End of life (Deconstruction) of parts maintained	1	m2	€ 0.13	€ 0.00	€ 0.00	€ 0.00	€ 0.00	
		Panel transportation to the Housing site	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	D	Panel Transportation for deconstruction process	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.60
		End of life (Deconstruction)	1	m2	€ 0.47	€ 0.03	€ 0.02	€ 0.00	€ 0.01	
					€ 4.95	€ 1.02	€ 0.61	€ 0.00	€ 0.47	€ 7.05

APPENDIX S - WEIGHTING FACTOR CONCEPT 2 3RD CIRCULARITY SCENARIO STUCCO CLADDING

A1-A3			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Product Manufacturing			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	1.59E+01	3.39E-02	2.72E-03	2.07E-13	2.58E-03	2.79E+02
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	1.88E+00	4.18E-03	6.96E-04	3.66E-08	5.62E-04	2.82E+01
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			5.57E+01	**1.66E-01**	**2.43E-02**	**1.95E-06**	**1.04E-02**	**7.82E+02**

A4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Materials Transportation to the factory			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m3	2.52E-02	1.16E-04	2.53E-05	4.98E-09	1.42E-06	7.17E-01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, high conten...	1.1	kg	6.98E-02	2.82E-04	6.06E-05	1.34E-08	5.82E-06	1.95E+00
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	4.01E-01	1.85E-03	4.02E-04	7.92E-08	2.26E-05	1.14E+01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	3.29E-02	1.51E-04	3.30E-05	6.49E-09	1.85E-06	9.35E-01
			7.73E-01	**3.52E-03**	**7.65E-04**	**1.52E-07**	**4.54E-05**	**2.19E+01**

			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Panel transportation to the Housing site			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	1.00	kg	1.47E-04	6.78E-07	1.47E-07	2.90E-11	8.28E-09	4.18E-03

A5			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Panel transportation to the Housing site			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	53.65	kg	8.67E-01	4.00E-03	8.69E-04	1.71E-07	4.89E-05	2.46E+01
			8.67E-01	**4.00E-03**	**8.69E-04**	**1.71E-07**	**4.89E-05**	**2.46E+01**

C1-C4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
End of life (Deconstruction)			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	2.93E-03	2,05E-5	2,91E-6	3,94E-10	9,95E-7	7,99E-2
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	3.75E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	2.13E-02	1.67E-04	3.46E-05	1.70E-14	1.65E-05	4.44E-01
			6.12E+00	**3.38E-03**	**7.40E-04**	**1.13E-12**	**2.84E-04**	**9.02E+00**

D			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Product Manufacturing			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	2.53E-01	5.91E-05	4.93E-06	2.03E-14	2.71E-06	1.37E-01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			1.10E+01	**6.60E-02**	**1.03E-02**	**9.61E-07**	**3.85E-03**	**2.51E+02**

D			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
End of life (Deconstruction)			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	2.13E-02	1.67E-04	3.46E-05	1.70E-14	1.65E-05	4.44E-01
			1.20E+00	**1.79E-03**	**3.91E-04**	**5.78E-13**	**1.52E-04**	**4.78E+00**

					Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
		Monetary value (Euros/Emission unit)			0.05	4	9	30	30	
HOME 1	A1-A3	Product Manufacturing	1	m2	€ 2.79	€ 0.66	€ 0.22	€ 0.00	€ 0.31	€ 4.11
		Materials Transportation to the factory	1	m2	€ 0.04	€ 0.01	€ 0.01	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.14
		End of life (Deconstruction)	1	m2	€ 0.06	€ 0.01	€ 0.00	€ 0.00	€ 0.00	
HOME 2	A1-A3	Product Manufacturing	1	m2	€ 0.55	€ 0.26	€ 0.09	€ 0.00	€ 0.12	€ 1.15
		Materials Transportation to the factory	1	m2	€ 0.04	€ 0.01	€ 0.01	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.14
		End of life (Deconstruction)	1	m2	€ 0.06	€ 0.01	€ 0.00	€ 0.00	€ 0.00	
HOME 3	A1-A3	Product Manufacturing	1	m2	€ 0.55	€ 0.26	€ 0.09	€ 0.00	€ 0.12	€ 1.15
		Materials Transportation to the factory	1	m2	€ 0.04	€ 0.01	€ 0.01	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.31	€ 0.01	€ 0.01	€ 0.00	€ 0.01	€ 0.34
		End of life (Deconstruction)	1	m2	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00	
HOME 4	A1-A3	Product Manufacturing	1	m2	€ 0.55	€ 0.26	€ 0.09	€ 0.00	€ 0.12	€ 1.15
		Materials Transportation to the factory	1	m2	€ 0.04	€ 0.01	€ 0.01	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.31	€ 0.01	€ 0.01	€ 0.00	€ 0.01	€ 0.67
		End of life (Deconstruction)	1	m2	€ 0.31	€ 0.01	€ 0.01	€ 0.00	€ 0.01	
					€ 5.89	€ 1.66	€ 0.60	€ 0.00	€ 0.71	€ 8.86
										€ 8.86

APPENDIX T - WEIGHTING FACTOR CONCEPT 2 3RD CIRCULARITY SCENARIO REAR VENTILATED CLADDING

A1-A3			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Product Manufacturing			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	1.59E+01	3.39E-02	2.72E-03	2.07E-13	2.58E-03	2.79E+02
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, low content...	1.6	kg	1.88E+00	4.18E-03	6.96E-04	3.66E-08	5.62E-04	2.82E+01
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
Butyl waterproofing membrane, 0.9 mm, 1.15 kg/m2, 1250 kg/m3...	1	m2	3.79E+00	5.93E-03	6.97E-04	4.61E-07	6.84E-04	5.70E+01
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	3.35E-01	2.65E-03	9.54E-03	3.25E-12	1.39E-04	1.09E+01
Threaded reinforcement steel bar (rebar) bolts, 1.7 kg/unit,...	0.2	kg	1.45E-01	7.16E-04	1.34E-04	6.61E-09	3.79E-05	3.13E+00
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	1.09E+00	5.76E-03	2.81E-04	6.99E-11	3.31E-04	1.95E+01
Bricks (KNB)	42	kg	7.88E+00	1.09E-02	1.89E-03	9.91E-07	1.75E-03	1.44E+02
			6.59E+01	**1.85E-01**	**3.61E-02**	**3.37E-06**	**1.28E-02**	**9.84E+02**

A4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Materials Transportation to the factory			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	2.52E-02	1.16E-04	2.53E-05	4.98E-09	1.42E-06	7.17E-01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, low content...	1.6	kg	7.06E-02	2.86E-04	6.14E-05	1.36E-08	5.90E-06	1.97E+00
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	4.01E-01	1.85E-03	4.02E-04	7.92E-08	2.26E-05	1.14E+01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Butyl waterproofing membrane, 0.9 mm, 1.15 kg/m2, 1250 kg/m3...	1	m2	1.89E-02	8.72E-05	1.90E-05	3.74E-09	1.07E-06	5.39E-01
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	1.65E-03	7.58E-06	1.65E-06	3.25E-10	9.28E-08	4.69E-02
Threaded reinforcement steel bar (rebar) bolts, 1.7 kg/unit,...	0.2	kg	2.83E-03	1.31E-05	2.84E-06	5.60E-10	1.60E-07	8.07E-02
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	3.42E-03	1.57E-05	3.43E-06	6.75E-10	1.93E-07	9.73E-02
Bricks (KNB)	42	kg	9.65E-02	4.44E-04	9.68E-05	1.91E-08	5.44E-06	2.75E+00
			8.64E-01	**3.94E-03**	**8.56E-04**	**1.70E-07**	**5.06E-05**	**2.45E+01**

			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Panel transportation to the Housing site			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	1.00	kg	1.47E-04	6.78E-07	1.47E-07	2.90E-11	8.28E-09	4.18E-03

A5			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Panel transportation to the Housing site			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	57.55	kg	9.30E-01	4.29E-03	9.32E-04	1.84E-07	5.24E-05	2.64E+01
			9.30E-01	**4.29E-03**	**9.32E-04**	**1.84E-07**	**5.24E-05**	**2.64E+01**

C1-C4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
End of life (Deconstruction)			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	2.93E-03	2.05E-05	2.91E-06	3.94E-10	9.95E-07	7.99E-02
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, low content...	1.6	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	3.75E+00	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
Butyl waterproofing membrane, 0.9 mm, 1.15 kg/m2, 1250 kg/m3...	1	m2	2.90E+00	6.79E-04	5.67E-05	2.34E-13	3.11E-05	1.58E+00
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	2.53E-01	5.91E-05	4.93E-06	2.03E-14	2.71E-06	1.37E-01
Threaded reinforcement steel bar (rebar) bolts, 1.7 kg/unit,...	0.2	kg	1.61E-04	9.54E-07	1.30E-07	1.52E-16	7.60E-08	2.41E-03
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	1.47E-03	5.85E-06	1.22E-06	2.87E-10	1.98E-07	4.19E-02
Bricks (KNB)	42	kg	1.15E-01	8.99E-04	1.86E-04	9.16E-14	8.88E-05	2.39E+00
			9.37E+00	**6.96E-03**	**1.82E-03**	**1.55E-08**	**4.18E-04**	**1.43E+01**

D1-D3			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Product Manufacturing			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Butyl waterproofing membrane, 0.9 mm, 1.15 kg/m2, 1250 kg/m3...	1	m2	5.69E+00	8.90E-03	1.05E-03	6.92E-07	1.03E-03	8.55E+01
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	3.35E-01	2.65E-03	9.54E-03	3.25E-12	1.39E-04	1.09E+01
			6.02E+00	**1.15E-02**	**1.06E-02**	**6.92E-07**	**1.17E-03**	**9.64E+01**

D1-D3			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
End of life (Deconstruction)			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Butyl waterproofing membrane, 0.9 mm, 1.15 kg/m2, 1250 kg/m3...	1	m2	2.90E+00	6.79E-04	5.67E-05	2.34E-13	3.11E-05	1.58E+00
Sealing tape with paper liner, waterproofing, for exterior s...	0.1	kg	2.53E-01	5.91E-05	4.93E-06	2.03E-14	2.71E-06	1.37E-01
			3.15E+00	**7.38E-04**	**6.16E-05**	**2.54E-13**	**3.38E-05**	**1.72E+00**

					Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
		Monetary value (Euros/Emission unit)			0.05	4	9	30	30	
HOME 1	A1-A3	Product Manufacturing	1	m2	€ 3.29	€ 0.74	€ 0.33	€ 0.00	€ 0.38	€ 4.89
		Materials Transportation to the factory	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.09
		End of life (Deconstruction)	1	m2	€ 0.01	€ 0.00	€ 0.00	€ 0.00	€ 0.00	
HOME 2	A1-A3	Product Manufacturing	1	m2	€ 0.02	€ 0.01	€ 0.09	€ 0.00	€ 0.00	€ 0.26
		Materials Transportation to the factory	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	B1 - B5	Panel Transportation to the factory	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.31
		Product Maintenance	1	m2	€ 0.08	€ 0.01	€ 0.02	€ 0.00	€ 0.01	
		End of life (Deconstruction) of parts maintained	1	m2	€ 0.04	€ 0.00	€ 0.00	€ 0.00	€ 0.00	
		Panel transportation to the Housing site	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.09
		End of life (Deconstruction)	1	m2	€ 0.01	€ 0.00	€ 0.00	€ 0.00	€ 0.00	
HOME 3	A1-A3	Product Manufacturing	1	m2	€ 0.02	€ 0.01	€ 0.09	€ 0.00	€ 0.00	€ 0.26
		Materials Transportation to the factory	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	B1 - B5	Panel Transportation to the factory	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.49
		Product Maintenance	1	m2	€ 0.19	€ 0.03	€ 0.06	€ 0.00	€ 0.02	
		End of life (Deconstruction) of parts maintained	1	m2	€ 0.04	€ 0.00	€ 0.00	€ 0.00	€ 0.00	
		Panel transportation to the Housing site	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.09
		End of life (Deconstruction)	1	m2	€ 0.01	€ 0.00	€ 0.00	€ 0.00	€ 0.00	
HOME 4	A1-A3	Product Manufacturing	1	m2	€ 0.02	€ 0.01	€ 0.09	€ 0.00	€ 0.00	€ 0.26
		Materials Transportation to the factory	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	B1 - B5	Panel Transportation to the factory	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.79
		Product Maintenance	1	m2	€ 0.30	€ 0.05	€ 0.10	€ 0.00	€ 0.03	
		End of life (Deconstruction) of parts maintained	1	m2	€ 0.16	€ 0.00	€ 0.00	€ 0.00	€ 0.00	
		Panel transportation to the Housing site	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.05	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.60
		End of life (Deconstruction)	1	m2	€ 0.47	€ 0.03	€ 0.02	€ 0.00	€ 0.01	
					€ 5.48	€ 1.19	€ 0.93	€ 0.00	€ 0.50	€ 8.10
										€ 8.10
									% vs Original	71.6%

APPENDIX U - WEIGHTING FACTOR CONCEPT 3 1ST CIRCULARITY SCENARIO STUCCO

A1-A3			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Product Manufacturing			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	1.59E+01	3.39E-02	2.72E-03	2.07E-13	2.58E-03	2.79E+02
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	1.88E+00	4.18E-03	6.96E-04	3.66E-08	5.62E-04	2.82E+01
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
Birch plywood with phenol film overlay. 680 kg/m3	0.52	m2	3.97E+00	3.08E-02	5.02E-03	4.80E-07	1.71E-03	1.14E+02
Fresh sawn timber,	0.17	m3	0.00E+00	1.42E-02	3.43E-03	9.64E-11	7.29E-04	5.90E+01
Flax fibre fleece. 38 kg/m3	0.55	kg	4.73E+00	9.65E-03	1.23E-03	6.75E-10	1.85E-03	1.03E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	1.59E+00	3.53E-03	5.87E-04	3.09E-08	4.74E-04	2.38E+01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			5.84E+01	**1.65E-01**	**2.49E-02**	**1.54E-06**	**1.19E-02**	**8.62E+02**

A4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Materials Transportation to the factory			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	2.52E-02	1.16E-04	2.53E-05	4.98E-09	1.42E-06	7.17E-01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, low content...	1.6	kg	7.06E-02	2.86E-04	6.14E-05	1.36E-08	5.90E-06	1.97E+00
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	4.01E-01	1.85E-03	4.02E-04	7.92E-08	2.26E-05	1.14E+01
Birch plywood with phenol film overlay. 680 kg/m3	0.52	m2	6.34E-02	2.92E-04	6.34E-05	1.25E-08	3.57E-06	1.80E+00
Fresh sawn timber,	0.17	m3	1.06E+00	4.88E-03	1.06E-03	2.09E-07	5.98E-05	3.02E+01
Flax fibre fleece. 38 kg/m3	0.55	kg	8.90E-03	4.10E-05	8.90E-06	1.76E-09	5.00E-07	2.53E-01
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	5.96E-02	2.41E-04	5.18E-05	1.15E-08	4.98E-06	1.66E+00
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	3.29E-02	1.51E-04	3.30E-05	6.49E-09	1.85E-06	9.35E-01
			1.84E+00	**8.42E-03**	**1.83E-03**	**3.63E-07**	**1.07E-04**	**5.24E+01**

A5			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Panel transportation to the Housing site			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	53.65	kg	8.67E-01	4.00E-03	8.69E-04	1.71E-07	4.89E-05	2.46E+01
			8.67E-01	**4.00E-03**	**8.69E-04**	**1.71E-07**	**4.89E-05**	**2.46E+01**

B1-B5			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
Maintenance and material replacement			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Flax fibre fleece. 38 kg/m3	0.55	kg	4.73E+00	9.65E-03	1.23E-03	6.75E-10	1.85E-03	1.03E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	1.59E+00	3.53E-03	5.87E-04	3.09E-08	4.74E-04	2.38E+01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			9.39E+00	**1.98E-02**	**2.49E-03**	**6.82E-08**	**2.89E-03**	**1.59E+02**

C1-C4			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
End of life (Deconstruction)			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	3.34E-02	2.62E-04	5.43E-05	2.67E-14	2.59E-05	6.97E-01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	3.75E+00	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
Birch plywood with phenol film overlay. 680 kg/m3	0.52	m2	1.74E-02	1.36E-04	2.82E-05	1.39E-14	1.35E-05	3.62E-01
Fresh sawn timber,	0.17	m3	0.00E+00	2.14E-02	4.69E-03	7.48E-12	1.77E-03	5.70E+01
Flax fibre fleece. 38 kg/m3	0.55	kg	4.87E-01	1.26E-03	5.24E-04	8.95E-09	1.59E-05	8.77E-01
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	3.73E-03	2.93E-05	6.06E-06	2.98E-15	2.89E-06	7.78E-02
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	2.13E-02	1.67E-04	3.46E-05	1.70E-14	1.65E-05	4.44E-01
			5.49E+00	**2.70E-02**	**6.56E-03**	**2.38E-08**	**2.01E-03**	**6.52E+01**

				Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
	Monetary value (Euros/Emission unit)			0.05	4	9	30	30	
A1-A3	Product Manufacturing	1	m2	€ 2.92	€ 0.66	€ 0.22	€ 0.00	€ 0.36	€ 4.37
	Materials Transportation to the factory	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
A5	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
B1 - B5	Panel Transportation to the factory	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.82
	Product Maintenance	1	m2	€ 0.47	€ 0.08	€ 0.02	€ 0.00	€ 0.09	
	End of life (Deconstruction) of parts maintained	1	m2	€ 0.013	€ 0.003	€ 0.003	€ 0.000	€ 0.001	
	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.57
	End of life (Deconstruction)	1	m2	€ 0.27	€ 0.11	€ 0.06	€ 0.00	€ 0.06	
				€ 3.94	€ 0.95	€ 0.36	€ 0.00	€ 0.51	€ 5.76
									€ 5.76

APPENDIX V - WEIGHTING FACTOR CONCEPT 3 1ST CIRCULARITY SCENARIO REAR VENTILATED CLADDING

A1-A3 Product Manufacturing			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	1.59E+01	3.39E-02	2.72E-03	2.07E-13	2.58E-03	2.79E+02
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	1.88E+00	4.18E-03	6.96E-04	3.66E-08	5.62E-04	2.82E+01
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
Birch plywood with phenol film overlay. 680 kg/m3	0.52	m2	3.97E+00	3.08E-02	5.02E-03	4.80E-07	1.71E-03	1.14E+02
Fresh sawn timber,	0.17	m3	0.00E+00	1.42E-02	3.43E-03	9.64E-11	7.29E-04	5.90E+01
Flax fibre fleece. 38 kg/m3	0.55	kg	4.73E+00	9.65E-03	1.23E-03	6.75E-10	1.85E-03	1.03E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	1.59E+00	3.53E-03	5.87E-04	3.09E-08	4.74E-04	2.38E+01
Threaded reinforcement steel bar (rebar) bolts, 1.7 kg/unit,...	0.2	kg	1.45E-01	7.16E-04	1.34E-04	6.61E-09	3.79E-05	3.13E+00
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	1.09E+00	5.76E-03	2.81E-04	6.99E-11	3.31E-04	1.95E+01
Bricks (KNB)	42	kg	7.88E+00	1.09E-02	1.89E-03	9.91E-07	1.75E-03	1.44E+02
			6.44E+01	**1.75E-01**	**2.65E-02**	**2.50E-06**	**1.35E-02**	**9.97E+02**

A4 Materials Transportation to the factory			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	2.52E-02	1.16E-04	2.53E-05	4.98E-09	1.42E-06	7.17E-01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, low content...	1.6	kg	7.06E-02	2.86E-04	6.14E-05	1.36E-08	5.90E-06	1.97E+00
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	4.01E-01	1.85E-03	4.02E-04	7.92E-08	2.26E-05	1.14E+01
Birch plywood with phenol film overlay. 680 kg/m3	0.52	m2	6.34E-02	2.92E-04	6.34E-05	1.25E-08	3.57E-06	1.80E+00
Fresh sawn timber,	0.17	m3	1.06E+00	4.88E-03	1.06E-03	2.09E-07	5.98E-05	3.02E+01
Flax fibre fleece. 38 kg/m3	0.55	kg	8.90E-03	4.10E-05	8.90E-06	1.76E-09	5.00E-07	2.53E-01
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	5.96E-02	2.41E-04	5.18E-05	1.15E-08	4.98E-06	1.66E+00
Threaded reinforcement steel bar (rebar) bolts, 1.7 kg/unit,...	0.2	kg	2.83E-03	1.31E-05	2.84E-06	5.60E-10	1.60E-07	8.07E-02
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	3.42E-03	1.57E-05	3.43E-06	6.75E-10	1.93E-07	9.73E-02
Bricks (KNB)	42	kg	9.65E-02	4.44E-04	9.68E-05	1.91E-08	5.44E-06	2.75E+00
			1.91E+00	**8.74E-03**	**1.90E-03**	**3.77E-07**	**1.11E-04**	**5.44E+01**

A5 Panel transportation to the Housing site			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	108.77	kg	1.76E+00	8.11E-03	1.76E-03	3.47E-07	9.90E-05	5.00E+01
			1.76E+00	**8.11E-03**	**1.76E-03**	**3.47E-07**	**9.90E-05**	**5.00E+01**

B1-B5 Maintenance and material replacement			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Flax fibre fleece. 38 kg/m3	0.55	kg	4.73E+00	9.65E-03	1.23E-03	6.75E-10	1.85E-03	1.03E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	1.59E+00	3.53E-03	5.87E-04	3.09E-08	4.74E-04	2.38E+01
			6.31E+00	**1.32E-02**	**1.82E-03**	**3.16E-08**	**2.32E-03**	**1.27E+02**

C1-C4 End of life (Deconstruction)			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	3.34E-02	2.62E-04	5.43E-05	2.67E-14	2.59E-05	6.97E-01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	3.75E+00	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
Birch plywood with phenol film overlay. 680 kg/m3	0.52	m2	1.74E-02	1.36E-04	2.82E-05	1.39E-14	1.35E-05	3.62E-01
Fresh sawn timber,	0.17	m3	0.00E+00	2.14E-02	4.69E-03	7.48E-12	1.77E-03	5.70E+01
Flax fibre fleece. 38 kg/m3	0.55	kg	4.87E-01	1.26E-03	5.24E-04	8.95E-09	1.59E-05	8.77E-01
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	3.73E-03	2.93E-05	6.06E-06	2.98E-15	2.89E-06	7.78E-02
Threaded reinforcement steel bar (rebar) bolts, 1.7 kg/unit,...	0.2	kg	1.61E-04	9.54E-07	1.30E-07	1.52E-16	7.60E-08	2.41E-03
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	1.47E-03	5.85E-06	1.22E-06	2.87E-10	1.98E-07	4.19E-02
Bricks (KNB)	42	kg	1.15E-01	8.99E-04	1.86E-04	9.16E-14	8.88E-05	2.39E+00
			5.58E+00	**2.77E-02**	**6.71E-03**	**2.40E-08**	**2.08E-03**	**6.72E+01**

				Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
	Monetary value (Euros/Emission unit)			0.05	4	9	30	30	
A1-A3	Product Manufacturing	1	m2	€ 3.22	€ 0.70	€ 0.24	€ 0.00	€ 0.40	€ 4.86
	Materials Transportation to the factory	1	m2	€ 0.10	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
A5	Panel transportation to the Housing site	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
B1 - B5	Panel Transportation to the factory	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	€ 0.77
	Product Maintenance	1	m2	€ 0.32	€ 0.05	€ 0.02	€ 0.00	€ 0.07	
	End of life (Deconstruction) of parts maintained	1	m2	€ 0.025	€ 0.005	€ 0.005	€ 0.000	€ 0.001	
	Panel transportation to the Housing site	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
B1 - B5	Panel Transportation to the factory	1	m2	€ 0.07	€ 0.03	€ 0.01	€ 0.00	€ 0.00	€ 0.65
	Product Maintenance	1	m2	€ 0.27	€ 0.04	€ 0.01	€ 0.00	€ 0.06	
	End of life (Deconstruction) of parts maintained	1	m2	€ 0.021	€ 0.004	€ 0.004	€ 0.000	€ 0.000	
	Panel transportation to the Housing site	1	m2	€ 0.07	€ 0.03	€ 0.01	€ 0.00	€ 0.00	
C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	€ 0.65
	End of life (Deconstruction)	1	m2	€ 0.28	€ 0.11	€ 0.06	€ 0.00	€ 0.06	
				€ 4.73	€ 1.14	€ 0.45	€ 0.00	€ 0.62	€ 6.93
									€ 6.93

APPENDIX X- WEIGHTING FACTOR CONCEPT 3 2ND CIRCULARITY SCENARIO STUCCO CLADDING

A1-A3 Product Manufacturing			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	1.59E+01	3.39E-02	2.72E-03	2.07E-13	2.58E-03	2.79E+02
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
Birch plywood with phenol film overlay. 680 kg/m3	0.52	m2	3.97E+00	3.08E-02	5.02E-03	4.80E-07	1.71E-03	1.14E+02
Fresh sawn timber,	0.17	m3	0.00E+00	1.42E-02	3.43E-03	9.64E-11	7.29E-04	5.90E+01
Flax fibre fleece. 38 kg/m3	0.55	kg	4.73E+00	9.65E-03	1.23E-03	6.75E-10	1.85E-03	1.03E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	1.59E+00	3.53E-03	5.87E-04	3.09E-08	4.74E-04	2.38E+01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			5.65E+01	**1.61E-01**	**2.42E-02**	**1.50E-06**	**1.13E-02**	**8.34E+02**

A4 Materials Transportation to the factory			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	2.52E-02	1.16E-04	2.53E-05	4.98E-09	1.42E-06	7.17E-01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, low content...	1.6	kg	7.06E-02	2.86E-04	6.14E-05	1.36E-08	5.90E-06	1.97E+00
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	4.01E-01	1.85E-03	4.02E-04	7.92E-08	2.26E-05	1.14E+01
Birch plywood with phenol film overlay. 680 kg/m3	0.52	m2	6.34E-02	2.92E-04	6.34E-05	1.25E-08	3.57E-06	1.80E+00
Fresh sawn timber,	0.17	m3	1.06E+00	4.88E-03	1.06E-03	2.09E-07	5.98E-05	3.02E+01
Flax fibre fleece. 38 kg/m3	0.55	kg	8.90E-03	4.10E-05	8.90E-06	1.76E-09	5.00E-07	2.53E-01
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	5.96E-02	2.41E-04	5.18E-05	1.15E-08	4.98E-06	1.66E+00
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	3.29E-02	1.51E-04	3.30E-05	6.49E-09	1.85E-06	9.35E-01
			1.84E+00	**8.42E-03**	**1.83E-03**	**3.63E-07**	**1.07E-04**	**5.24E+01**

A5 Panel transportation to the Housing site			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	53.65	kg	8.67E-01	4.00E-03	8.69E-04	1.71E-07	4.89E-05	2.46E+01
			8.67E-01	**4.00E-03**	**8.69E-04**	**1.71E-07**	**4.89E-05**	**2.46E+01**

C1-C4 End of life (Deconstruction)			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	3.34E-02	2.62E-04	5.43E-05	2.67E-14	2.59E-05	6.97E-01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	8.05E-01	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	3.75E+00	5.09E-03	1.11E-03	1.78E-12	4.20E-04	1.35E+01
Birch plywood with phenol film overlay. 680 kg/m3	0.52	m2	6.08E-01	8.27E-04	1.81E-04	2.90E-13	6.86E-05	2.20E+00
Fresh sawn timber,	0.17	m3	2.53E-01	5.91E-05	4.93E-06	2.03E-14	2.71E-06	1.37E-01
Flax fibre fleece. 38 kg/m3	0.55	kg	1.61E-04	9.54E-07	1.30E-07	1.52E-16	7.60E-08	2.41E-03
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	1.47E-03	5.85E-06	1.22E-06	2.87E-10	1.98E-07	4.19E-02
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	1.15E-01	8.99E-04	1.86E-04	9.16E-14	8.88E-05	2.39E+00
			6.74E+00	**1.08E-02**	**2.75E-03**	**1.51E-08**	**7.65E-04**	**2.47E+01**

D1-D3 Product Manufacturing			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Flax fibre fleece. 38 kg/m3	0.55	kg	4.73E+00	9.65E-03	1.23E-03	6.75E-10	1.85E-03	1.03E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	1.59E+00	3.53E-03	5.87E-04	3.09E-08	4.74E-04	2.38E+01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			9.39E+00	**1.98E-02**	**2.49E-03**	**6.82E-08**	**2.89E-03**	**1.59E+02**

D1-D3 End of life (Deconstruction)			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Flax fibre fleece. 38 kg/m3	0.55	kg	1.61E-04	9.54E-07	1.30E-07	1.52E-16	7.60E-08	2.41E-03
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	1.47E-03	5.85E-06	1.22E-06	2.87E-10	1.98E-07	4.19E-02
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	1.15E-01	8.99E-04	1.86E-04	9.16E-14	8.88E-05	2.39E+00
			1.17E-01	**9.06E-04**	**1.87E-04**	**2.87E-10**	**8.91E-05**	**2.43E+00**

					Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
		Monetary value (Euros/Emission unit)			0.05	4	9	30	30	
HOME 1	A1-A3	Product Manufacturing	1	m2	€ 2.83	€ 0.64	€ 0.22	€ 0.00	€ 0.34	€ 4.24
		Materials Transportation to the factory	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.08
		End of life (Deconstruction)	1	m2	€ 0.01	€ 0.00	€ 0.00	€ 0.00	€ 0.00	
HOME 2	D	Product Manufacturing	1	m2	€ 0.47	€ 0.08	€ 0.02	€ 0.00	€ 0.09	€ 0.87
		Materials Transportation to the factory	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
	D	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	D	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.50
		End of life (Deconstruction)	1	m2	€ 0.34	€ 0.04	€ 0.02	€ 0.00	€ 0.02	
					€ 4.00	€ 0.90	€ 0.33	€ 0.00	€ 0.46	€ 5.69

APPENDIX Y- WEIGHTING FACTOR CONCEPT 3 2ND CIRCULARITY SCENARIO REAR VENTILATED CLADDING

A1-A3 Product Manufacturing			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	1.59E+01	3.39E-02	2.72E-03	2.07E-13	2.58E-03	2.79E+02
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
Birch plywood with phenol film overlay. 680 kg/m3	0.52	m2	3.97E+00	3.08E-02	5.02E-03	4.80E-07	1.71E-03	1.14E+02
Fresh sawn timber,	0.17	m3	0.00E+00	1.42E-02	3.43E-03	9.64E-11	7.29E-04	5.90E+01
Flax fibre fleece. 38 kg/m3	0.55	kg	4.73E+00	9.65E-03	1.23E-03	6.75E-10	1.85E-03	1.03E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	1.59E+00	3.53E-03	5.87E-04	3.09E-08	4.74E-04	2.38E+01
Threaded reinforcement steel bar (rebar) bolts, 1.7 kg/unit,...	0.2	kg	1.45E-01	7.16E-04	1.34E-04	6.61E-09	3.79E-05	3.13E+00
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	1.09E+00	5.76E-03	2.81E-04	6.99E-11	3.31E-04	1.95E+01
Bricks (KNB)	42	kg	7.88E+00	1.09E-02	1.89E-03	9.91E-07	1.75E-03	1.44E+02
			6.25E+01	**1.71E-01**	**2.58E-02**	**2.46E-06**	**1.29E-02**	**9.69E+02**

A4 Materials Transportation to the factory			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	2.52E-02	1.16E-04	2.53E-05	4.98E-09	1.42E-06	7.17E-01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, low content...	1.6	kg	7.06E-02	2.86E-04	6.14E-05	1.36E-08	5.90E-06	1.97E+00
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	4.01E-01	1.85E-03	4.02E-04	7.92E-08	2.26E-05	1.14E+01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.52	m2	6.34E-02	2.92E-04	6.34E-05	1.25E-08	3.57E-06	1.80E+00
Fresh sawn timber,	0.17	m3	1.06E+00	4.88E-03	1.06E-03	2.09E-07	5.98E-05	3.02E+01
Flax fibre fleece. 38 kg/m3	0.55	kg	8.90E-03	4.10E-05	8.90E-06	1.76E-09	5.00E-07	2.53E-01
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	5.96E-02	2.41E-04	5.18E-05	1.15E-08	4.98E-06	1.66E+00
Threaded reinforcement steel bar (rebar) bolts, 1.7 kg/unit,...	0.2	kg	2.83E-03	1.31E-05	2.84E-06	5.60E-10	1.60E-07	8.07E-02
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	3.42E-03	1.57E-05	3.43E-06	6.75E-10	1.93E-07	9.73E-02
Bricks (KNB)	42	kg	9.65E-02	4.44E-04	9.68E-05	1.91E-08	5.44E-06	2.75E+00
			1.91E+00	**8.74E-03**	**1.90E-03**	**3.77E-07**	**1.11E-04**	**5.44E+01**

A5 Panel transportation to the Housing site			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	108.77	kg	1.76E+00	8.11E-03	1.76E-03	3.47E-07	9.90E-05	5.00E+01
			1.76E+00	**8.11E-03**	**1.76E-03**	**3.47E-07**	**9.90E-05**	**5.00E+01**

C1-C4 End of life (Deconstruction)			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	3.34E-02	2.62E-04	5.43E-05	2.67E-14	2.59E-05	6.97E-01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	3.75E+00	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.52	m2	6.08E-01	8.27E-04	1.81E-04	2.90E-13	6.86E-05	2.20E+00
Fresh sawn timber,	0.17	m3	0.00E+00	2.14E-02	4.69E-03	7.48E-12	1.77E-03	5.70E+01
Flax fibre fleece. 38 kg/m3	0.55	kg	4.87E-01	1.26E-03	5.24E-04	8.95E-09	1.59E-05	8.77E-01
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	3.73E-03	2.93E-05	6.06E-06	2.98E-15	2.89E-06	7.78E-02
Threaded reinforcement steel bar (rebar) bolts, 1.7 kg/unit,...	0.2	kg	1.61E-04	9.54E-07	1.30E-07	1.52E-16	7.60E-08	2.41E-03
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	1.47E-03	5.85E-06	1.22E-06	2.87E-10	1.98E-07	4.19E-02
Bricks (KNB)	42	kg	1.15E-01	8.99E-04	1.86E-04	9.16E-14	8.88E-05	2.39E+00
			6.17E+00	**2.84E-02**	**6.87E-03**	**2.40E-08**	**2.13E-03**	**6.91E+01**

D1-D3 Product Manufacturing			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	1.59E+00	3.53E-03	5.87E-04	3.09E-08	4.74E-04	2.38E+01
Flax fibre fleece. 38 kg/m3	0	kg	4.73E+00	9.65E-03	1.23E-03	6.75E-10	1.85E-03	1.03E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	1.59E+00	3.53E-03	5.87E-04	3.09E-08	4.74E-04	2.38E+01
			7.90E+00	**1.67E-02**	**2.40E-03**	**6.24E-08**	**2.80E-03**	**1.51E+02**

C1-C4 End of life (Deconstruction)			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Flax fibre fleece. 38 kg/m3	0.55	kg	4.87E-01	1.26E-03	5.24E-04	8.95E-09	1.59E-05	8.77E-01
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	3.73E-03	2.93E-05	6.06E-06	2.98E-15	2.89E-06	7.78E-02
			4.91E-01	**1.29E-03**	**5.30E-04**	**8.95E-09**	**1.87E-05**	**9.55E-01**

					Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
		Monetary value (Euros/Emission unit)			0.05	4	9	30	30	
HOME 1	A1-A3	Product Manufacturing	1	m2	€ 3.13	€ 0.69	€ 0.23	€ 0.00	€ 0.39	€ 4.72
		Materials Transportation to the factory	1	m2	€ 0.10	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
	B1 - B5	Panel Transportation to the factory	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	€ 0.88
		Product Maintenance	1	m2	€ 0.39	€ 0.07	€ 0.02	€ 0.00	€ 0.08	
		End of life (Deconstruction) of parts maintained	1	m2	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.00	
		Panel transportation to the Housing site	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	€ 0.69
		End of life (Deconstruction)	1	m2	€ 0.31	€ 0.11	€ 0.06	€ 0.00	€ 0.06	
	D	Product Manufacturing	1	m2	€ 0.39	€ 0.07	€ 0.02	€ 0.00	€ 0.08	€ 0.86
		Materials Transportation to the factory	1	m2	€ 0.10	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
	D	Panel transportation to the Housing site	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
HOME 2	D	Panel Transportation to the factory	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	€ 0.88
		Product Maintenance	1	m2	€ 0.39	€ 0.07	€ 0.02	€ 0.00	€ 0.08	
		End of life (Deconstruction) of parts maintained	1	m2	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.00	

APPENDIX Z - WEIGHTING FACTOR CONCEPT 3 3RD CIRCULARITY SCENARIO STUCCO CLADDING

A1-A3 Product Manufacturing			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	1.59E+01	3.39E-02	2.72E-03	2.07E-13	2.58E-03	2.79E+02
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
Birch plywood with phenol film overlay. 680 kg/m3	0.52	m2	3.97E+00	3.08E-02	5.02E-03	4.80E-07	1.71E-03	1.14E+02
Fresh sawn timber,	0.17	m3	0.00E+00	1.42E-02	3.43E-03	9.64E-11	7.29E-04	5.90E+01
Flax fibre fleece. 38 kg/m3	0.55	kg	4.73E+00	9.65E-03	1.23E-03	6.75E-10	1.85E-03	1.03E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	1.59E+00	3.53E-03	5.87E-04	3.09E-08	4.74E-04	2.38E+01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			5.65E+01	**1.61E-01**	**2.42E-02**	**1.50E-06**	**1.13E-02**	**8.34E+02**

A4 Materials Transportation to the factory			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	2.52E-02	1.16E-04	2.53E-05	4.98E-09	1.42E-06	7.17E-01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, low content...	1.6	kg	7.06E-02	2.86E-04	6.14E-05	1.36E-08	5.90E-06	1.97E+00
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	4.01E-01	1.85E-03	4.02E-04	7.92E-08	2.26E-05	1.14E+01
Birch plywood with phenol film overlay. 680 kg/m3	0.52	m2	6.34E-02	2.92E-04	6.34E-05	1.25E-08	3.57E-06	1.80E+00
Fresh sawn timber,	0.17	m3	1.06E+00	4.88E-03	1.06E-03	2.09E-07	5.98E-05	3.02E+01
Flax fibre fleece. 38 kg/m3	0.55	kg	8.90E-03	4.10E-05	8.90E-06	1.76E-09	5.00E-07	2.53E-01
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	5.96E-02	2.41E-04	5.18E-05	1.15E-08	4.98E-06	1.66E+00
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	3.29E-02	1.51E-04	3.30E-05	6.49E-09	1.85E-06	9.35E-01
			1.84E+00	**8.42E-03**	**1.83E-03**	**3.63E-07**	**1.07E-04**	**5.24E+01**

A5 Panel transportation to the Housing site			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	53.65	kg	8.67E-01	4.00E-03	8.69E-04	1.71E-07	4.89E-05	2.46E+01
			8.67E-01	**4.00E-03**	**8.69E-04**	**1.71E-07**	**4.89E-05**	**2.46E+01**

C1-C4 End of life (Deconstruction)			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	3.34E-02	2.62E-04	5.43E-05	2.67E-14	2.59E-05	6.97E-01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	8.05E-01	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	3.75E+00	5.09E-03	1.11E-03	1.78E-12	4.20E-04	1.35E+01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.52	m2	6.08E-01	8.27E-04	1.81E-04	2.90E-13	6.86E-05	2.20E+00
Fresh sawn timber,	0.17	m3	2.53E-01	5.91E-05	4.93E-06	2.03E-14	2.71E-06	1.37E-01
Flax fibre fleece. 38 kg/m3	0.55	kg	1.61E-04	9.54E-07	1.30E-07	1.52E-16	7.60E-08	2.41E-03
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	1.47E-03	5.85E-06	1.22E-06	2.87E-10	1.98E-07	4.19E-02
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	1.15E-01	8.99E-04	1.86E-04	9.16E-14	8.88E-05	2.39E+00
			6.74E+00	**1.08E-02**	**2.75E-03**	**1.51E-08**	**7.65E-04**	**2.47E+01**

D1-D3 Product Manufacturing			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Flax fibre fleece. 38 kg/m3	0.55	kg	4.73E+00	9.65E-03	1.23E-03	6.75E-10	1.85E-03	1.03E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	1.59E+00	3.53E-03	5.87E-04	3.09E-08	4.74E-04	2.38E+01
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	3.08E+00	6.64E-03	6.69E-04	3.66E-08	5.62E-04	3.21E+01
			9.39E+00	**1.98E-02**	**2.49E-03**	**6.82E-08**	**2.89E-03**	**1.59E+02**

D1-D3 End of life (Deconstruction)			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Flax fibre fleece. 38 kg/m3	0.55	kg	1.61E-04	9.54E-07	1.30E-07	1.52E-16	7.60E-08	2.41E-03
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	1.47E-03	5.85E-06	1.22E-06	2.87E-10	1.98E-07	4.19E-02
Rendering mortar – normal / finishing render, 1300 - 1800 kg...	7.8	kg	1.15E-01	8.99E-04	1.86E-04	9.16E-14	8.88E-05	2.39E+00
			1.17E-01	**9.06E-04**	**1.87E-04**	**2.87E-10**	**8.91E-05**	**2.43E+00**

					Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
		Monetary value (Euros/Emission unit)			0.05	4	9	30	30	
HOME 1	A1-A3	Product Manufacturing	1	m2	€ 2.83	€ 0.64	€ 0.22	€ 0.00	€ 0.34	€ 4.24
		Materials Transportation to the factory	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.08
		End of life (Deconstruction)	1	m2	€ 0.01	€ 0.00	€ 0.00	€ 0.00	€ 0.00	
HOME 2	A1-A3	Product Manufacturing	1	m2	€ 0.47	€ 0.08	€ 0.02	€ 0.00	€ 0.09	€ 0.87
		Materials Transportation to the factory	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.50
		End of life (Deconstruction)	1	m2	€ 0.34	€ 0.04	€ 0.02	€ 0.00	€ 0.02	
HOME 3	A1-A3	Product Manufacturing	1	m2	€ 0.47	€ 0.08	€ 0.02	€ 0.00	€ 0.09	€ 0.76
		Materials Transportation to the factory	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.03	€ 0.00	€ 0.00	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.08
		End of life (Deconstruction)	1	m2	€ 0.01	€ 0.00	€ 0.00	€ 0.00	€ 0.00	
HOME 4	A1-A3	Product Manufacturing	1	m2	€ 0.47	€ 0.08	€ 0.02	€ 0.00	€ 0.09	€ 0.87
		Materials Transportation to the factory	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.04	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.50
		End of life (Deconstruction)	1	m2	€ 0.34	€ 0.04	€ 0.02	€ 0.00	€ 0.02	
					€ 5.57	€ 1.21	€ 0.45	€ 0.00	€ 0.67	€ 7.90

APPENDIX AA - WEIGHTING FACTOR CONCEPT 3 3RD CIRCULARITY SCENARIO REAR VENTILATED CLADDING

A1-A3 Product Manufacturing			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	1.59E+01	3.39E-02	2.72E-03	2.07E-13	2.58E-03	2.79E+02
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	7.64E+00	5.93E-02	9.66E-03	9.24E-07	3.29E-03	2.19E+02
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	1.96E+01	2.52E-03	8.53E-04	2.94E-08	1.44E-04	4.29E+00
Birch plywood with phenol film overlay. 680 kg/m3	0.52	m2	3.97E+00	3.08E-02	5.02E-03	4.80E-07	1.71E-03	1.14E+02
Fresh sawn timber,	0.17	m3	0.00E+00	1.42E-02	3.43E-03	9.64E-11	7.29E-04	5.90E+01
Flax fibre fleece. 38 kg/m3	0.55	kg	4.73E+00	9.65E-03	1.23E-03	6.75E-10	1.85E-03	1.03E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	1.59E+00	3.53E-03	5.87E-04	3.09E-08	4.74E-04	2.38E+01
Threaded reinforcement steel bar (rebar) bolts, 1.7 kg/unit,...	0.2	kg	1.45E-01	7.16E-04	1.34E-04	6.61E-09	3.79E-05	3.13E+00
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	1.09E+00	5.76E-03	2.81E-04	6.99E-11	3.31E-04	1.95E+01
Bricks (KNB)	42	kg	7.88E+00	1.09E-02	1.89E-03	9.91E-07	1.75E-03	1.44E+02
			6.25E+01	**1.71E-01**	**2.58E-02**	**2.46E-06**	**1.29E-02**	**9.69E+02**

A4 Materials Transportation to the factory			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	2.52E-02	1.16E-04	2.53E-05	4.98E-09	1.42E-06	7.17E-01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.22E-01	5.61E-04	1.22E-04	2.41E-08	6.87E-06	3.47E+00
Epoxy resin, EU avg., 1-1.25 kg/l, solvent-free, low content...	1.6	kg	7.06E-02	2.86E-04	6.14E-05	1.36E-08	5.90E-06	1.97E+00
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	4.01E-01	1.85E-03	4.02E-04	7.92E-08	2.26E-05	1.14E+01
Birch plywood with phenol film overlay. 680 kg/m3	0.52	m2	6.34E-02	2.92E-04	6.34E-05	1.25E-08	3.57E-06	1.80E+00
Fresh sawn timber,	0.17	m3	1.06E+00	4.88E-03	1.06E-03	2.09E-07	5.98E-05	3.02E+01
Flax fibre fleece. 38 kg/m3	0.55	kg	8.90E-03	4.10E-05	8.90E-06	1.76E-09	5.00E-07	2.53E-01
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	5.96E-02	2.41E-04	5.18E-05	1.15E-08	4.98E-06	1.66E+00
Threaded reinforcement steel bar (rebar) bolts, 1.7 kg/unit,...	0.2	kg	2.83E-03	1.31E-05	2.84E-06	5.60E-10	1.60E-07	8.07E-02
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	3.42E-03	1.57E-05	3.43E-06	6.75E-10	1.93E-07	9.73E-02
Bricks (KNB)	42	kg	9.65E-02	4.44E-04	9.68E-05	1.91E-08	5.44E-06	2.75E+00
			1.91E+00	**8.74E-03**	**1.90E-03**	**3.77E-07**	**1.11E-04**	**5.44E+01**

A5 Panel transportation to the Housing site			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Trailer combination. 40 ton capacity	108.77	kg	1.76E+00	8.11E-03	1.76E-03	3.47E-07	9.90E-05	5.00E+01
			1.76E+00	**8.11E-03**	**1.76E-03**	**3.47E-07**	**9.90E-05**	**5.00E+01**

C1-C4 End of life (Deconstruction)			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Aluminium foil (th=0.1 mm), 0.1 mm, 0.28 kg/m2, 2800 kg/m3	1	m2	3.34E-02	2.62E-04	5.43E-05	2.67E-14	2.59E-05	6.97E-01
Plywood, for exterior cladding, max 22 mm, 7.8 kg/m2	0.018	m3	1.17E+00	1.59E-03	3.49E-04	5.57E-13	1.32E-04	4.24E+00
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	4.42E-03	3.47E-05	7.18E-06	3.53E-15	3.43E-06	9.22E-02
Insulation from expanded corkboard (ICB), > 50 mm, 115 kg/m2...	1	m2	3.75E+00	2.08E-03	8.66E-04	1.48E-08	2.62E-05	1.45E+00
Birch plywood with phenol film overlay. 680 kg/m3	0.52	m2	1.74E-02	1.36E-04	2.82E-05	1.39E-14	1.35E-05	3.62E-01
Fresh sawn timber,	0.17	m3	0.00E+00	2.14E-02	4.69E-03	7.48E-12	1.77E-03	5.70E+01
Flax fibre fleece. 38 kg/m3	0.55	kg	4.87E-01	1.26E-03	5.24E-04	8.95E-09	1.59E-05	8.77E-01
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	3.73E-03	2.93E-05	6.06E-06	2.98E-15	2.89E-06	7.78E-02
Threaded reinforcement steel bar (rebar) bolts, 1.7 kg/unit,...	0.2	kg	1.61E-04	9.54E-07	1.30E-07	1.52E-16	7.60E-08	2.41E-03
Aluminum, extruded, 2660-2840 kg/m3 (Aluminum Association)	0.19	kg	1.47E-03	5.85E-06	1.22E-06	2.87E-10	1.98E-07	4.19E-02
Bricks (KNB)	42	kg	1.15E-01	8.99E-04	1.86E-04	9.16E-14	8.88E-05	2.39E+00
			5.58E+00	**2.77E-02**	**6.71E-03**	**2.40E-08**	**2.08E-03**	**6.72E+01**

D1-D3 Product Manufacturing			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.6	kg	1.59E+00	3.53E-03	5.87E-04	3.09E-08	4.74E-04	2.38E+01
Flax fibre fleece. 38 kg/m3	#REF!	kg	4.73E+00	9.65E-03	1.23E-03	6.75E-10	1.85E-03	1.03E+02
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	1.59E+00	3.53E-03	5.87E-04	3.09E-08	4.74E-04	2.38E+01
			7.90E+00	**1.67E-02**	**2.40E-03**	**6.24E-08**	**2.80E-03**	**1.51E+02**

C1-C4 End of life (Deconstruction)			Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	Total use of primary energy ex. raw materials
			kg CO_2e	kg SO_2e	kg PO_4e	kg CFC11e	kg Ethenee	MJ
Flax fibre fleece. 38 kg/m3	0.55	kg	4.87E-01	1.26E-03	5.24E-04	8.95E-09	1.59E-05	8.77E-01
BioEpoxy resin. EU avg.. 1-1.25 kg/l. solvent-free.	1.35	kg	3.73E-03	2.93E-05	6.06E-06	2.98E-15	2.89E-06	7.78E-02
			4.91E-01	**1.29E-03**	**5.30E-04**	**8.95E-09**	**1.87E-05**	**9.55E-01**

					Global warming	Acidification	Eutrophication	Ozone depletion potential	Formation of ozone of lower atmosphere	
		Monetary value (Euros/Emission unit)			0.05	4	9	30	30	
HOME 1	A1-A3	Product Manufacturing	1	m2	€ 3.13	€ 0.69	€ 0.23	€ 0.00	€ 0.39	€ 4.72
		Materials Transportation to the factory	1	m2	€ 0.10	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	€ 0.17
		End of life (Deconstruction)	1	m2	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.00	
HOME 2	A1-A3	Product Manufacturing	1	m2	€ 0.39	€ 0.07	€ 0.02	€ 0.00	€ 0.08	€ 0.86
		Materials Transportation to the factory	1	m2	€ 0.10	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	€ 0.17
		End of life (Deconstruction)	1	m2	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.00	
HOME 1	A1-A3	Product Manufacturing	1	m2	€ 0.39	€ 0.07	€ 0.02	€ 0.00	€ 0.08	€ 0.86
		Materials Transportation to the factory	1	m2	€ 0.10	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	€ 0.17
		End of life (Deconstruction)	1	m2	€ 0.02	€ 0.01	€ 0.00	€ 0.00	€ 0.00	
HOME 2	A1-A3	Product Manufacturing	1	m2	€ 0.39	€ 0.07	€ 0.02	€ 0.00	€ 0.08	€ 0.86
		Materials Transportation to the factory	1	m2	€ 0.10	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
	A5	Panel transportation to the Housing site	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	
	C1-C4	Panel Transportation for deconstruction process	1	m2	€ 0.09	€ 0.03	€ 0.02	€ 0.00	€ 0.00	€ 0.65
		End of life (Deconstruction)	1	m2	€ 0.28	€ 0.11	€ 0.06	€ 0.00	€ 0.06	
					€ 5.75	€ 1.41	€ 0.57	€ 0.00	€ 0.74	€ 8.47
										€ 8.47
									% vs Original	74.8%

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