This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723583

# RE⁴ Project

## REuse and REcycling of CDW materials and structures in energy efficient pREfabricated elements for building REfurbishment and construction

| D7.2<br>Framework for LCA/LCCA/S-LCA | |
|---|---|
| Author(s)[1]: | STRESS, RISE |
| Date: | 01/04/2019 |
| Work package: | WP7 - Life-cycle and HSE analysis and certification/standardization strategy definition |
| Distribution[2] | PU |
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| Abstract: | This is the updated version of D7.2. This report is the definition of the methodological framework for LCA/LCCA/SLCA of RE[4] innovative solutions. |
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| Version | Date | Description | Written By | Approved by |
|---|---|---|---|---|
| V0.1 | January 2018 | Deliverable structure | STRESS | |
| V0.2 | 27.02.2018 | New structure and complemented | RISE | |
| V0.3 | 23.03.2018 | Deliverable structure validation | RISE | |
| V0.4 | 31.07.2018 | New LCC text and comments on the report | RISE | |
| V0.5 | 02.08.2018 | Final version | STRESS | |
| V0.6 | 16.08.2018 | Smaller corrections and questions | RISE | |
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*[1] Just mention the partner(s) responsible for the Deliverable*
*[2] PU: Public, RE: restricted to a group specified by the consortium, CO: Confidential, only for members of the consortium; Commission services always included.*
*[3] Draft, Revised, Final*

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|---|---|
| **D.7.2 - V.2.0** (changes compared with the V.1.0 submitted in M24) | Detailed description of the solutions being analysed (Description of main differences and similarities).A |
| | Re-design of timber façade panel for warm climate with more sustainable materials (earth blocks).B |
| | Re-design of timber façade panel for cold climate with more sustainable layers.C |
| | Definition of the functional units according to the location of the demonstration sites.D |

## ACRONYMS & ABBREVIATIONS

| | |
|---|---|
| **LCA** | Life Cycle Assessment |
| **LCC** | Life Cycle Cost |
| **SLCA** | Social Life Cycle Assessment |
| **GWP** | Global Warming Potential (100a) |
| **ODP** | Ozone Depletion Potential |
| **AP** | Acidification Potential |
| **EP** | Eutrophication Potential |
| **POCP** | Photochemical Ozone Creation Potential |
| **ADP-elements** | Abiotic depletion potential (elements) |
| **ADP-fossil fuels** | Abiotic depletion potential (fossil fuels) |
| **TRPE** | Total renewable primary energy |
| **TNRPE** | Total non-renewable primary energy |

# 1. EXECUTIVE SUMMARY

This is the updated version of the 1st release of D7.2 submitted in M24. The present document reports the activities carried out in Task 7.2, led by STRESS with the collaboration of RISE. Task 7.2 **Goal and scope definition**, is included into the context of Work Package 7 **"Life-cycle and HSE analysis and certification/standardization strategy definition**. The Goal and Scope is the first phase of sustainability methodologies followed by the other phases such as Life Cycle Inventory, Life cycle Impact Assessment and the Conclusion and results interpretation phase.

The main goal of this task is to develop an integrated assessment framework for Life Cycle Assessment (LCA), Life Cycle Costing (LCCA) and Social- Life Cycle Assessment (S-LCA), covering and aligning the analyses related to the case studies and their methodological aspects in order to compare, in an integrated and consistent way, environment, economic and social impacts of the RE$^4$ technologies/products.

Life Cycle Assessment (LCA) is a holistic approach used to quantify the potential environmental impacts of a product or activity throughout its life cycle from raw material and resource extraction to manufacture, consumer use, and end of life. Results from LCA studies can be used to inform decisions at many levels, including design considerations, corporate strategy, and policy.

The RE$^4$ LCA Team aims to provide insight into life cycle impacts to:

• engage value chain partners in conversations about sustainability, enabling collaboration to reduce cradle-to-grave impacts and maximize brand value;

• guide RE$^4$'s product and technology portfolio management and strategy, driving responsible innovation throughout product and process development; and

• create a culture within RE$^4$ workgroup that promotes life cycle thinking.

RE$^4$ LCAs are calculated using the Simapro software package. As part of the Simapro platform, LCA workgroup has access to many of the most widely used and accepted published LCA databases.

LCA RE$^4$ workgroup makes its best effort to conduct LCAs according to ISO standards 14040 and 14044. In addition, the workgroup uses the International Reference Life Cycle Data System (ILCD) Handbook for chemical products, and the Greenhouse Gas Protocol Product Life Cycle Accounting and Reporting Standard to provide more detailed guidance. The researchers operate complex and highly integrated chemical processes which require careful consideration of LCA scope, allocation methods, cut off criteria, and other details.

The LCC process is a way to predict the most cost-effective solution; it does not guarantee a particular result, but allows the planner, designer and/or architect to make a reasonable comparison between alternate solutions within the limits of the available data.

The LCC will be carried out according the international standard ISO 15686-5:2008 (Building and construction assets-Service life planning-Life cycle costing) and the European Standards EN 15643-4:2012 (Framework for the assessment of economic performance planning) and EN 16627:2015 Sustainability of construction works - Assessment of economic performance of buildings -calculation methods.

The Sustainability Life Cycle Assessment consists in assessing the sustainability of products and services, as well as the production cycles associated with them, during their entire life cycle, taking into account environmental, social and economic criteria.

In this context, this section focuses on the analysis of socio-economic aspects related to the solutions provided by the RE$^4$ project and, in particular, aims to present the study carried out for the assessment of their social impact (Social Life Cycle Assessment, S-LCA).
The main challenge of RE$^4$ project is both to define individually the environmental, economic and social impacts of RE$^4$ elements, and to define an innovative method to integrate all the results through a definition of Framework for Weighting Sustainability.
About a global framework for weighting sustainability WP7 workgroup have identified the following areas that need more development in order to advance the implementation of LCSA (where LCSA = LCA + LCC + SLCA) tool:

- Strengthen more applications by combining (environmental) LCA, LCC and S-LCA and obtain findings and lessons learned. For example, with more LCSAs, 'trade-off errors' in sustainability decision support should be overcome – for example, not supporting a product chain that is environmentally positive but socially questionable, not claiming that a product is more sustainable because it uses less resources, or has lower direct carbon emissions, without assessing other aspects needed in a sustainability assessment.
- Acquire more data. The implementation of consistent and harmonized data management systems for each of the techniques (LCC, S-LCA and environmental LCA) may support the broader availability of data and promote the generation of data – especially in developing countries and emerging economies. Subsequently, this will facilitate the implementation of the three techniques in a linked and consistent way.
- Discuss LCSA principles and criteria and explore how to read the results of the LCIAs for each technique in the light of 'trade-off' analysis among the three sustainability pillars. This may help stakeholders to advance the implementation of more case studies and assist decision-makers in making better informed decisions.
- Engage actively in the definition process. Common understanding and consensus of the areas of protection (endpoints) within an LCSA is a new field for further discussion, which requires an active engagement of stakeholders and decision makers in the definition process.

D7.2 includes the following main sections:

- Introduction to the deliverable, task scope and objectives, relevant Work Package/task input/output, and description of the methodology used (Chapter 2).
- general goal and scope about six innovative RE$^4$ building elements containing construction and demolition waste CDW; an overview of each innovative RE$^4$ building element is also included and the main differences with the correspondent conventional element is also described (Chapter 3);
- Life Cycle Assessment method (Chapter 4);
- Life Cycle Cost Assessment method (Chapter 5);
- Social LCA (S_LCA) of RE$^4$ products (Chapter 6);
- framework for weighting sustainability (Chapter 7).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723583

# 2. INTRODUCTION

## 2.1 Task scope and objectives

The present document is included in the framework of the ongoing RE$^4$ research project, funded by the European Commission in the context of Horizon 2020 research funding programme, call H2020-EEB-2016. It reports the activities carried out in Task 7.2, led by STRESS with the collaboration of RISE.

Task 7.2 **Goal and scope definition**, is included into the context of Work Package 7 **"Life-cycle and HSE analysis and certification/standardization strategy definition"**, which was forecasted to begin in Month 13 of the project (i.e. September 2017) and to end by Month 42 (i.e. February) of the project. In particular, Task 7.2 timing foresaw the activities to be performed from Month 13 to Month 24 (i.e. August 2018). The Goal and Scope is the first phase of sustainability methodologies followed by the other phases such as Life Cycle Inventory, Life cycle Impact Assessment and the Conclusion and results interpretation phase.

The main goal of this task is to develop an integrated assessment framework for Life Cycle Assessment (LCA), Life Cycle Costing (LCCA) and Social- Life Cycle Assessment (S-LCA), covering and aligning the analyses related to the case studies and their methodological aspects in order to compare, in an integrated and consistent way, environment, economic and social impacts of the RE$^4$ technologies/products. Indeed, in order to obtain fully comparable impacts in all the assessments this deliverable is focused on the definition of a comparable Goal and Scope with similar boundary limits and Functional Units. The Goal and Scope represents the first phase of LCA, LCC and S-LCA followed by other three connected phases that will deal with tasks 7.3 and 7.4.

Indeed, the Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA) and the results interpretation are analysed in task 7.3 and Task 7.4, respectively. The relationship between the phases is illustrated in Figure 1.

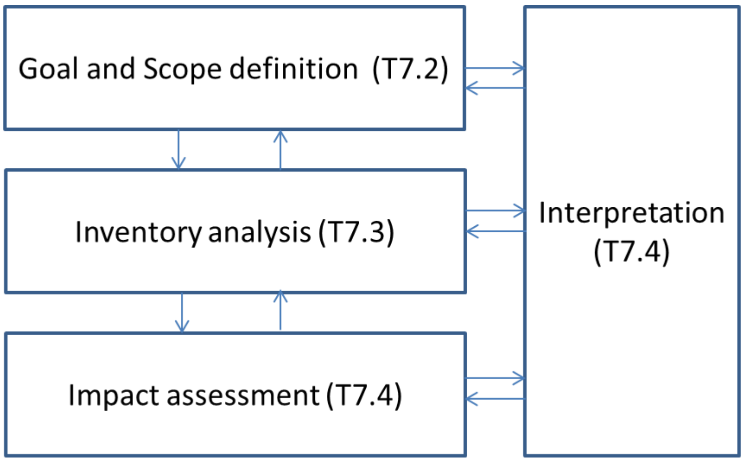



**Figure 1 – Relationship between the phases**

The objective of each phase is summarized as follow:

1. Goal and Scope: where the reasons for carrying out the study and its intended use are described and where details are given on the approach taken to conduct the study. Notably,

it is in this phase of the study that the functional unit is defined, and that modelling approaches are specified.
2. Life Cycle Inventory (LCI): where the product system (or systems) and its constituent unit processes are described, including the inputs and outputs (data) to conduct the analysis. Their amounts are in reference to one functional unit and to system boundary, as defined in the Goal and Scope phase.
3. Life Cycle Impact Assessment (LCIA): where the magnitude and significance of impacts associated with the inputs and outputs compiled during the previous phase are evaluated. This is done by associating the life cycle inventory results with impact categories and category indicators.
4. Interpretation: where the findings of the previous two phases are combined with the defined goal and scope in order to reach conclusions or recommendations.

The most obvious difference between LCA, LCC and S-LCA is the focus. While the former is concerned with the evaluation of environmental impacts, the LCC is focused on the evaluation of the economic impacts and the latter aims to assess social and socio-economic impacts. Then, the LCI and LCIA phases slightly differ for each methodology, since the collected data and the impacts categories are different. With regards to LCA, data (LCI) within the systems boundary include energy inputs, raw material inputs, products, co-products and waste, emissions to air, discharges to water and soil, etc. and the selection of impact categories (LCIA) shall reflect a comprehensive set of environmental issues related to the product system being studied (e.g. Climate Change).
In LCC, data include the quantification of investment (i.e. raw materials, energy- OPEX) and operative costs (i.e. equipment-CAPEX) and the LCIA should contain the evaluation of total cost per functional unit calculated as the sum of OPEX and CAPEX.
In the S-LCA, instead, the inventory and the LCIA are carried out according to the selected subcategories related to the different stakeholders, namely socially significant themes or attributes which include human rights, work conditions, cultural heritage, poverty, disease, and political conflict.
However, the goal and scope definition, as well as data collection and the LCIA, will be performed in the same time in order to have social, environmental and economic impacts comparable.
The LCA/LCCA analysis will be carried out on six RE$^4$ elements each one comparatively with a reference state-of-the-art product. S-LCA analysis will be performed on two RE$^4$ products. The selection of the products to be analysed has been identified jointly by the Consortium in the framework of WP3, WP4 and WP5 activities.

## 2.2 Deliverable structure

D7.2 includes the following sections:

- general goal and scope about six innovative RE$^4$ building elements containing construction and demolition waste (CDW); an overview of each innovative RE$^4$ building element is also included and the main differences with the correspondent conventional element is also described;
- Life Cycle Assessment method;
- Life Cycle Cost Assessment method;

- Social LCA (S-LCA) of RE$^4$ products;
- framework for weighting sustainability.

## 2.3 Relevant Work Package/task input/output

The activities performed on T7.2 and the results presented in D7.2 builds upon the knowledge obtained from WP2, WP3, WP4 and WP5.

- **WP3:** information on the development of innovative design concepts (e.g. reversible connections) for an energy efficient building, both for renovation and new construction;
- **WP2/WP4:** Information on innovative strategies to sort the Construction and Demolition Waste (CDW) and on the technical characterisation results of CDW-derived materials for the production of building elements, including the definition of a strategy for the reuse and recycling of timber
- **WP5:** Information on the material development and prefabricated elements with a high level of incorporation of CDW (e.g. Concrete and timber façade panels; Load bearing concrete elements; Non-load bearing internal partition walls)

The results of T7.2, as mentioned, will be used in the other task of WP7 and in particular in Tasks 7.3 and 7.4. In addition, all the outputs of WP7 will be transferred to WP6 for the manufacturing and testing of the prefabricated elements prototypes in order to monitor and validate their energy and sustainability performance.

## 2.4 Methodologies

WP7 activities and in particular the activities performed in the framework of Tasks 7.2, 7.3 and 7.4 are focused on all the aspects related to the environmental, social, and cost analysis connected with the RE$^4$ elements, with the aim of addressing and evaluating their sustainability be means of a Life Cycle Sustainability Assessment (LCSA approach, Figure 2 ). Using the LCSA all environmental, social and economic impacts and/or benefits of RE$^4$ products throughout their life cycle are taken into account addressing towards low-impact solutions with comparison with benchmark solutions. The LCSA combines the results of LCA, LCC and S-LCA considering a:

- Life cycle perspective:
  all phases ("from the cradle to the grave") of the life cycle of a product, from the extraction and processing of the resources, over production and further processing, distribution and transport, use and consumption to recycling and disposal are considered;
- Complete sustainability approach: all relevant environmental, economic and social impacts are taken into account.

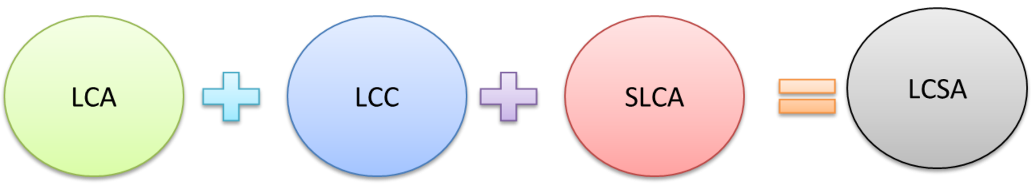



**Figure 2 – Life cycle Sustainability Assessment (SLCA) approach**

The main challenge of RE$^4$ project is both to define individually the environmental, economic and social impacts of RE$^4$ elements, and to define an innovative method to integrate all the results through a definition of Framework for Weighting Sustainability.
The methodology is discussed in section 7.

# 3. GENERAL GOAL AND SCOPE FOR SUSTAINABLE ASSESSEMENT

## 3.1 Introduction

WP7 aims to assess the sustainable performance of six innovative RE$^4$ building elements containing CDW. The innovative elements will be compared with common reference elements on the European market with the same functional performance. Before the sustainable assessment the innovative and conventional products will be defined by WP3 with innovative concepts, by WP2 and WP4 with sorting and technical characterisation of CDW and by WP5 by development of materials, components and elements. More in detail, the selection of the most promising products to be analysed has been done jointly by the Consortium and it has been based on the outputs of task 5.3 focused on the development of prefabricated elements. The list of the elements to be analysed is reported in
Table 1.
The LCA and LCC analysis will be performed on all elements. Instead, the S-LCA will be performed on only two elements: Concrete and Timber façade panels. On these two elements an integration of all results according to a LSCA approach is also provided. The partners in charge of the definition and development of elements are also presented. In collaboration with these partners, the main information for the Goal and Scope definition (i.e. Functional unit, system boundary, data quality requirements, etc.) on the elements, both conventional and innovative, have been collected. The description of these information, for each element, are reported in the following section.

**Table 1 – Compared elements**

| Elements | Partners in charge for design | LCA | LCC | S-LCA | LCSA | Partner in charge of LCA, LCC, SLCA |
|---|---|---|---|---|---|---|
| Timber Façade Panel for cold climate | ZRS | X | X | X | | LCA, LCC: STRESS |
| Timber Façade Panel for warm climate | ZRS | X | X | | X | LCA, LCC: STRESS<br>SLCA: RINA (LTD STRESS)<br>LCSA (STRESS) |
| Concrete Façade Panel for cold climate | CREAGH + RISE | X | X | | | LCA, LCC: RISE |
| Concrete Façade Panel for warm climate | CREAGH + RISE | X | X | X | X | LCA, LCC: RISE<br>SLCA: RINA (LTD STRESS)<br>LCSA (RISE) |
| Prefabricated internal partition wall system | ZRS | X | X | | | LCA, LCC:STRESS |
| Ventilated façade for refurbishment for warm climate | Vortex | X | X | | | LCA, LCC:RISE |

## 3.2 Main information for the Goal and Scope definition

### 3.2.1 Functional unit

The functional unit is a key element of LCA, LCC and S-LCA which has to be clearly defined. The functional unit is a measure of the function of the studied system and it provides a reference to which the inputs and outputs can be related. This enables comparison of two essential different systems. Definition of a functional unit could be difficult. The definition should be precise and comparable enough so that the unit can be used throughout the study as reference. For example, the functional unit for a paint system may be defined as the unit surface protected for 10 years.
A comparison of the environmental impact of two different paint systems with the same functional unit is therefore possible. The functional unit used for a project should be determined though the elaboration of the collected data and study. Also, potential restrictions with respect to the depth of the study, the sources and quality of data are determined during the process of the study.
About RE$^4$ products, the square meter of panel RE$^4$ is compared to the analogous commercial product with the same structural and thermal performance.

### 3.2.2 System boundaries

The system boundaries determine which unit processes to be included in the LCA study. Defining system boundaries is partly based on a subjective choice, made during the scope phase when the boundaries are initially set.
The following boundaries can be considered:

- boundaries between the technological system and nature. A life cycle usually begins at the extraction point of raw materials and energy carriers from nature. Final stages normally include waste generation and/or heat production;
- geographical area. Geography plays a crucial role in most LCA studies, e.g. infrastructures, such as electricity production, waste management and transport systems, vary from one region to another. Moreover, ecosystems sensitivity to environmental impacts differs regionally too;
- time horizon. Boundaries must be set not only in space, but also in time. Basically LCAs are carried out to evaluate present impacts and predict future scenarios. Limitations to time boundaries are given by technologies involved, pollutants lifespan, etc.

Boundaries between the current life cycle and related life cycles of other technical systems. Most activities are interrelated, and therefore must be isolated from each other for further study. For example production of capital goods, economic feasibility of new and more environmentally friendly processes can be evaluated in comparison with currently used technology. Interrelation of product systems has the tendency to be interrelated in a very complex manner. Ideally, life cycles of products used to produce the materials and product under investigation are also required. That however would lead to an endless and complex list of inflows and outflows.
Consequently, limits, boundaries have to be set for the exclusion of certain parts, which can however alter the final output of the study. A diagram of the system is very helpful for the

identification of the boundaries, and so are some choices such as production and disposal of capital goods, and nature boundaries.

In more details, in the framework of RE[4] project a **"cradle to grave"** system boundary will be taken into account. For each element to be considered, all life cycle phases, such as **production**, **construction**, **use** and **end of life** phases and connected modules (EN 15804:2012, Table 2) will be included in the analysis.

**Table 2 – Life cycle stages/modules**

| Life cycle stage | PRODUCT | | | CONSTRUCTION | | USE | | | | | | | END OF LIFE | | | | BENEFITS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Modules | A1 | A2 | A3 | A4 | A5 | B1 | B2 | B3 | B4 | B5 | B6 | B7 | C1 | C2 | C3 | C4 | D |
| | Raw material supply | Transport | Manufacturing | Transport | Construction | Use | Maintenance | Repair | Replace | Refurbishment | Operation energy use | Operational water use | Demolition | Transport | Waste processing | Disposal | Reuse/ Recovery/ recycling potential |
| Cradle to grave | | | | | | | | | | | | | | | | | |

In Table 3, a description of each module is provided.

**Table 3 – Modules description**

| Life cycle phase | Sub-module | Description |
|---|---|---|
| PRODUCTION | A1 | Raw materials supply, including the processing of secondary materials |
| | A2 | Transport of raw materials (A1) to the manufacturer |
| | A3 | Manufacture of the construction product |
| CONSTRUCTION | A4 | Transport of the construction product to the building site |
| | A5 | Building installation/construction |
| USE | B1 | Use of installed product |
| | B2 | Maintenance of product |
| | B3 | Repair of product |
| | B4 | Replacement of product |
| | B5 | Refurbishment of product |
| | B6 | Operation energy (related to the operation of building) |
| | B7 | Operation water use (related to the operation of building) |
| END OF LIFE | C1 | Demolition of the building product |
| | C2 | Transport of the demolition waste comprising the EOL construction product to waste process facility |
| | C3 | Waste processing operation for reuse, recovery or recycling |
| | C4 | Final disposal of EOL construction product |
| BENEFITS | D | Reuse, recovery, recycling potential evaluated as net impact and benefits |

### 3.2.3 Data quality requirements

Reliability of the results from LCA studies strongly depends on the extent to which data quality requirements are met. The following parameters should be taken into account: time-related coverage, geographical coverage, technology coverage, precision, completeness representativeness of the data. Consistency and reproducibility of the methods used throughout the data collection. Uncertainty of the information and data gaps. Threshold points can also be placed in addition to the boundaries, below or above which data collection for inflow or outflow can't be considered, increasing the quality and usefulness of the data.

### 3.2.4 Data collection: life cycle inventory

LCI comprises of all stages dealing with data retrieval and management. Data for each process considered is required for the completion of the model. This data set is a compilation of inputs and outputs related to the function or product generated by the process. The forms to be used for data collection must be properly designed for optimal collection. Subsequently data is validated and related to the functional unit in order to allow the aggregation of results. A very sensitive step in this calculation process is the allocation of flows e.g. releases to air, water and land. Most of the existing technical systems yield more than one product. Therefore, materials and energy flows regarding the process as a whole, as well as environmental releases must often be allocated to the different products. The data collection is the most resource consuming part of the LCA. Reuse of data from other studies can simplify the work but this must be made with great care so that the data is representative. Nevertheless, product systems usually contain process types common to nearly all studies, namely, energy supply, transport, waste treatment services, and the production of commodity chemicals and materials. The quality aspect is therefore also crucial. Problems that may be faced by people performing the LCI during data collection include:

- large number of unit processes resulting to mutual learning of many process 'owners' may be necessary;
- work often requiring communication across several organizational borders, outside the regular business information flow;
- throughout the LCA, for all unit processes, the quantity of each product, pollutant, resource, etc. has to be measured in the same way.

Additionally, the nomenclature used for the denotation of flows and other environmental exchanges also needs to be consistent throughout the product system.

### 3.2.5 Data types

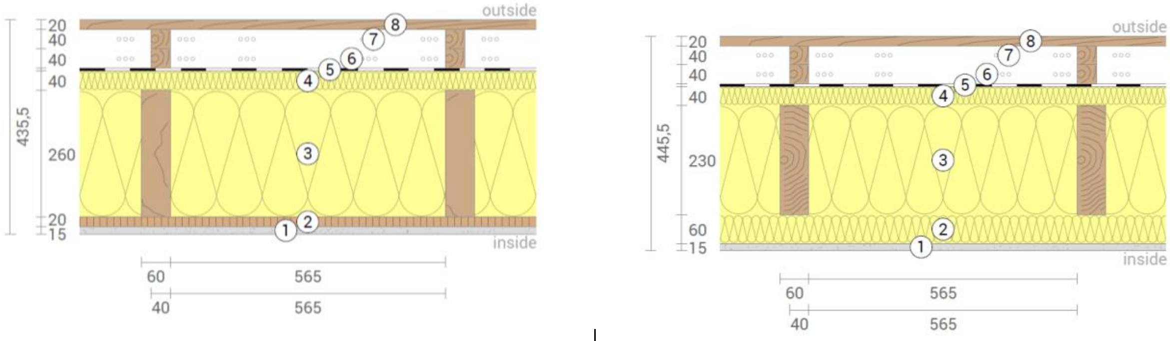
Even though much data is available through databases, there are always some processes that are not listed or the available data is not representative of the process required. Data is separated into two types:

- foreground data: specific data required to model the specific system. Typically data describing a specific product and production system.
- background data: information for generic materials, energy, transport and waste management systems. This type of data can be typically found in literature and databases.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723583

## 3.3 Timber façade panel for cold climate

### 3.3.1 Conventional and RE⁴ timber façade panel overview (Figure 3)




| (a) | (b) |
|---|---|

Timber façade panels, layers details: (a) conventional timber façade panel; (b) RE⁴ timber façade panel

**Figure 3 – Compared timber façade panel for cold climate**

RE⁴ timber façade panel and conventional timber façade panel have the same layer composition but they are made by different materials (Table 4, Table 5).

**Table 4 – Conventional timber façade panel, layer composition**

| | Layer | Thickness (mm) | Composition |
|---|---|---|---|
| 1 | Mineral earth plaster | 15 | Clayey soil (up to 5 mm), mixed corn washed or broken sand (0 – 2.8 mm) |
| 2 | OSB/3 | 20 | Wood content, approx. 90% (predominantly wood species pine,<br>partially PEFC or FSC-certified)<br>• Adhesive, PUR resin (MDI-Basis) 2 - 4 %<br>• Water in the form of wood moisture 4 - 6%<br>• wax emulsion <1% |
| 3a | Cellulose blow in insulation (89%) | 260 | Cellulose fibres |
| 3b | Timber studs (11%) | | Timber studs (except fasteners); spruce 6 x 26 cm |
| 3c | Timber frame beam (top) | | Timber studs (except fasteners); spruce 6 x 26 cm |
| 3d | Timber frame beam (sleeper) | | Timber studs (except fasteners); spruce 10 x 26 cm |
| 4 | Wood fibre board | 40 | 97% wooden fibres 3% binder (i.e. polymers diphenylmethane + paraffin) |
| 5 | Breather membrane sd=0.5 | 0.05 | 3-layered membrane, made of tear-resistant, vapour permeable PP spun bonded film |
| 6 | Rear ventilated level | 40 | 40 mm x 40 mm spruce battens |
| 7 | Rear ventilated level | 40 | 40 mm x 40 mm spruce battens |
| 8 | Larch | 20 | 100% timber battens (except fasteners) |
| Total | | 435 | |

**Table 5 – RE[4] timber façade panel, layer composition**

| | Layer | Thickness (mm) | Composition |
|---|---|---|---|
| 1 | RE[4] CDW Earthen Plaster | 15 | Clayey soil (up to 5 mm, commercial product), CDW sand 0 – 2 mm (mixing ration 1:2, (per volume)) |
| 2 | Wood fibre board | 60 | 95% wooden fibres from CDW, 5% binder. Or only wooden fibres from CDW (wetting and pressing the fibres in order to ensure the isolation function)<br>Commercial product |
| 3a | Infill insulation sawdust+clay (89%) | 230 | 100% wooden fibres from the processing CDW timber, 100% clay from CDW recycling<br>Ratio wood fibres to clay: 75% volume weight – 25 % volume weight |
| 3b | Timber studs (11%) | | 100% CDW timber studs (except fixage); 6 x 24 cm |
| 3c | Timber frame beam (top) | | Timber studs (except fasteners); spruce 6 x 26 cm |
| 3d | Timber frame beam (sleeper) | | Timber studs (except fasteners); spruce 10 x 26 cm |
| 4 | Wood fibre board | 40 | 95% wooden fibres from CDW, 5% binder. Or only wooden fibres from CDW (wetting and pressing the fibres in order to ensure the isolation function)<br>Commercial product |
| 5 | Breather membrane sd=0.5 | 0.05 | 3-layered membrane, made of tear-resistant, vapour permeable PP spun bonded film<br>Commercial product |
| 6 | Rear ventilated level | 40 | 40 mm x 40 mm RE[4] CDW spruce battens |
| 7 | Rear ventilated level | 40 | 40 mm x 40 mm RE[4] CDW spruce battens |
| 8 | Larch | 20 | 100% timber battens from RE[4] CDW (except fixage) |
| Total | | 445 | |

### 3.3.2 Functional units (m$^2$ element + building physical characteristically functions)

***Functional unit: m$^2$ of elements with the same thermal transmittance (U-value): 0.14 W/m$^2$K.***

The U-value for panels has been determined from the following relationship, according to the EN ISO 6946:2017 and considering the target values for Germany, even if Germany is not among the demonstrator sites.

Although the mandatory u-value for external walls (opaque parts) in Germany is only 0.24 W/m$^2$K, this value does not fulfil current energy efficiency standards as e.g. thermal bridging and accommodation of windows is not considered in this value. From planning projects carried out an average u-value of 0.20 W/m$^2$K would meet current standards. However, as the project aims to meet highest energy efficiency targets it has been decided to undercut current legislation.

This because especially when it comes to the timber facade panel, the u-value for Northern Ireland is too high for the application in Germany since the climate in wintertime is colder and the energy requirements are much more stringent. As the application of timber facade elements is more pronounced in Germany, is more beneficial for the project to stick to the targeted value of this place. Both panels have been designed in order to guarantee this thermal performance (Table 6, Table 7). Any details related to the adopted calculation are reported below.

$$\mathbf{U} = \frac{\mathbf{1}}{\mathbf{R_{SI} + R_1 + R_2 + R_3 + \cdots R_n + R_{SE}}}$$

Where:

- $d_i$ is the thickness of the i-th layer and $\lambda_i$ is its thermal conductivity
- $R_{SI}$ is the resistivity of a "boundary layer" of air on the inside surface of the panel and it is equal to 0,13 $m^2K/W$;
- $R_{SE}$ is the resistivity of the "air boundary layer" on the outside surface of the panel and it is equal to 0,04 $m^2K/W$;

$R_1$, $R_2$.......$R_n$ represent the resistivity of each component of the panels and can be calculated as the product between the thickness of each component for its thermal conductivity λ. $R_i$ is equal to:

$$R_i = \frac{d_i}{\lambda_i}$$

**Table 6 – Conventional timber façade panel, U value calculation**

| | Layer | Thickness (mm) | λ (W/mK) | R (m² K/W) | Weight (kg/m²) | U [W/m²K] |
|---|---|---|---|---|---|---|
| $R_{SI}$ | | | | 0.13 | | |
| 1 | Mineral earth plaster | 15 | 1.1 | 0.014 | 30.0 | |
| 2 | OSB/3 | 20 | 0.13 | 0.15 | 12.4 | |
| 3a | Cellulose blow in insulation (89%) | 260 | 0.039 | 6.66 | 11.8 | |
| 3b | Timber studs (11%) | | 0.13 | 2.0 | 11.2 | |
| 4 | Wood fibre board | 40 | 0.044 | 0.90 | 6.4 | |
| 5 | Breather membrane sd=0.5 | 0.05 | 0.2 | 0.003 | 0.4 | **0.14** |
| 6 | Rear ventilated level | 40 | | | | |
| 7 | Rear ventilated level | 40 | | | | |
| 8 | Larch | 20 | | | 9.2 | |
| $R_{SE}$ | | | | 0.04 | | |
| **Total** | | **435** | | **6.916** | **83,8**[4] | |

[4] This value comes from the data sheet, but is not the sum of the listed values. It could be related to the battens and counter battens that provide the rear ventilation or it could be an assumption by the program for fixings.

**Table 7 – RE[4] timber façade panel, U value calculation**

| | Layer | Tickness (mm) | λ (W/mK) | R ($m^2$ K/W) | Weight ($kg/m^2$) | U [$W/m^2K$] |
|---|---|---|---|---|---|---|
| $R_{SI}$ | | | | 0,13 | | 0.14 |
| 1 | RE[4] CDW earthen plaster | 15 | 1.1 | 0.014 | 25.1 | |
| 2 | Wood fibre board | 60 | 0.038 | 1.05 | 13.5 | |
| 3a | Infill insulation sawdust+clay (89%) | 230 | 0.045[5] | 4.89 | 20.8 | |
| 3b | Timber studs (11%) | | 0.13 | 0.15 | 9.9 | |
| 4 | Wood fibre board | 40 | 0.045 | 0.89 | 6.4 | |
| 5 | Breather membrane sd=0.5 | 0.05 | 0.2 | 0.003 | 0.4 | |
| 6 | Rear ventilated level | 40 | | | | |
| 7 | Rear ventilated level | 40 | | | | |
| 8 | Larch | 20 | | | 9.2 | |
| $R_{SE}$ | | | | 0.04 | | |
| **Total** | | **445** | | **6.884** | **87.7[4]** | |

### **3.3.3** Service life

The typical timber facade panel life is assumed to be the life of the building or 50+ years. For the purpose of this study, 50 years of use is assumed for conventional panel and over 50 years of use is assumed for RE[4] panel. The RE[4] panel is reused after its first service life for other 50 years or disassembled in its components to be reused. Considering that the two panels have a different lifetime, the environmental impacts will be presented as [impact/$m^2$*year][6]

### **3.3.4** System boundaries

The sustainability assessment of both panels will include the following phase:

- manufacturing (modules A1-A2-A3), transport from manufacturing to the building site (A4) panel installation (A5) and replacement operations (B4);
- deconstruction of the panel (C1), the transport of the panel to the landfill site or the recycling plant (module C2) as well as the End of Life of panel.
- For both panels, two different scenario for the EOL are considered:
  Conventional: Landfilling (C4). The conventional panel is assumed to be landfilled after 50 years of service life based on actual practices.
  RE[4] Panel: It is assumed that through reversible connections between the structural support system and the façade panel, the panel can be taken without causing any damages to the element. It is assumes that a complete reuse of the panel is possible. RE[4] panel is assumed to be reused in other product system after 50 years of service life. Therefore, waste processing (module C3) is included in the system boundary of the analysed product system. Reuse of the RE[4] panel is considered as credits allocated to this panel by considering 100

[5] This value is not the measured but the calculated value.

[6] 1 $m^2$ of the panel is the function unit of the analysis as defined in section 3.3.2

years of service life for this panel. RE[4] panel is assumed to be landfilled after 100 years of service life (C4)[7].

For the timber façade elements, transport has been considered based on experience from planning projects in Germany. Due to the fact that most of the manufacturers of timber elements are based in Southern Germany, Switzerland or Austria, such elements are often transported from the South to the construction site. As Berlin as building site for this LCA assessment has been chosen, transport has been assumed to be approx. 800 km on average. For the RE[4] solution it has been assumed that the building element will be dismantled and reused in close proximity to the location of dismantling in order to minimise the negative impact of transport. Although this is still a theoretical exercise it will be beneficial for this study to determine the impact of transport on the overall LCA results. As average distance for transport 50 km have been assumed. Accordingly, the analysis is a cradle-to-grave.
For both panel, each phase is described in Table 8, pointing out the main differences and similarities.

**Table 8 – Description of main differences and similarities**

| **Module** | **Sub-Module** | **Conventional timber façade panel** | **RE[4] timber façade panel** |
|---|---|---|---|
| PRODUCTION | A1: Supply of raw materials | All solid timber components (weatherboard, studs) are taken from virgin material. Wood fibre boards and OSB boards might obtain materials from saw mills, which can then be classified as secondary raw material.<br>Earthen plaster is taken from virgin material (clayey soil and sand). | In the RE[4] timber façade panel, timber studs, top and bottom plate and the weatherboards are made out of recycled or reused timber. Wood fibre boards and wood fibre insulation are also made from recycled timber.<br>For the RE[4] panel wood fibre based components are not actually manufactured within the consortium.<br>Timber has been obtained from different construction sites, where timber roofs have been dismantled. Timber elements have been brought down by means of a winch etc.<br>RE[4] earth plaster is made from CDW sand and virgin clayey soil (binder). |
| | A2: Transport of raw materials | | Distance of 50 km by truck |

[7] In case that e.g. the weatherboarding has reached its end of life or the performance of the insulation is not sufficient any longer, the panel itself can be fully dismantled and functioning parts can be reused in another construction. As timber enables a cascading use it is assumed that the weather boards can be recycled and used as insulation material. For the insulation material it is likely that the material will be burned or used for compost, in case no artificial binder has been used.

| | | | |
|---|---|---|---|
| | | Distance of 300 – 500 km by truck | |
| | A3: Manufacturing | Timber will be cut in the forest and processed by saw mills. From there the processed timber will be brought into composite lumber plant, where the timber is further processed to glulam timber.<br>Wood fibre boards and wood fibre insulation mats are manufactured by other manufacturers using secondary raw materials from saw mills.<br>Additional materials are sarking membrane and screws and other metal fittings.<br>The final prefabricated panel will be assembled by carpenters in a carpenter's workshop, using screws and other fasteners. Reversible connections are not necessarily carried out.<br>Earthen plaster will be applied on site. | Timber will be assessed against the occurrence of wood preservatives. If no wood preservatives or other harmful substances or funguses are found, beams, columns and flooring boards will be dismantled from existing buildings.<br>The harvested material will be brought to a saw mill investigated with regards to fittings, cleaned, planed and cut into lamellas.<br>The final prefabricated panel will be assembled by carpenters in a carpenter's workshop, using screws and other fasteners to enable reversible connections.<br>Earth plaster will be applied in the workshop. Only a final thin coat will be applied on site. |
| CONSTRUCTION | A4: Transport to building site | The prefabricated panel will be put on a lorry by crane and be brought to site.<br>Distance of 800 km by truck | The prefabricated panel will be put on a lorry by crane and be brought to site.<br>Distance of 50 km by truck |
| | A5: Installation/Construction[8] | The installation process is similar in both panels. | The installation process is similar in both panels. However, for the $RE^4$ panel the installation will be slightly more time consuming as reversible connections will be realised. |
| USE STAGE[9] | B4: Replace[10] | The weatherboards are protecting the main body of the panel against environmental impact through the weather. In case these boards do show defects, they can be dismantled and replaced. The internal earthen plaster, covering the | The weatherboards are protecting the main body of the panel against environmental impact through the weather. In case these boards do show defects, they can be dismantled and replaced. |

[8] This phase differs only for the materials used (reversible connections for fixing the $RE^4$ panel against the support structure)

[9] The general maintenance/replace procedure should be equal for both panels. However the panel's layers to be replaced in both configurations are different for the materials used. Moreover, In case of repair, the $RE^4$ panel can be easily repaired, as connections are reversible.

[10] The number of the replacement of layers in both panels will be different because of the different considered lifetime.

| | | | |
|---|---|---|---|
| | | board from the inside, can be wettened and reworked or replaced, in case this layer shows any defects. In the unlikely case, that the insulation layer demonstrates any defects, the weatherboards, battens and counter battens and the wood fibre board can be dismantled so that the insulation layer can be replaced. Likewise the entire panels could be dismantled and taken down, in order to replace the insulation layer on ground.<br><br>Replaced Frequency:<br>Entire panel: 50 years<br>Weatherboards: 20 years<br>Earthen plaster: 15 years<br>Insulation layer: 50 years | The internal earthen plaster, covering the board from the inside, can be wettened and reworked or replaced, in case this layer shows any defects.<br>In the unlikely case, that the insulation layer demonstrates any defects, the weatherboards, battens and counter battens and the wood fibre board can be dismantled so that the insulation layer can be replaced. Likewise the entire panels could be dismantled and taken down, in order to replace the insulation layer on ground.<br><br>Replaced Frequencies:<br>Entire panel: 50 years +<br>Weatherboards: 20 years<br>Earthen plaster: 15 years<br>Insulation layer: 50 years |
| END OF LIFE | C1: Deconstruction and demolition | For up to two story houses, buildings will be demolished with diggers and caterpillars.<br>For multi-family houses there are no examples yet, as these buildings are very modern. Standard timber façade elements don't allow for future reuse. They often use connections that are difficult to disassemble, which means that the facade has to be cut in parts. The salvaged sections can only be recycled. | Due to the reversible connections the façade can be disassembled in reverse order to the assembly process. It is anticipated that the element can either be fully reused or that parts of it can be reused or recycled. The deconstruction of RE[4] panel will be included many manual operations in order to avoid damage and compromise the integrity of each layer. |
| | C2: Transport | Distance of 200 km by truck | Distance of 50 km by truck |
| | C3: Waste processing | NI[11] | Waste processing for reuse: The panel can either be reused in full or complete separation of all components for further |

11 The panel might be used for thermal recovery.

| | | | |
|---|---|---|---|
| | | | reuse or recycling so that no waste occurs. |
| | C4: Disposal | After 50 years, the façade element will either go to energetic recovery or 100 % landfilling without further processing (After 50 years) | After 100 years |
| BENEFITS | D: Reuse, Recovery, Recycling Potential | NI | One of the innovative features of the RE4 element is its capability to be reused thus further contributing to the minimize both the waste disposal and the virgin materials consumption. |

### 3.3.5 Limitations

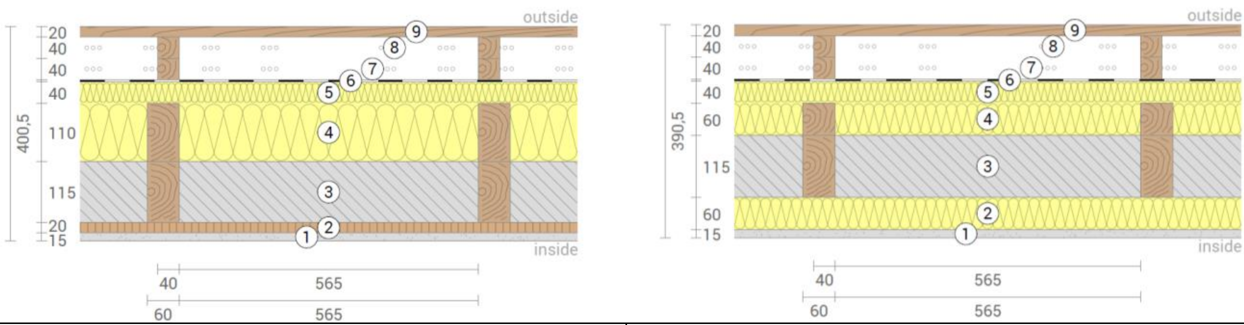
No limitation.

### 3.3.6 Data quality requirements

The LCA of wooden façade panels will be modelled by using primary data and EcoInvent 3.0 datasets. Primary data will be provided by RE4 partners or will be collected through interviews to producers and main stakeholders.

## 3.4 Timber façade panel for warm climate

### 3.4.1 Conventional and RE[4] timber façade panel overview




| (a) | (b) |
|---|---|

Timber façade panels, layers details: (a) conventional timber façade panel; (b) RE[4] timber façade panel

Figure 4 – RE[4] timber façade panel (a) and conventional concrete façade (b) for warm climate

The layer composition of each solution are reported in the following tables (Table 9, Table 10, and Table 11). For the RE[4] timber panel two solutions are considered (Table 10, Table 11). Both proposals differ only regarding the solution for the insulation layer and the respective thickness, all other components have been kept the same. Solution one will consider an insulation layer composed of a wood fibre insulation made from recycled timber and earth blocks, the latter have been included to provide additional thermal mass (RE[4] panel 1a). The second proposal suggests solely the usage of the wood fibre insulation made from recycled timber (RE[4] panel 1b). Although additional investigation regarding the protection against overheating of both solutions are required, it will be very beneficial to understand the environmental impact of both proposals and potential differences.

**Table 9 – Conventional timber façade panel, layer composition**

| | Layer | Thickness (mm) | Composition |
|---|---|---|---|
| 1 | Mineral earth plaster | 15 | Clayey soil (up to 5 mm), mixed corn washed or broken sand (0 – 2.8 mm) |
| 2 | OSB/3 | 20 | Wood content, approx. 90% (predominantly wood species pine,<br>partially PEFC or FSC-certified)<br>• Adhesive, PUR resin (MDI-Basis) 2 - 4 %<br>• Water in the form of wood moisture 4 - 6%<br>• wax emulsion <1% |
| 3 | Earth blocks 1500 kg/m³ | 115 | Clayey soil |
| 4 | Cellulose blow in insulation (89%) | 110 | Cellulose fibres |
| 3/4 | Timber studs (11%) | (225) | Timber studs (except fasteners); spruce 6 x 22.5 cm |
| 3/4a | Timber frame beam (top) | | Timber studs (except fasteners); spruce 6 x 22.5 cm |
| 3/4b | Timber frame beam (sleeper) | | Timber studs (except fasteners); spruce 10 x 22.5 cm |
| 5 | Wood fibre board | 40 | 97% wooden fibres (conifer wood) 3% binder (i.e. polymers diphenylmethane + paraffin), Commercial product |
| 6 | Breather membrane sd=0.5 | 0.05 | 3-layered membrane, made of tear-resistant, |

| | | | |
|---|---|---|---|
| | | | vapour permeable PP spunbonded film |
| 7 | Rear ventilated level | 40 | 40 mm x 40 mm spruce battens |
| 8 | Rear ventilated level | 40 | 40 mm x 40 mm spruce battens |
| 9 | Larch | 20 | 100% timber battens (except fasteners) |
| Total | | 400 | |

**Table 10 – 1a RE⁴ timber façade panel for warm climate, layer composition**

| | Layer | Thickness (mm) | Composition |
|---|---|---|---|
| 1 | RE⁴ CDW Earthen Plaster | 15 | Clayey soil (up to 5 mm, commercial product), CDW sand 0 – 2 mm (mixing ration 1:2, (per volume)) |
| 2 | Wood fibre board | 60 | 95% wooden fibres from CDW, 5% binder. Or only wooden fibres from CDW (wetting and pressing the fibres in order to ensure the isolation function) Commercial product |
| 3 | Earth blocks 1500 kg/m³ | 115 | The whole Insulation layer is composed by: a wood fibre insulation ("RE⁴ wood fibre insulation")made from recycled timber and earth blocks ("Earth blocks 1500 kg/m³"- Commercial product). The blocks have been included to provide additional thermal mass. |
| 4 | RE⁴ wood fibre insulation (89%) | 60 | |
| 3/4 | Timber studs (11%) | 175 | 100% CDW timber studs (except fixage); 6 x 17.5 cm |
| 3/4a | Timber frame beam (top) | | Timber studs (except fasteners); spruce 6 x 17.5 cm |
| 3/4b | Timber frame beam (sleeper) | | Timber studs (except fasteners); spruce 10 x 17.5 cm |
| 5 | Wood fibre board | 40 | 97% wooden fibres and 3% binder (i.e. polymers diphenylmethane + paraffin), Commercial product |
| 6 | Breather membrane sd=0.5 | 0.05 | 3-layered membrane, made of tear-resistant, vapour permeable PP spunbonded film Commercial product |
| 7 | Rear ventilated level | 40 | 40 mm x 40 mm RE⁴ CDW spruce battens |
| 8 | Rear ventilated level | 40 | 40 mm x 40 mm RE⁴ CDW spruce battens |
| 9 | Larch | 20 | 100% timber battens from RE⁴ CDW (except fixage) |
| Total | | 390 | |

**Table 11 – 1b RE⁴ timber façade panel for warm climate, layer composition**

| | Layer | Thickness (mm) | Composition |
|---|---|---|---|
| 1 | RE⁴ CDW Earthen Plaster | 15 | Clayey soil (up to 5 mm, commercial product), CDW sand 0 – 2 mm (mixing ration 1:2, (per volume)) |
| 2 | Wood fibre board | 40 | 95% wooden fibres from CDW, 5% binder. Or only wooden fibres from CDW (wetting and pressing the fibres in order to ensure the isolation function) Commercial product |
| 3 | RE⁴ wood fibre insulation (89%) | 100 | Wood fibre insulation made from recycled timber |
| 4 | Timber studs (11%) | 100 | 100% CDW timber studs (except fixage); 6 x 10 cm |
| 3/4a | Timber frame beam (top) | | Timber studs (except fasteners); spruce 6 x 10cm |

| | | | |
|---|---|---|---|
| 3/4b | Timber frame beam (sleeper) | | Timber studs (except fasteners); spruce 10 x 10 cm |
| 5 | Wood fibre board | 40 | 97% wooden fibres and 3% binder (i.e. polymers diphenylmethane + paraffin),<br>Commercial product |
| 6 | Breather membrane sd=0.5 | 0.05 | 3-layered membrane, made of tear-resistant, vapour permeable PP spunbonded film<br>Commercial product |
| 7 | Rear ventilated level | 40 | 40 mm x 40 mm RE[4] CDW spruce battens |
| 8 | Rear ventilated level | 40 | 40 mm x 40 mm RE[4] CDW spruce battens |
| 9 | Larch | 20 | 100% timber battens from RE[4] CDW (except fixage) |
| Total | | 300 | |

### 3.4.2 Functional units ($m^2$ element + building physical characteristically functions)

***Functional unit: $m^2$ of elements with the same thermal transmittance (U-value): 0.25 $W/m^2K$.***

The U-value for panels has been determined according to the relationship defined in section 3.3.2. considering the target values for Spain, that represents the demonstrator site for warm climate scenario. All panels have been designed in order to guarantee this thermal performance.

### 3.4.3 Service life

The typical timber facade panel life is assumed to be the life of the building or 50+ years. For the purpose of this study, 50 years of use is assumed for conventional panel and over 50 years of use is assumed for RE[4] panel. The RE[4] panel is reused after its first service life for other 50 years or disassembled in its components to be reused. Considering that the two panels have a different lifetime, the environmental impacts will be presented as [impact/$m^2$*year][12]

### 3.4.4 System boundaries

The sustainability assessment of both panels will include the following phases:

- manufacturing (modules A1; A3), panel installation (A5) and replacement operations (B4);
- deconstruction of the panel (C1), the transport of the panel to the landfill site or the recycling plant (module C2) as well as the End of Life of panel.
- For both panels, two different scenario for the EOL are considered:
  Conventional: Landfilling (C4). The conventional panel is assumed to be landfilled after 50 years of service life based on actual practices.
  RE[4] Panel: It is assumed that through reversible connections between the structural support system and the façade panel the panel can be taken without causing any damages to the element. Scenario one therefore assumes that a complete reuse of the panel is possible. RE[4] panel is assumed to be reused in other product system after 50 years of service life. Therefore, waste processing (module C3) is included in the system boundary of the analysed product system. Reuse of the RE[4] panel is considered as credits allocated to this panel by

[12] $m^2$ of the panel is the function unit of the analysis as defined in section 3.4.2

considering 100 years of service life for this panel. RE4 panel is assumed to be landfilled after 100 years of service life (C4)[13].

Modules A2 and A4 are excluded from the analysis since not reliable data have been provided. Accordingly, the analysis is a cradle-to-grave.
For both panel, each phase is described in Table 12, pointing out the main differences and similarities.

**Table 12 – Description of main differences and similarities**

| Module | Sub-Module | Conventional timber façade panel | RE4 timber façade panel |
|---|---|---|---|
| PRODUCTION | A1: Supply of raw materials | All solid timber components (weatherboard, studs) are taken from virgin material. Wood fibre boards and OSB boards might obtain materials from saw mills, which can then be classified as secondary raw material. Earthen plaster is taken from virgin material (clayey soil and sand). | In the RE4 timber façade panel, timber studs, top and bottom plate and the weatherboards are made out of recycled or reused timber. Wood fibre boards and wood fibre insulation are also made from recycled timber.<br>For the RE4 panel wood fibre based components are not actually manufactured within the consortium.<br>Timber has been obtained from different construction sites, where timber roofs have been dismantled. Timber elements have been brought down by means of a winch etc.<br>RE4 earth plaster is made from CDW sand and virgin clayey soil (binder).<br>Two different insulation layers will be included in the analysis: in the 1a RE4 panel is composed of a wood fibre insulation made from recycled timber and earth blocks, in the 1b RE4 panel is composed of wood fibre insulation made from recycled timber. |

13 In case that e.g. the weatherboarding has reached its end of life or the performance of the insulation is not sufficient any longer, the panel itself can be fully dismantled and functioning parts can be reused in another construction. As timber enables a cascading use it is assumed that the weather boards can be recycled and used as insulation material. For the insulation material it is likely that the material will be burned or used for compost, in case no artificial binder has been used.

| | | | |
|---|---|---|---|
| | A2: Transport of raw materials | NI | NI |
| | A3: Manufacturing | Timber will be cut in the forest and processed by saw mills. From there the processed timber will be brought into composite lumber plant, where the timber is further processed to gluam timber.<br>Wood fibre boards and wood fibre insulation mats are manufactured by other manufacturers using secondary raw materials from saw mills.<br>Additional materials are sarking membrane and screws and other metal fittings.<br>The final prefabricated panel will be assembled by carpenters in a carpenter's workshop, using screws and other fasteners. Reversible connections are not necessarily carried out.<br>Earthen plaster will be applied on site. | Timber will be assessed against the occurrence of wood preservatives. If no wood preservatives or other harmful substances or fungies are found, beams, columns and flooring boards will be dismantled from existing buildings.<br>The harvested material will be brought to a saw mill investigated with regards to fittings, cleaned, planed and cut into lamellas.<br>The final prefabricated panel will be assembled by carpenters in a carpenter's workshop, using screws and other fasteners to enable reversible connections[14].<br>Earth plaster will be applied in the workshop. Only a final thin coat will be applied on site. |
| CONSTRUCTION | A4: Transport to building site | NI | NI |
| | A5: Installation/Construction [15] | The installation process is similar in both panels. | The installation process is similar in both panels. However, for the RE$^4$ panel the installation will be slightly more time consuming as reversible connections will be realised. |
| USE STAGE[16] | B4: Replace[17] | The weatherboards are protecting the main body of the panel against environmental impact through the weather. In case these boards do show defects, they can be dismantled and replaced. The internal earthen plaster, covering the board from the inside, can be wettened and reworked or replaced, in case this layer shows any defects. In the unlikely case, | The weatherboards are protecting the main body of the panel against environmental impact through the weather. In case these boards do show defects, they can be dismantled and replaced. The internal earthen plaster, covering the board from the inside, can be wettened and reworked or |

14 https://www.halfen.com/en/781/product-ranges/construction/industrial-technology/halfen-framing-channels-and-halfen-t-bolts/introduction/
15 This phase differs only for the materials used (reversible connections for fixing the RE$^4$ panel against the support structure)
16 The general maintenance/replace procedure should be equal for both panels. However the panel's layers to be replaced in both configurations are different for the materials used. Moreover, In case of repair, the RE$^4$ panel can be easily repaired, as connections are reversible..
17 The number of the replacement of layers in both panels will be different because of the different considered lifetime.

| | | | |
|---|---|---|---|
| | | that the insulation layer demonstrates any defects, the weatherboards, battens and counter battens and the wood fibre board can be dismantled so that the insulation layer can be replaced. Likewise the entire panels could be dismantled and taken down, in order to replace the insulation layer on ground.<br><br>Replaced Frequency:<br>Entire panel: 50 years<br>Weatherboards: 20 years<br>Earthen plaster: 15 years<br>Insulation layer: 50 years | replaced, in case this layer shows any defects. In the unlikely case, that the insulation layer demonstrates any defects, the weatherboards, battens and counter battens and the wood fibre board can be dismantled so that the insulation layer can be replaced. Likewise the entire panels could be dismantled and taken down, in order to replace the insulation layer on ground.<br><br>Replaced Frequency:<br>Entire panel: 50+ years<br>Weatherboards: 20 years<br>Earthen plaster: 15 years<br>Insulation layer: 50 years |
| END OF LIFE | C1: Deconstruction and demolition | For up to two story houses, buildings will be demolished with diggers and caterpillars.<br>For multi-family houses there are no examples yet, as these buildings are very modern. Standard timber façade elements don't allow for future reuse. They often use connections that are difficult to disassemble, which means that the facade has to be cut in parts. The salvaged sections can only be recycled. | Due to the reversible connections the façade can be disassembled in reverse order to the assembly process. It is anticipated that the element can either be fully reused or that parts of it can be reused or recycled. |
| | C2: Transport | Distance of 200 km by truck | Distance of 50 km by truck |
| | C3: Waste processing | NI [18] | Waste processing for reuse: The panel can either be reused in full or complete separation of all components for further reuse or recycling so that no waste occurs. |
| | C4: Disposal | After 50 years, the façade element will either go to energetic recovery or 100 % landfilling without further processing. | After 100 years |

[18] The panel might be used for thermal recovery.

| | | | |
|---|---|---|---|
| BENEFITS | D: Reuse, Recovery, Recycling Potential | NI | One of the innovative features of the RE$^4$ element is its capability to be reused thus further contributing to the minimize both the waste disposal and the virgin materials consumption. |

### **3.4.5** Limitations

No limitations.

### **3.4.6** Data quality requirements

The LCA of wooden façade panels will be modelled by using primary data and EcoInvent v3.0 datasets.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723583

## 3.5 Concrete façade panel for cold climate

### 3.5.1 Conventional and RE4 load bearing concrete façade panel overview

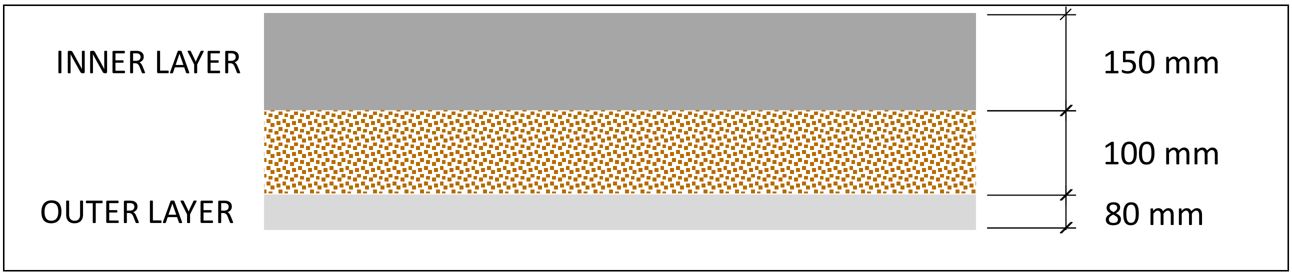



**Figure 5 – Dimensions of concrete façade panel for cold climate**

The layer configuration of conventional and RE4 concrete panels are reported in Table 13, Table 14, respectively. In more details, RE4 concrete façade panel and conventional concrete façade panel have the same layer composition but they are made by different materials (recycled vs virgin materials).

**Table 13 – Conventional concrete façade panel, layer composition**

| | Layer | Thickness (mm) | Composition |
|---|---|---|---|
| Inner | Concrete | 150 | Concrete C40/50 |
| Insulation | PE-PIR | 100 | (λ = 0.022, density 30 kg/m$^3$) |
| Outer | Concrete | 80 | Concrete C40/50 |
| Total | | 330 | |

**Table 14 – RE4 concrete façade panel**

| | Layer | Thickness (mm) | Composition |
|---|---|---|---|
| Inner | Concrete | 150 | SCC CDW concrete (C40/50) |
| Insulation | PE-PIR | 100 | (λ = 0.022, density 30 kg/m$^3$) |
| Outer | Concrete | 80 | SCC CCDW concrete (C40/50) |
| Total | | 330 | |

### 3.5.2 Functional units (m$^2$ element + building physical characteristically functions)

***Functional unit: m$^2$ of elements with the same thermal transmittance (U-value): 0,21 W/m$^2$K***.
The U-value for panels has been determined according to the relationship defined in section 3.3.2, considering the target values for Ireland that represents the demonstrator site for cold climate scenario. All panels have been designed in order to guarantee this thermal performance (

Table 15, Table 16).

**Table 15 – Conventional concrete façade panel, U value calculation**

| | Layer | Tickness (mm) | λ (W/mK) | R (m² K/W) | Weight (kg/m²) | U [W/m²K] |
|---|---|---|---|---|---|---|
| $R_{SI}$ | | | | 0.13 | | |
| 1 | Inner layer: concrete | 150 | 2.3 | 0.065 | 375 | |
| 2 | Insulation: PE-PIR | 100 | 0.022 | 4,545 | 4.5 | **0.207** |
| 3 | Outer layer: concrete | 80 | 2.3 | 0.035 | 75 | |
| $R_{SE}$ | | | | 0.04 | | |
| **Total** | | **330** | | **4.815** | **454.5** | |

**Table 16 – RE[4] concrete façade panel, U value calculation**

| | Layer | Thickness (mm) | λ (W/mK) | R (m² K/W) | Weight (kg/m²) | U [W/m²K] |
|---|---|---|---|---|---|---|
| $R_{SI}$ | | | | 0.13 | | |
| 1 | Inner layer: SCC CDW concrete | 150 | 2.3 | 0.065 | 375 | |
| 2 | Insulation: PE-PIR | 100 | 0.022 | 4.545 | 4.5 | **0.207** |
| 3 | Outer layer: mix with CEM I 42.5 | 80 | 2.3 | 0.035 | 75 | |
| $R_{SE}$ | | | | 0.04 | | |
| **Total** | | **330** | | **4.815** | **454.5** | |

### 3.5.3 Service life

The typical concrete facade panel life is assumed to be the life of the building or 50+ years. For the purpose of this study, the default assessment, for conventional panel is conducted 50 years of use and for RE[4] panel is over 50 years of use. The RE[4] panel is assumed to be reused after its first service life. Considering that the two panels have a different lifetime, the environmental impacts will be presented per year for the considered functional unit [19] [impact/(m²*year)].

### 3.5.4 System boundaries

The sustainability assessment of both panels will include the following phase:

- manufacturing (modules A1-A3);
- deconstruction of the panel (C1), as well as the End of Life of panel. For both panels, two different scenarios for the EOL are considered:
  - Conventional: Landfilling (C4). The conventional panel is assumed to be landfilled after 50 years of service life based on actual practices.

[19] m² of the panel is the function unit of the analysis as defined in section 3.5.2

- RE$^4$: Reuse of RE$^4$ panel. RE$^4$ panel is assumed to be reused in other product system after 50 years of service life for 50 years more. Therefore, waste processing (module C3) is included in the system boundary of the analysed product system. Reuse of the RE$^4$ panel is considered as credits allocated to this panel by considering 100 years of service life for this panel. RE$^4$ panel is assumed to be landfilled after 100 years of service life.

The transportation of the panels to the construction site (A4), installation of the panels (A5),the Use phase (Module B) and transportation to waste processing / disposal site (C2) are excluded from the analysis since it is equal for both panels, causing the same impacts. Accordingly, the analysis is a cradle-to-gate with options according to EN15804[20]. For both panel, each phase is described in Table 17, pointing out the main differences and similarities.

**Table 17 – Description of main differences and similarities**

| Module | Sub-Module | Conventional concrete façade panel (cold climate) | RE$^4$ concrete façade panel (cold climate) |
|---|---|---|---|
| PRODUCTION | A1: Supply of raw materials | The mix design of the inner and outer layers of the sandwich panel includes virgin materials. | Recycled aggregates produced with CDW are used as aggregates in the mix design of the inner and outer layers of the sandwich panel (inputs from WP5/6)<br>The innovative sorting system for CWD recycling, developed in the framework of WP2, will be included in this module. |
| | A2: Transport of raw materials | Different transportation distances for different materials (in Module A1) | Different transportation distances for different materials (in Module A1) |
| | A3: Manufacturing | manufacturing of the conventional concrete façade panel in the factory | Manufacturing of RE$^4$ panel in the factory mainly |
| | A4: transport to building site | NI | |
| | A5: Installation/Construction | NI | |
| USE STAGE | | NI | |
| END OF LIFE | C1: Deconstruction and demolition | Conventional demolition | Selective demolition |
| | C2: Transport | NI | |
| | C3: Waste processing | NI | Waste processing for reuse |
| | C4: Disposal | 100 % landfilling of concrete façade panel is assumed without further processing after the first service life (after 50 years) | After 100 years |
| BENEFITS | D: Reuse, Recovery, Recycling Potential | NI | Reuse of all components |

[20] Cradle to gate: A1-A3 modules;
Cradle to gate with options: A1-A3 modules plus any other modules;
Cradle to grave: all life cycle stages

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723583

### 3.5.5 Limitations

No limitations

### 3.5.6 Data quality requirements

The LCA of concrete façade panels will be modelled by using primary data and Ecoinvent v3.datasets.

## 3.6 Concrete façade panel for warm climate

### 3.6.1 Conventional and RE4 non-load bearing concrete façade panel overview

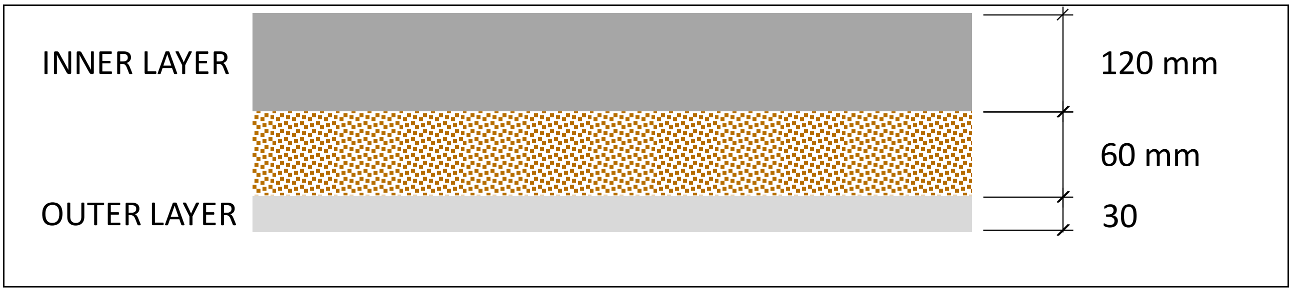



**Figure 6 – Dimensions of RE4 concrete façade panel for warm climate**

The layer configuration of conventional and RE4 concrete panels are reported in Table 19, Table 18, respectively. The inner and outer layers of conventional sandwich panel are usually thicker than innovative one (RE4 panel), as the outer layer of the RE4 panel is HPC.

**Table 18 – Conventional concrete façade panel, layer composition**

| | Layer | Thickness (mm) | Composition |
|---|---|---|---|
| Inner | Concrete | 150 | Concrete C40/50 |
| Insulation | PE-PIR | 60 | (λ = 0.022, density 30 kg/m$^3$) |
| Outer | Self-standing | 80 | Concrete C40/50 |
| Total | | 290 | |

**Table 19 – RE4 concrete façade panel, layer composition**

| | Layer | Thickness (mm) | Composition |
|---|---|---|---|
| Inner | Concrete | 120 | SCC CDW concrete (C40/50) |
| Insulation | PE-PIR | 60 | (λ = 0.022, density 30 kg/m$^3$) |
| Outer | Self-standing | 40 | HPC C60/C75 |
| Total | | 220 | |

### 3.6.2 Functional units (m$^2$ element + building physical characteristically functions)

***Functional unit: m$^2$ of elements with the same thermal transmittance (U-value): 0,34 W/m$^2$K.***

The U-value for panels has been determined according to the relationship defined in section 3.3.2, considering the target values for Spain that represents the demonstrator site for warm climate scenario. All panels have been designed in order to guarantee this thermal performance (Table 20, Table 21).

**Table 20 – Conventional concrete façade panel, U value calculation**

| | Layer | Tickness (mm) | λ (W/mK) | R ($m^2$ K/W) | Weight (kg/$m^2$) | U [W/$m^2$K] |
|---|---|---|---|---|---|---|
| $R_{SI}$ | | | | 0.13 | | |
| 1 | Inner layer: concrete | 120 | 2.3 | 0.052 | 375 | |
| 2 | Insulation: PE-PIR | 60 | 0.022 | 2.72 | 1.8 | |
| 3 | Outer layer: concrete | 40 | 2.3 | 0.017 | 75 | **0.3389** |
| $R_{SE}$ | | | | 0.04 | | |
| **Total** | | **210** | | **2.95** | **451.8** | |

**Table 21 – RE4 concrete façade panel, U value calculation**

| | Layer | Thickness (mm) | λ (W/mK) | R ($m^2$ K/W) | Weight (kg/$m^2$) | U [W/$m^2$K] |
|---|---|---|---|---|---|---|
| $R_{SI}$ | | | | 0.13 | | |
| 1 | Inner layer: SCC CDW concrete | 120 | 2.3 | 0.0652 | 375 | |
| 2 | Insulation: PE-PIR | 60 | 0.022 | 2.72 | 1.8 | |
| 3 | Outer layer: mix with CEM I 42.5 | 80 | 2.3 | 0.0347 | 75 | **0.3344** |
| $R_{SE}$ | | | | 0.04 | | |
| **Total** | | **210** | | **2.98** | **451.8** | |

### 3.6.3 Service life

The typical concrete facade panel life is assumed to be the life of the building or 50+ years. For the purpose of this study, the default assessment, for conventional panel is conducted 50 years of use and for RE4 panel is over 50 years of use. The RE4 panel is assumed to be reused after its first service life. Considering that the two panels have a different lifetime, the environmental impacts will be presented per year for the considered functional unit [21] [impact/($m^2$*year)].

### 3.6.4 System boundaries

The sustainability assessment of both panels will include the following phase:

- manufacturing (modules A1-A3);
- deconstruction of the panel (C1), as well as the End of Life of panel. For both panels, two different scenarios for the EOL are considered:

[21] $m^2$ of the panel is the function unit of the analysis as defined in section 3.5.2

Conventional: Landfilling (C4). The conventional panel is assumed to be landfilled after 50 years of service life based on actual practices.
RE$^4$: Reuse of RE$^4$ panel. RE$^4$ panel is assumed to be reused in other product system after 50 years of service life for 50 years more. Therefore, waste processing (module C3) is included in the system boundary of the analysed product system. Reuse of the RE$^4$ panel is considered as credits allocated to this panel by considering 100 years of service life for this panel. RE$^4$ panel is assumed to be landfilled after 100 years of service life (C4).

The transportation of the panels to the construction site (A4), installation of the panels (A5), the Use phase (Module B) and transportation to waste processing/ disposal site (C2) are excluded from the analysis since it is equal for both panels, causing the same impacts. Accordingly, the analysis is a cradle-to-gate with options according to EN 15804. For both panels, each phase is described in Table 22, pointing out the main differences and similarities.

**Table 22 – Description of main differences and similarities**

| Module | Sub-Module | Conventional concrete façade panel (warm climate) | RE$^4$ concrete façade panel (warm climate) |
|---|---|---|---|
| PRODUCTION | A1: Supply of raw materials | The mix design of the inner and outer layers of the sandwich panel includes virgin materials. | Recycled aggregates recycled from CDW are used as aggregates in the mix design of the inner and outer layers of the sandwich panel (inputs from WP5/6)<br>The innovative sorting system for CWD recycling, developed in the framework of WP2, will be included in this module. |
| | A2: Transport of raw materials | Different transportation distances for different materials (in Module A1) | Different transportation distances for different materials (in Module A1) |
| | A3: Manufacturing | Manufacturing of the conventional concrete façade panel in the factory | manufacturing of RE$^4$ concrete façade panel in the factory |
| CONSTRUCTION | A4: Transport to building site | NI | |
| | A5: Installation/Construction | NI | |
| USE STAGE | | NI | |
| END OF LIFE | C1: Deconstruction and demolition | Conventional demolition | Selective demolition |
| | C2: Transport | NI | |
| | C3: Waste processing | Not included/expected | Waste processing for reuse |
| | C4: Disposal | 100 % landfilling of concrete façade panel is assumed without further processing after the first service life (after 50 years) | After 100 years |
| BENEFITS | D: Reuse, Recovery, Recycling Potential | NI | Reuse of all components |

### 3.6.5 Limitations

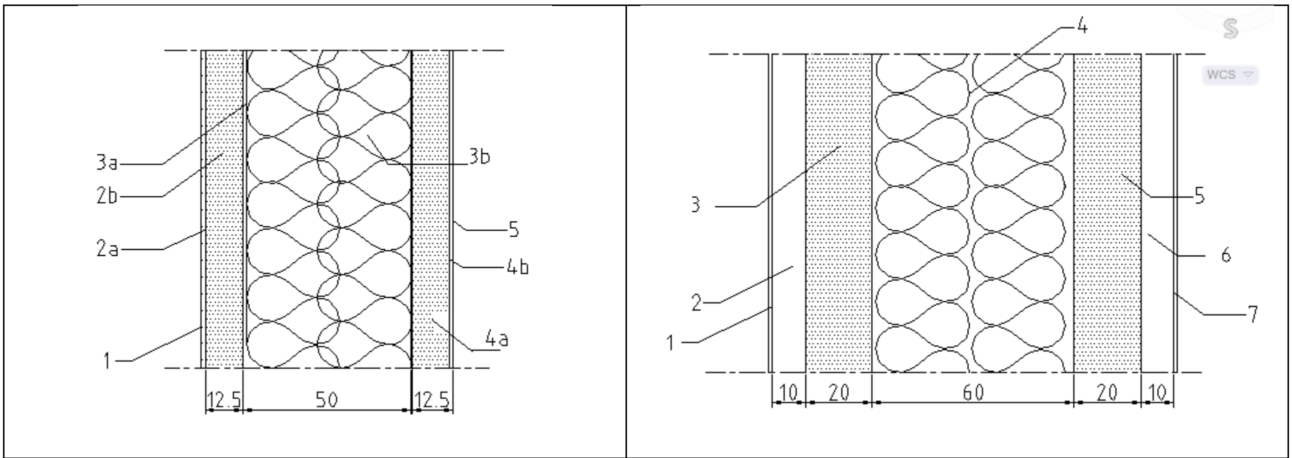
No limitations.

### 3.6.6 Data quality requirements

The LCA of concrete façade panels will be modelled by using primary data and Ecoinvent v3.0 datasets.

## 3.7 Prefabricated internal partition wall system

### 3.7.1 Conventional and RE⁴ internal partition wall system




| (a) | (b) |
|---|---|
| Internal partition wall system, layers details: (a) conventional internal partition; (b) RE4 internal partition | |

**Figure 7 – Compared prefabricated internal partition wall system**

The layer composition of both wall systems are reported in the following

Table 23 and Table 24.

**Table 23 - Conventional internal partition wall system panel, layer composition**

| | Layer | Thickness (mm) | Composition |
|---|---|---|---|
| 1 | Dispersion paint | 1 | Binder (polystyrene) acrylate / potassium silicate), titanium dioxide, Silicates, water, additives |
| 2a | Primer | 2 | > 95% mineral components, water, <5% of organic excipients / dispersion powder |
| 2b | Gypsum plaster board | 12,5 | Stucco and additives for the gypsum core (including starch and foaming agent), high-quality, multiple cardboard |

| | | | |
|---|---|---|---|
| | | | Boards are fixed to metal stud with dry wall screws, 3.5 x 25 mm |
| 3a | Metal stud, U-Type, 75 mm, distance = 62,5 cm and for connection to floor & ceiling | 50 | Steel stud, U-type section |
| 3b | Mineral / glass wool | | Glass wool production: shards (40 mass%), Sand (20 mass%), Soda, borax, phonolite and dolomite (approx. 510 mass%). up to 8% binder (based on urea-modified phenol-formaldehyde resin) |
| 4a | Gypsum plaster board | 12,5 | Stucco and additives for the gypsum core (including starch and foaming agent), high-quality, multiple cardboard Boards are fixed to metal stud with dry wall screws, 3.5 x 25 mm |
| 4b | Primer | 2 | > 95% mineral components, water, <5% of organic excipients / dispersion powder |
| 5 | Dispersion paint | 1 | Binder (polystyrene) acrylate / potassium silicate), titanium dioxide, Silicates, water, additives |
| Total | | 81 | |

**Table 24 – RE[4] internal partition wall system panel, layer composition**

| | Layer | Thickness (mm) | Composition |
|---|---|---|---|
| 1 | Chalk paint | 1 | Marble hydrated lime, marble flour and sand, sintered water, methylcellulose, citric acid |
| 2 | RE[4] CDW Earthen Plaster | 10 | Clayey soil (up to 5 mm, commercial product), CDW sand 0 – 2 mm (mixing ration 1:2, (per volume)) |
| 3 | Wood fibre board | 20 | 95% wooden fibres from CDW, 5% binder. Or only wooden fibres from CDW (wetting and pressing the fibres in order to ensure the isolation function) Commercial product |
| 4a | Infill insulation sawdust+clay (91%) | 60 | 100% wooden fibres from the processing CDW timber, 100% clay from CDW recycling Ratio wood fibres to clay: 75% volume weight – 25 % volume weight |
| 4b | Timber studs (9%) | | 100% CDW timber studs (except fixage); |
| 5 | Wood fibre board | 20 | 95% wooden fibres from CDW, 5% binder. Or only wooden fibres from CDW (wetting and pressing the fibres in order to ensure the isolation function) Commercial product |
| 6 | RE[4] CDW Earthen Plaster | 10 | Clayey soil (up to 5 mm, commercial product), CDW sand 0 – 2 mm (mixing ration 1:2, (per volume)) |

| | | | |
|---|---|---|---|
| 7 | Chalk paint | 1 | Marble hydrated lime, marble flour and sand, sintered water, methylcellulose, citric acid |
| Total | | 122 | |

### 3.7.2 Functional units (m2 element + building physical characteristically functions)

***Functional unit:*** m$^2$ of elements with the purpose to separate two rooms and to provide a self-supporting structural system and comparable thermal and acoustic insulation performances Both wall system have been designed according to the fixed functional unit.

### 3.7.3 Service life

The typical prefabricated internal partition wall system life is assumed to be the life of the building or 50+ years. For the purpose of this study, 50 years of use is assumed for conventional panel and over 50 years of use for RE$^4$ panel. The RE$^4$ panel is assumed to be reused after its first service life for other 50 years. Considering that the two panels have a different lifetime, the environmental impacts will be presented as [impact/m$^2$*year] [22]

The typical concrete facade panel life is assumed to be the life of the building or 50+ years. For the purpose of this study,

### 3.7.4 System boundaries

The sustainability assessment of both panels will include the following phase:

- manufacturing (modules A1-A3) and the installation of the wall (A5);
- maintenance (B2) and replacement (B4) of wall;;
- deconstruction of the panel (C1), and-the End of Life of panel. For both panels, two different scenario for the EOL are considered:
  Conventional:  Landfilling (C4) after 50 years
  RE$^4$: Reuse RE$^4$ wall system. RE$^4$ wall system is assumed to be reused in other product system after 50 years of service life for others years. Therefore, waste processing (module C3) is included in the system boundary of the analysed product system. Reuse of the RE$^4$ system is considered as credits allocated to this wall by considering 100 years of service life. RE$^4$ wall system is assumed to be landfilled after 100 years of service life (C4).

Transports (i.e. Modules A2, A4 and C2) are excluded from the analysis since not reliable data have been provided. Accordingly, the analysis is a cradle-to-grave.
For both wall systems, each phase is described in Table 25, pointing out the main differences and similarities.

**Table 25 – Description of main differences and similarities**

| Module | Sub-Module | Conventional prefabricated internal partition wall | RE$^4$ prefabricated internal partition wall |
|---|---|---|---|

[22] m$^2$ of the panel is the function unit of the analysis as defined in section 3.4.2

| | | | |
|---|---|---|---|
| PRODUCTION | A1: Supply of raw materials | All components are supplied from virgin material. | In the RE⁴ production internal partition wall, the timber studs are obtained from the processing of timber CDW. Wood fibre boards and wood fibre insulation are also made from recycled timber. These components are not actually manufactured within the consortium. Timber has been obtained from different construction sites, where timber roofs have been dismantled. Timber elements have been brought down by means of a winch etc. RE⁴ earth plaster is made from CDW sand and virgin clayey soil (binder). |
| | A2: Transport of raw materials | NI | NI |
| | A3: Manufacturing | Installation of top track (steel U profile); tracks should be fastened to structural elements by using anchor bolt or fastener. Installation of bottom track (steel C profile); tracks should be fastened to structural elements by using anchor bolt or fastener; Installation of vertical starter studs (steel C profile); studs should be taken in direct contact with doors frame jambs, abutting partitions, partition corners/edges, and existing construction elements. Installation of intermediate vertical studs; studs to be installed at interval of 60 cm; The connections among the steel profiles is made by clinching connection. The wall steel frame is sheathed with gypsum panels on both sides (12, 5 mm). The connection between sheathing and steel profiles is made by 2 ballistic nails spaced at 150 mm both at the field and at the perimeter of the panels. The wall system is made of a stratified dry construction, where the insulation is provided by mineral wool. | Timber will be assessed against the occurrence of wood preservatives. If no wood preservatives or other harmful substances or funguses are found, beams, columns and flooring boards will be dismantled from existing buildings. The harvested material will be brought to a saw mill investigated with regards to fittings, cleaned, planed and cut into lamellas. Timber studs will be cut to size. Off cuts will be used for the production of wood fibre boards (although not carried out in the RE⁴ project). Wood fibre boards will be fixed against the studs and RE⁴ CDW earth plaster will be applied onto the boards to manufacturer a prefabricated element. Earth plaster will be applied in the workshop. Only a final thin coat will be applied on site. |

| | | | |
|---|---|---|---|
| | | Treatment of the various types of joints, edges and corners using acoustic sealant, corner beads, joint tapes, jointing compound and topping compound and external corner bead.<br>Final treatment to the external angle and to all joint treatment by applying three coats of joint compound.<br>Use of jointing tape for reinforcement of plasterboard recessed joints, internal angles, surface fractures and repairs to internal walls.<br>Final treatment of gypsum board applying fine plaster, which are sanded and then painted to achieve an even appearance | |
| CONSTRUCTION | A4: Transport to building site | NI | NI |
| | A5: Installation/Construction | Single components will be brought to site and assembled manually.<br>Metal studs are fixed against floor and ceiling. Mineral wool will be placed between the studs and gypsum plaster boards will be screwed against these studs. The boards will be fillered and painted. | Timber support battens will be fixed to floor and ceiling. The prefab internal partition wall elements will be fixed to this support structure and plastered with a 2 mm finish earthen plaster. |
| USE STAGE | B2: Maintenance | Wall will be repainted every 3 - 7 years[23] | No maintenance is required due to the durability of the earth plaster. |
| | B4: Replace | Replaced Frequencies:<br>Entire panel: 50 years<br>Earthen plaster: 15 years | Replaced Frequencies:<br>Entire panel: 50 years +<br>Earthen plaster: 15 years |
| END OF LIFE | C1: Deconstruction and demolition | Internal partition walls will be demolished. | Prefabricated and fully reversible RE[4] internal partition walls will be fully dismantled and can either be reused or parts can be disassembled and reused or recycled. |
| | C2: Transport | NI | NI |
| | C3: Waste processing | NI | Waste processing for reuse |
| | C4: Disposal | After 50 years, 100 % landfilling of gypsum plaster board[24] and mineral wool. | After 100 years |
| BENEFITS | D: Reuse, Recovery, Recycling Potential | NI | Reuse of all components |

[23] In Germany tenants are obliged to repaint kitchen, living rooms every 3 years and bathrooms and bedrooms every 7 years.

[24] Gypsum has to be landfilled on special landfills that have a special waterproofing as the contained sulphate is damaging the environment.

### 3.7.5 Limitations

No limitations.

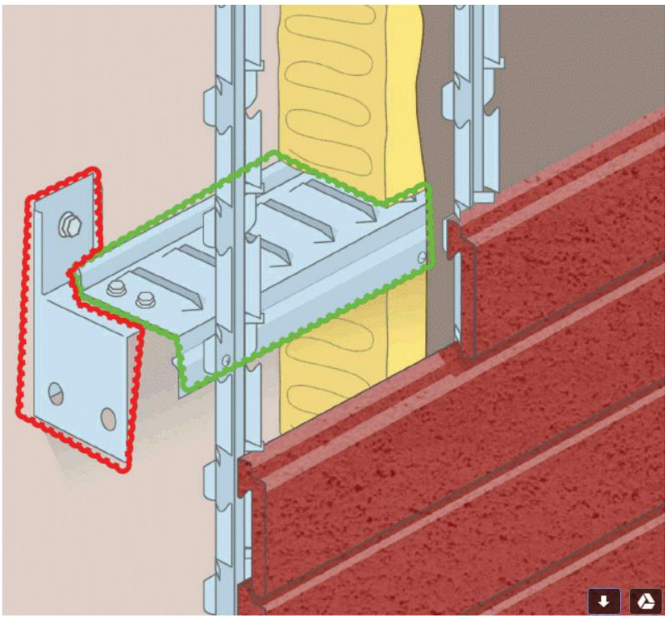
### 3.7.6 Data quality requirements

The LCA of internal partition wall systems will be modelled by using primary data and Ecoinvent v3.0 datasets.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723583

## 3.8 Ventilated façade for refurbishment (warm climate)

### 3.8.1 Conventional and RE[4] ventilated façade for refurbishment (warm climate)



| (a) | (b) |
|---|---|

Ventilated facade solution, layers details: (a) conventional ventilated façade solution; (b) RE[4] ventilated façade solution

**Figure 8 – Compared ventilated façade for refurbishment**

The layers composition of both façade panels are reported in the following Table 26,

Table 27. As can be seen they differ only for the materials used in the insulation and outer layers. Therefore, they are compared in terms of insulation and the outer layer.

**Table 26 – Conventional ventilated façade panel, layer composition**

| | Layer | Thickness (mm) | Composition |
|---|---|---|---|
| 1 | Plasterboard | 15 | Plasterboard |
| 2 | Concrete block | 100 | Concrete |
| 3 | Insulation: PE-PIR | 45 | PE-PIR insulation |
| 4 | Outer layer: Vortex structure | | Limestone/marble, cement, water, pigment iron oxide based, soap lime, 5 hot dip galvanized steel sheets |

**Table 27 – RE4 ventilated façade panel, layer composition**

| | Layer | Thickness (mm) | Composition |
|---|---|---|---|
| 1 | Plasterboard | 15 | Plasterboard |
| 2 | Inner layer: existing wall warm climate | 100 | Concrete |
| 3 | Insulation: wood fibre | 130 | Wood insulation |
| 4 | Outer layer: Vortex structure | | Recycled sand, cement, water, pigment iron oxide based, soap lime, 5 hot dip galvanized steel sheets |

### **3.8.2** Functional units ($m^2$ element + building physical characteristically functions)

***Functional unit: m² of elements with the same thermal transmittance (U-value): 0,34 W/m²K.***

The U-value for façade panels has been determined according to the relationship defined in section 3.3.2, considering the target values for Italy (Benevento) that represents the demonstrator site for warm climate scenario. All façade panels have been designed in order to guarantee this thermal performance (Table 28, Table 29).

**Table 28 – Conventional ventilated façade panel, U value calculation**

| | Layer | Tickness (mm) | λ (W/mk) | R ($m^2$ K/W) | U [$W/m^2K$] |
|---|---|---|---|---|---|
| $R_{SI}$ | | | | 0.13 | **0.34** |
| 1 | Plasterboard | 15 | 0.9 | 0.01 | |
| 2 | Concrete block | 100 | 0.116 | 0.86 | |
| 3 | Insulation: PE-PIR | 45 | 0.024 | 1.87 | |
| 4 | Outer layer: Vortex structure | | | | |
| $R_{SE}$ | | | | 0,04 | |
| **Total** | | | | **2.91** | |

**Table 29 – RE4 ventilated façade panel, U value calculation**

| | Layer | Thickness (mm) | λ (W/mk) | R ($m^2$ K/W) | U [$W/m^2K$] |
|---|---|---|---|---|---|
| $R_{SI}$ | | | | 0,13 | **0.34** |
| 1 | Plasterboard | 15 | 0.9 | 0.01 | |
| 2 | Inner layer: existing wall warm climate | 100 | 0.116 | 0.86 | |
| 3 | Insulation: wood fibre | 130 | 0.07 | 1.85 | |
| 4 | Outer layer: Vortex structure | | | | |
| $R_{SE}$ | | | | 0.04 | |
| **Total** | | | | **2.89** | |

### 3.8.3 Service life

It is assumed that the service life of ventilated façade panel is 50 years. The insulation layer is changed, and the outer layer is refurbished after 50 years.

### 3.8.4 System boundaries

The sustainability assessment of both panels will include the following phase:

- manufacturing (Modules A1-A3)

The transportation of the panels to the construction site (A4), the installation of the panels (A5), the Use phase (Module B) and end of life (Module C) are excluded from the analysis since they are equal for both panels, causing the same impacts. Accordingly, the analysis is a cradle-to-gate according to EN 15804.

For both ventilated façade panels, each phase is described in Table 30, pointing out the main differences and similarities.

**Table 30 – Description of main differences and similarities**

| Module | Sub-Module | Conventional ventilated façade for refurbishment (warm climate) | RE4 ventilated façade for refurbishment (cold climate) |
|---|---|---|---|
| PRODUCTION | A1: Supply of raw materials | Virgin materials are used as raw materials | The wooden fibres and tiles are obtained from the processing of CDW. |
| | A2: Transport of raw materials | Different transportation distances for different materials (in Module A1) | Different transportation distances for different materials (in Module A1) |
| | A3: Manufacturing | Manufacturing of the conventional panel in the factory | manufacturing of RE4 panel in the factory |
| CONSTRUCTION | A4: Transport to building site | NI | |
| | A5: Installation/Construction | NI | |
| USE STAGE | | NI | |
| END OF LIFE | C1: Deconstruction and demolition | NI | |
| | C2: Transport | NI | |
| | C3: Waste processing | NI | |
| | C4: Disposal | NI | |
| BENEFITS | D: Reuse, Recovery, Recycling Potential | NI | Reuse of insulation and outer layers |

### 3.8.5 Limitations

No limitations.

### 3.8.6 Data quality requirements

The LCA of ventilated façade panels will be modelled by using primary data and Ecoinvent v3.0 datasets.

# 4. METHOD - LIFE CYCLE ASSESSMENT, LCA

## 4.1 Standards

The LCA will be carried out according ISO 14040:2006, ISO 14044:2006 ILCD, EN 15804:2012.

- ISO 14040:2006 describes the principles and framework for LCA including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements.
- ISO 14040:2006 covers life cycle assessment (LCA) studies and life cycle inventory (LCI) studies. It does not describe the LCA technique in detail, nor does it specify methodologies for the individual phases of the LCA.
- EN 15804:2012 provides core product category rules (PCR) for Type III environmental declarations for any construction product and construction service. PCR defines the parameters to be declared and the way in which they are collated and reported, describes which stages of a product's life cycle are considered in the EPD and which processes are to be included in the life cycle stages; defines rules for the development of scenarios; includes the rules for calculating the Life Cycle Inventory and the Life Cycle Impact.

## 4.2 Planning

### 4.2.1 Data sources

Primary data will be provided by RE$^4$ partners or will be collected through interviews to producers and main stakeholders.
The Ecoinvent Life Cycle Inventory (LCI) database, used for many life cycle assessment projects, ecodesign, and product environmental declarations, will provide secondary data.
The Ecoinvent database is integrated in SimaPro, which gives you unlimited access to all the LCI datasets.

### 4.2.2 Used LCA tool

LCA analyses are developed by SimaPro 8.4 software. SimaPro is the leading LCA software package, with a 25-year reputation in industry and academia in more than 80 countries.

### 4.2.3 Data quality requirements and data management

Before a data quality score can be applied, specific Data Quality (DQ) should be clearly established. This process should take place during the goal and scope phase of any LCA project. The data quality goals should explicitly define needs for representativeness, including temporal, geographic, and technological aspects, and completeness. It is important to note that representativeness (temporal, geographic and technological) and completeness are dynamic indicators. Dynamic indicators are

measuring properties of the data that change based on the DQ of the project. Static indicators (e.g. reliability) are based on unchanging properties of the data, such as the data generation method.
Data can be classified into the following categories:

- inputs – energy, raw materials, ancillary and other physical inputs;
- outputs – products, co-products, waste;
- releases to the environment (air, water, soil);
- other environmental aspects (noise, odour, radiation, waste heat, etc.).

The qualitative and quantitative data for inclusion in the inventory shall be collected for each unit process that is included within the system boundary. The data inventory shall cite the sources (if those are public) as well as other specifics of each data (e.g. details about data sampling, whether or not data complies with data quality requirements, etc.). The data shall be reported in a clear way to decrease the risk of misunderstandings.
The ISO 14044 series defines in section 4.2.3.6 Data Quality the ten key categories required for addressing data quality (ISO, 2006b). The definitions of the different categories can be found in Section 10. Glossary of this guidance. ISO requires LCA practitioners to address the following data quality areas if the "study is intended to be used in comparative assertions that are intended to be released to the public" (ISO, 2006b).
1) Time related coverage
2) Geographical coverage
3) Technology coverage
4) Precision
5) Completeness
6) Representativeness
7) Consistency
8) Reproducibility
9) Sources of the data
10) Uncertainty of the information
ISO 14044:2006 provides guidelines about the procedures for defining and elaborating the data describing the product system and each process unit. This standard indicates the aspects such as the operational steps for the validation of data, re-definition of the system boundary to include just the data that has significance for the study (based on a sensitivity analysis) and data allocation procedures.

## 4.3 Inventory

### 4.3.1 Life cycle system boundaries and modules according EN 15804:2012

The system boundaries for the reference building assemblies are from cradle (i.e. virgin or waste materials) to grave (i.e. reusable waste materials). The system boundaries are described by Figure 4.1 (EN 15804). In the inventory of reference assemblies, environmental impacts are inventoried in A1-A5, B1-B7, C1-C4, D (Table 2, Table 3).

For sake of clarity, several modules for the concrete material are explicated:

- A1 includes raw material production like cement production and concrete additives production and for the prefabricated concrete also the fastening products;
- A2 includes transport of materials to the concrete factory;
- A3 includes environmental impact on the concrete factory. Mostly comes from energy used. For the ready mixed concrete, A3 also includes the impact from production of insulation and reinforcement;
- A4 includes transport of building products to the building site;
- A5 includes impact from construction of the building onsite. The impact is mainly due to the energy used;
- B1 includes carbonation of concrete during the use stage;
- B4 includes two replacement of façade mortal for the ready mixed walls;
- C1 includes demolition of the building;
- C2 includes transport of demolished waste to treatment facility;
- C3 includes crushing and sieving concrete waste to produce new materials, such as aggregates for new concrete. Energy for size reduction of concrete is estimated from size reduction of stone. The processes are first a jaw crusher (0,4 kWh/ton) and then a gyratory crusher (0,5 kWh/ton). Sieving uses approximately 0,34 kWh/ton and conveyor belts 0,5 kWh/ton. It is estimated that approximately 1,74 kWh electricity/ton concrete of energy is requested for this phase.

For each investigated solution (both conventional and RE$^4$), the selected system boundary is reported in the connected section.

## 4.4 Life Cycle Impact Assessment

Life Cycle Impact Assessment (LCIA) is a vital phase of any LCA. An LCIA helps interpret emissions and resource consumption data that are associated with a product's life cycle in terms of environmental burdens, human health, and resources.

### 4.4.1 Impact categories

The chosen impact categories are[25] reported in Table 31:

**Table 31 – Impact categories**

| **Global Warming Potential (GWP)** | **kg CO2-eq.** |
|---|---|
| **Ozone Depletion Potential (ODP)** | Kg R11-eq. |
| **Acidification Potential (AP)** | Kg SO2- eq. |
| **Eutrophication Potential (EP)** | Kg PO4-eq. |
| **Photochemical Ozone Creation Potential (POCP)** | Kg C2H4-eq |
| **Embodied Energy (EE)** | MJ |

[25] Embodied energy = total primary energy (non-renewable and renewable)

### **4.4.2** Assessment of recycled CDW content

All the RE4 elements are composed by CDW-derived materials and structures. In the framework of RE4 project an innovative effective solutions in terms of sorting technology in the CDW recycling value chain has been developed in WP2. Indeed, the maximization of recycled valuable materials from CDW for high-value applications will be pursued by the development of advanced sorting technologies based on innovative wet processing and classification systems and automated robotics equipped with advanced sensors and artificial intelligence software. As example, this sorting system will be taken into account in the production process of high-quality recycled aggregates for concrete materials. Moreover, in order to fully exploit the CDW recycling potential, the quality of the output of sorting has to be established in a quantitative way, assessing the compliance of each sorted fraction against relevant National and European specifications. In this regards, the chemical and physical properties of the obtained materials is assessed in the framework of WP4. Instead, the effect of quality variability on the technical properties of developed products has been investigated in WP5 and WP6. The RE4 project is aimed at to reach 80% of the CDW available in high quality fraction for structural and non-structural building components. As matter of fact, in the innovative solutions, considered for the sustainability assessment, all solid timber components are made out reused timber, insulation materials are composed by wood fibres made from recycled timber, aggregates are obtained from the processing of CDW in the mix-design of concrete, etc., thus fulfilling the expected and fixed results.

### **4.4.3** Allocation principals in the End of life phase

Several allocation procedures can be applied for reuse and recycling, as reported in the LCA standards, such as physical and economic allocations, system expansion, etc.

In the framework of RE4 project the following method will be taken into account:

- Method 1 (system expansion): The conventional solutions have a lifetime of 50 years; after this period, components are demolished, through conventional demolition operations, and waste are sent to landfill without further processes.
- The RE4 solutions have a lifetime larger than 50 years; considering the use of reversible connections between the structural support system and the RE4 panel, the panel can be taken (through selective demolition procedures) without causing any damages to the element. For this reason, a complete reuse of the panel or each of its layer is possible. RE4 panel is assumed to be reused in another product system after the first 50 years of service life for other years. Reuse of the RE4 panel is considered as credits allocated to this panel by considering 50+ years of service life for this panel. RE4 panel is assumed to be landfilled after 100 years of service life.
- Given the different service life of both the panels, in order to provide an environmental comparison, the environmental impacts will be calculated considering 1 year of service life. To this aim, the impacts will be divided by 50 in case of conventional panel, and

by 100 in case of innovative one. Only for environmental impacts, the results will be provided in [impact/$m^2$*year]

Method 2 (cut-off method):

- This method considers the first service life of the product understudy. The product system under study will receive credits for using recycled material, but will not gain burdens nor credits from the end of life recycling process or reuse of the analysed product system.
- Environmental burdens from the analysed product system should be calculated including the burdens from production of required primary material and recycled materials entering the system as well as burdens from the disposal of waste generated by the system and not from recycling or reusing of the analysed product.
- The conventional solutions have a lifetime of 50 years; after this period, components are demolished, through conventional demolition operations, and waste are sent to landfill without further processes.
- The reuse of the $RE^4$ elements in a subsequent product system would not be considered in this method. The system boundary considered for the $RE^4$ solution contains the first service life of the element, which means it will be cut at selective demolition.

In Task 7.4, the sensitivity of the environmental comparison results to the choice of allocation method would be analysed. More details about the adopted methodologies will be provided in deliverable 7.4.

#### 4.4.4 Interpretation

Interpretation is "a systematic technique to identify, quantify, check, and evaluate information from the results of the life cycle inventory (LCI) and/or the life cycle impact assessment (LCIA)". The purpose of performing life cycle interpretation is to determine the level of confidence in the final results and communicate them in a fair, complete, and accurate manner.

#### 4.4.5 Sensitivity analysis

Sensitivity analysis (SA) is a significant tool for studying the robustness of results and their sensitivity to uncertainty factors in LCA. It highlights the most important set of model parameters to determine whether data quality needs to be improved, and to enhance interpretation of results. Interactions within the LCA calculation model and correlations within Life Cycle Inventory (LCI) input parameters are two main issues among the LCA calculation process. It proposes a methodology for conducting a proper SA which takes into account the effects of these two issues. This study first presents the SA in an uncorrelated case, comparing local and independent global sensitivity analysis. Independent global sensitivity analysis aims to analyse the variability of results because of the variation of input parameters over the whole domain of uncertainty, together with interactions among input parameters.

### 4.4.6 Identification of key parameters

In this step, the modeller must define the criteria to detect the inputs' description that are eventually influent on the identification of the set of key parameters. To do that, the modeller must first clarify what is the condition for being identified within the set of key parameters, by establishing a targeted threshold for their "aggregated contribution", for example 60% (or more). In this case that the key parameters (showing the highest $S_i^{First}$) must be together responsible of at least 60% of the overall variability of the output: namely the sum of their $S_i^{First}$ must be higher than 0.6. Indeed, the number of selected key parameters depends on this threshold: for instance two key parameters may be sufficient in the baseline scenario, nevertheless a deeper analysis may show that - under different hypothesis - three or even four parameters may be necessary to achieve the targeted 60%. Therefore, the modeller will be interested in observing whether the set of key parameters remains the same or not after different GSA calculations. If such ambiguity is found, then the description of the inputs has a significant influence.

An alternative approach for the selection of the key parameters consists in focusing on their single contribution rather than their aggregated one (i.e. observing if each $S_i^{First}$ is above a certain threshold). However, such approach alone may not be sufficient to identify a set able to cover a given share of the output variance: in the case study, we'll use it only for a complementary analysis.

### 4.4.7 Conclusions

Global sensitivity analysis (GSA) is a powerful tool to study the influence of the different parameters of complex models and to establish a ranking among them, in order to identify the ones that are most influent on the variability of the output. However, the application of GSA has to be handled with care, since its results can be heavily influenced by the initial assumptions: this aspect is particularly critical when studying new products or emerging technologies. With the CDW case study we provided a clear illustration of how the description of the variability of one input can affect its position in the ranking and its contribution to the output's variance.

# 5. METHOD - LIFE CYCLE COST ASSESSMENT, LCC

## 5.1 Standards

The LCC will be carried out according the international standard ISO 15686-5:2008 (Building and construction assets-Service life planning-Life cycle costing) and the European Standards EN 15643-4:2012 (Framework for the assessment of economic performance planning) and EN 16627:2015 Sustainability of construction works - Assessment of economic performance of buildings -calculation methods.

### **5.1.1** Data quality requirements and data management

The economic assessment shall be calculated excluding VAT. Cost data will be used from partners, Literature data and Eurostat. For energy and water, we will use average cost in EU. If local costs given by partners should be use, we shall declare the geographic system boundaries for the data.

All costs will be taken into account, namely investment costs (CAPEX) and operative costs (OPEX). Typically investment costs are business expenses that are not dependent on the level of goods or services produced by the business. Conversely, operative costs are volume-related (and are paid per quantity produced). Raw materials are typically operative costs, while the capital cost to build the production line is an investment cost.

Generally, the LCC analysis is divided in four steps, considering the same functional unit and system boundary defined for the LCA:

1) Identification of main process steps, the relevant equipment and their features such as the life span, the installed power, etc.;
2) Definition of the amount of raw materials and energy consumed, considering a yearly production
3) Definition of the costs associated to the process, investment (CAPEX) and operative (OPEX) that constituted by the equipment purchase costs and the expenditures for the raw materials, energy, maintenance and personnel, respectively
4) Calculation of the Total cost (C) per functional unit [IMPACT ASSESSMENT], calculated as the sum of OPEX and CAPEX.

As already mentioned, the functional unit of the six elements has been calculated considering the location of demo sites, such as Ireland and Spain for cold and warm climate, respectively. As a consequence, costs of the demo sites will be taken into account. Where the costs will be not provided, an average cost, considering 4/5 representative countries, will be considered.

Moreover, the specific issues of each country like legislations in force in different countries, the relevant costs and availability of virgin materials will be examined for the analysis.

### 5.1.2 Discount rate

The indicator in the LCC is the only indicator in this sustainability assessment that depending on when in time the effect occurs. It could be explained with that if you have a certain amount of money and save it on a place where the rate is higher than the inflation (real discount rate [r]) the value of the money will increase by time if you want to use it in the future. Real discount rate is the rate adjusted by inflation and could be calculated as:

***r= n-i***
where:
r= real discount rate
n=nominal rate (the rate from a bank for example)
i= inflation

According EN 16627:2015 the real discount rate is set to 3%.

### 5.1.3 Net Present Value, NPV

According EN 16627:2015 the value today for an economic transaction in the future could be calculated by using the discount factor CF (T), calculated according to the equation:

$$\boldsymbol{CF(T) = \frac{1}{(1+r)^T}}$$

where
r    is the annual real discount rate
T    is the number of years in the future

Net Present Value is the sum of the discounted future cash flows:

$$\boldsymbol{NPV = \sum CF(T)_i \times C_i}$$

where
$C_i$    is the real cost or benefit for a specific product or service.

### 5.1.4 Waste disposal

Special attention will be laid on cost for waste disposal as this is a core subject to avoid in RE4.

### 5.1.5 Rest value

Rest value will be calculated in module D with respect to Net Present Value and not included in the total score. The benefits will be separately declared. If CDW are used for new products or as secondary fuel the avoided cost for virgin material or energy shall be used. If a building element could be reused in a new building the benefit will be declared as the NPV of the production cost of the element.

## 5.2 Economical assessment

### 5.2.1 Comparative economic analysis

All six innovative RE[4] building elements described in table 1 with respective references of building elements used today with same performance will be assessed in the LCC. Every element will be compared with respective reference. A typical cross section is studied in the analyse wish this mean that special details for corners, windows, doors and connections between elements, etc. are excluded as we start to assume that there is no difference in cost between reference and RE[4] elements.

### 5.2.2 Functional unit

The basic functional unit is a square meter of element with a typical section. Thermal resistance (or thermal mass) shall also be equal between compared facade elements.

### 5.2.3 Life cycle system boundaries

For a fair comparison all modules in the lifecycle shall be included. The only reason that could allowed to not declare a module is:

1. There is no impact in the module.
2. There is the same impact in the compared RE[4] element and the reference.

This lead to that comparisons only shall be done between RE[4] elements and their references and not between different types of elements, for example a concrete element for cold climate shall not be compared with a wood element for cold climate as there could be modules not declared because they are equal to the reference. The minimum of declared modules are described in Figure 9. If good data are available for modules with similar impact they shall be included in the cost analysis. The costs shall be declared as total cost in the product system and cost per module including module D.

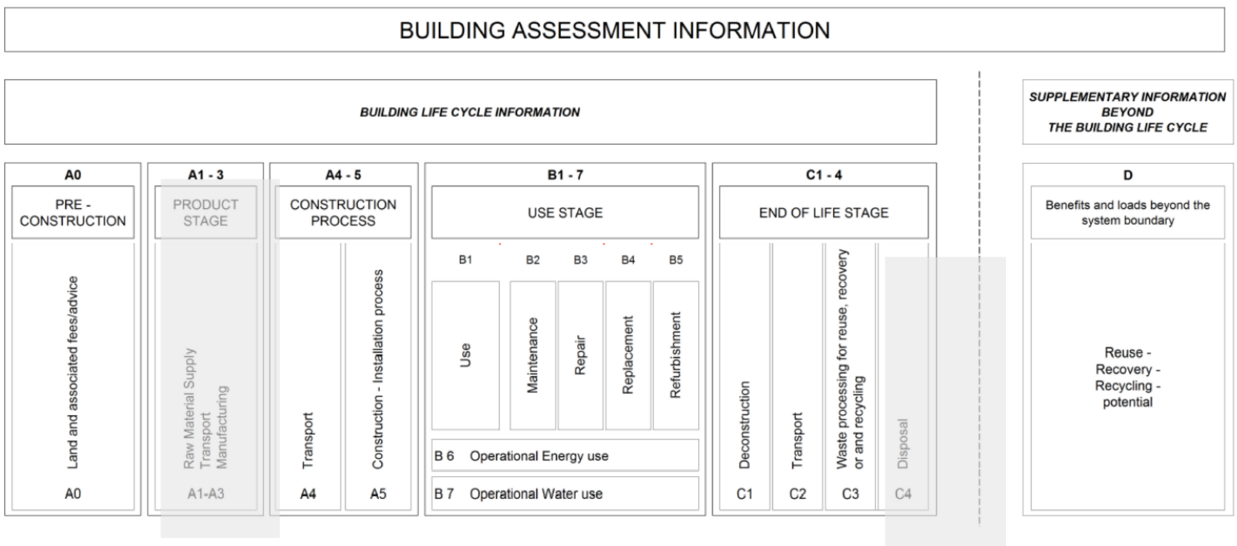



**Figure 9 – Minimum declared modules for LCC**

### **5.2.4** Sensitivity analysis

Historically real discount rate reflects the general productivity for a sector and over long term the productivity have been between 0 % and 2 %. Discount rate also reflect the preference for money for people living today. But if we look at definition of sustainability we will valuate future generations need as if they were our needs. Therefor we do a sensitivity with 0% as real discount rate.

### **5.2.5** Identification of key parameters

Key parameters that have big impact on the economic performance will be identified and could be objects for sensitivity analysis if we see that common use differences in the product system give different results.

### **5.2.6** Conclusions

The economic performance from the $RE^4$ elements will be compared with the technology used today and economic conclusions about the innovative elements will be taken.

# 6. SOCIAL LCA (S-LCA) OF RE⁴ PRODUCTS

The needs of technological and social development on one side and the need of environmental protection on the other one, led to the development of methodologies aimed at quantifying and reducing the impacts connected to the production processes of goods and services.
One of these techniques, the Sustainability Life Cycle Assessment (LCSA), consists in assessing the sustainability of products and services, as well as the production cycles associated with them, during their entire life cycle, taking into account environmental, social and economic criteria.
In this context, this section focuses on the analysis of socio-economic aspects related to two solutions provided by the RE⁴ project and, in particular, aims to present the study carried out for the assessment of their social impact (Social Life Cycle Assessment, S-LCA).
The objective of the present S-LCA consists in the evaluation of the social aspects associated with the adoption of two new panel solutions, in particular the Timber Facade Panel and Concrete Facade Panel for warm climate, comparing social performances of standard version (made with virgin materials) with that one developed/in development in the course of the project, mainly based by construction and demolition wastes (CDW).
The solutions identified respond to the need to pursue savings both in terms of management costs and emissions abatement, while respecting the surrounding environment, with benefits for the manufacturers and the tenants of the buildings.
The results of the study are intended to define the social impact of the application of the aforementioned solutions, both with respect to the direct beneficiaries of the project, i.e. the consortium partners responsible of the production and the testing, and with respect to the other stakeholders involved once these products will reach the market.

## 6.1 Methodology

The Social LCA is a methodology that allows to analyze social and socio-economic aspects, associated with a product or service, and to evaluate the potential impacts, positive or negative, during the entire life cycle. These social and socio-economic aspects can influence, positively or negatively, all the stakeholders involved and can be linked to the behavior of companies, to socio-economic processes, or to have an impact on social capital.
In particular, the results obtained from such kind of study, can be useful to facilitate a decision-making process and to promote the communication of aspects concerning the production and consumption of the analyzed product / service, with the aim of improving the performances of the companies and, ultimately, contribute to the well-being of all the stakeholders involved.
The present S-LCA study is performed in accordance with the guidelines of the S-LCA methodology (UNEP / SETAC guidelines: "Guidelines for Social Life Cycle Assessment of products", 2009) and the LCA main standards (ISO 14044: 2006 and ISO 14040: 2006).
The main phases of S-LCA are the following:

- Definition of the objective and the application fields (function, functional unit, system boundaries). This phase involves the identification of the main stakeholders categories, linked to the processes of the primary and secondary system, as well as the definition of

particular themes or areas, related to the stakeholders, called "sub-categories", which refer to the categories of impact;
- Inventory analysis, which involves the collection of characteristic and functional data for the development of the S-LCA analysis;
- Evaluation of social impacts;
- Interpretation of results and identification of hotspots (critical points).

In this report, D7.2, the Goal and Scope of the S-LCA will be reported, as output of the activities of Task 7.2 – Goal and Scope definition.

In the next deliverables the other 3 main phases of S-LCA according UNEP/SETAC guidelines, will be studied:
- Inventory (Task 7.3 – D7.3 at M32 – April 2019) – All the inventory data used for the Social LCA s, and in particular the social aspects and assumptions related to the four life cycle phases analysed in the study: manufacturing, installation, use and end of life.
- Social Life Cycle Impact Assessment & Interpretation (Task 7.4 – D7.5 at M40 – December 2019) - The assessment of the impacts of the S-LCA identifies and evaluates the quantity and importance of potential social impacts resulting from the inventory analysis (S-LCI).

## 6.2 Goal of the Study

### 6.2.1 Intended Application

The intended application is to evaluate the social impact related to life cycle phases of two different panels, in particular, to identify, from a social point of view, the presence of any critical points (hotspots). The analysis will consider the two different solutions, described in sections 3.4 and 3.5, comparing the standard and innovative versions of each typology.
The limits of applicability, functional units and any other aspect useful for contextualizing the study will be defined in the next paragraphs.
The study analyses different phases of the life cycle of the panels, taking into consideration the production and installation of the elements, followed by the use phase and subsequent phase of demolition and reuse or disposal of the materials.

### 6.2.2 Reasons for carrying out the study

The S-LCA will provide the results to assess whether the commitment associated with the implementation of the RE$^4$ technologies for the panels production brings to an advantage in terms of social benefits such as to justify the investment itself.

### 6.2.3 Decisional Support

In Table 32 is provided the decisional support related to the S-LCA study.

**Table 32 – Decisional Support**

| | YES | NO |
|---|---|---|
| This S-LCA study is utilized to support a decision by the Client. | | X |
| The S-LCA study is interested in the potential changes of this decision. | | X |

### 6.2.4 Intended Audience

The target audience of this study is:

- RE[4] consortium (mainly technical personnel). No need for a Confidential Agreement;
- European Commission.

### 6.2.5 Information to be provided to the public

In relation to S-LCA study no confidentiality issue is present. The results of the study can be presented to the public through a brief summary, to be produced at the end of the project, to highlight the social benefits linked to the technological improvements developed by the project itself.

## 6.3 Scope of the study

The purpose of the present study is the assessment of sustainability, in terms of social impact, connected to the life cycle of two different panels (concrete and timber based) mainly constituted by construction and demolition waste, compared to the current ones based on virgin materials. In particular, the study aims to compare the social benefits related to the various intervention solutions proposed, with particular focus on the manufacturing phase. The "gate to grave" approach is considered for the assessment of the impacts of the individual products described above, including the phases of production, installation, use and end of life, as shown in Figure 10.

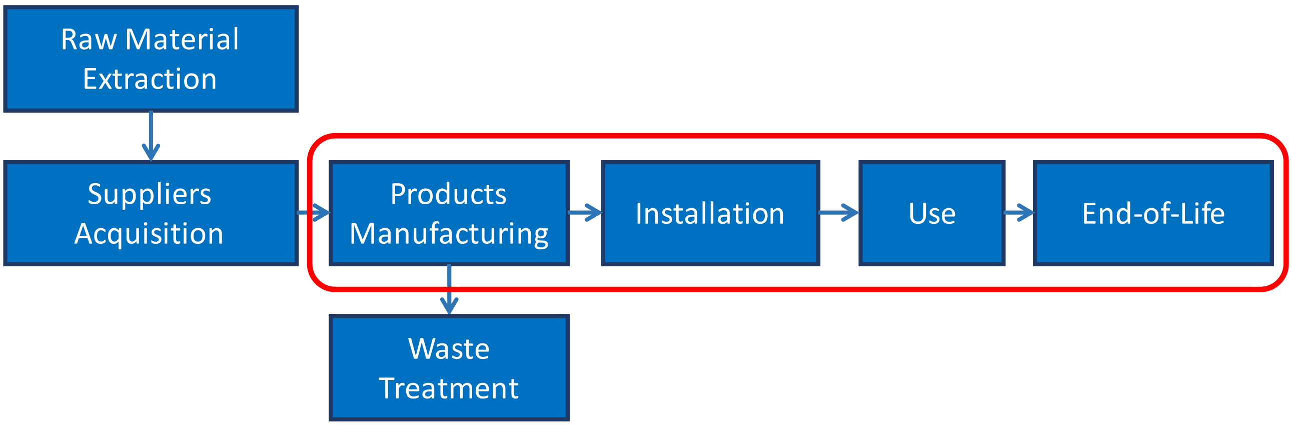



**Figure 10 – Phases of S-LCA study**

The S-LCA will allow the identification of any critical points (hotspots), and will provide the basis for the evaluation of the benefits, in terms of social impact, between the proposed efficiency measures and the current status for the panels production (and related benefits across the entire life cycle).

### 6.3.1 Function, Functional Unit and Reference Flow

The analysed system includes several life cycle phases of the timber panels and concrete panels for warm climate. The functional unit is the square meter of panel, with a thickness able to warrant an U Value of 0,33 W/m²K for Concrete Version and an U Value of 0,14 W/m²K for Timber Version.
The typical timber/concrete facade panel life is assumed to be the life of the building or 50+ years. For the purpose of this study, the default assessment, for both panels, conventional and RE4, is conducted over 50 years of use.
The social utility of the panel, as part of the RE4 project, is the increase in attention towards the social consequences linked to the development of new process, the circular economy approach and the technological refurbishment interventions.

### 6.3.2 System boundaries

The boundaries of the system must include all relevant phases in the life cycle and the processes that are necessary for impact assessment. The system is divided into two subsystems: a primary and a secondary system. The primary system collects those processes that are specific to the type of project analysed, while the secondary system contemplates those processes that are not specific to the analysed system. In particular, the processes belonging to the secondary system are modelled according to the principles of the homogeneous market. The total system will be equal to the sum of the primary and secondary systems. Furthermore, processes or steps that are considered less important in terms of social impact are not taken into consideration. These "cut-off" assumptions are applied to simplify the analysis or compensate for the lack of data.
Within this study the social aspects associated with the manufacturing, installation, use and end of life phases are taken into consideration. The "product" system taken into consideration from the social point of view is schematized in Figure 11, also specifying primary/foreground system (I) and secondary/background system (II).

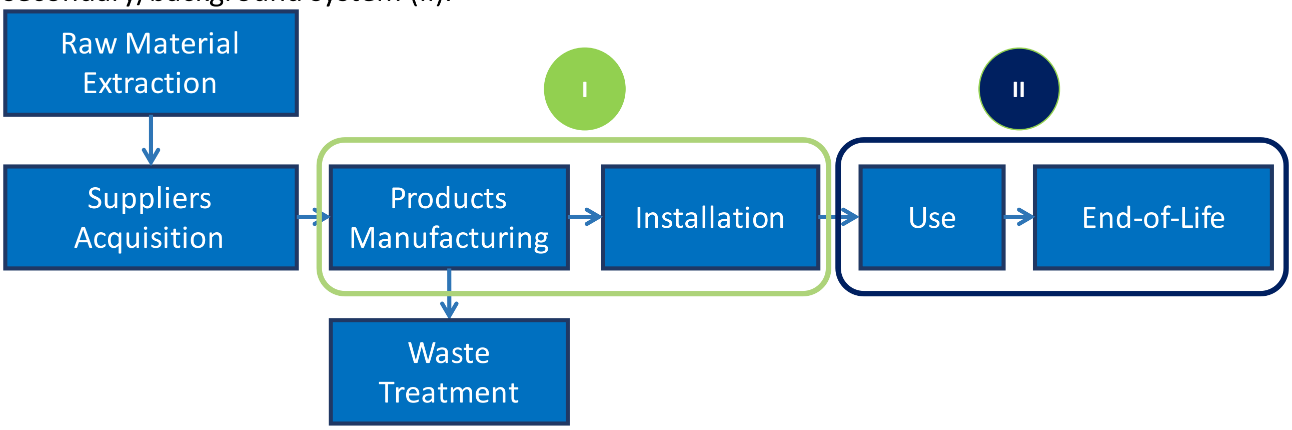



**Figure 11– Boundaries for Primary and Secondary Systems**

S-LCA does not include use phase as stated in UNEP guidelines, but for this project this phase has been accounted also for considering the social benefit linked to energy saving in buildings due to the use of RE⁴ panels. Since the objective of the S-LCA study is to compare social benefits of standard and RE⁴ versions of the two different panels, with particular attention to the manufacturing phase, the information related to this phase will be collected specifically for the different versions of the two panels. Instead the information from the S-LCA analysis regards the installation, use and disposal operations, on the other hand, will be contained in an aggregated form, not having significant differences between the different solutions across these phases.

### **6.3.3** Data requirements (specific for SLCA)

The data used in the analysis should be consistent and reproducible. LCA data quality requirements are summarized in Table 33.

**Table 33 – Data quality requirements**

| | **Foreground processes** | **Background processes** |
|---|---|---|
| **Technological representativeness** | The data must be specific to the organization and the place[26]; however, data specific to one sector or country are also used as reference values. | Country or sector level data are considered. If a sector in a specific country consists of a few companies, then all companies are considered in the social inventory analysis. If a sector instead includes a multitude of companies, only some of them are considered and only half described. |
| **Time representativeness** | The data must be valid for a time interval of at least 3 years. | The data must be valid for a time interval of at least 5 years. |
| **Geographical representativeness** | The data should refer to the specific place where the product is manufactured, used or disposed. | The data should refer to the Country where the processes actually take place. In the event that these data are missing, data from European averages or data from neighbouring countries can be considered. |
| **Data Source** | Data sources can include NGOs, government organizations, literature, involved companies and workers. Different sources of data must be taken into account to identify possible similarities and differences. | |

This procedure ensures that Life Cycle Inventory - LCI will be performed with high accuracy and reproducibility, and that representativeness is assured.

[26] Site-specific data refer to data collected for a specific process, which occurs in a specific company and in a specific place with stakeholders involved or interested.

### 6.3.4 Stakeholders and Subcategories (specific for SLCA)

The S-LCA is carried out taking into consideration different categories of stakeholders, considered relevant for primary and secondary processes, which group several subjects with similar relationships respect to the product system under examination. These categories are also connected to particular themes or characteristics of interest, called sub-categories. Depending on the phase analysed and on the type of system considered (primary or secondary), only the categories of stakeholders considered to be most relevant and significant, as shown in Figure 12, have been taken into consideration.

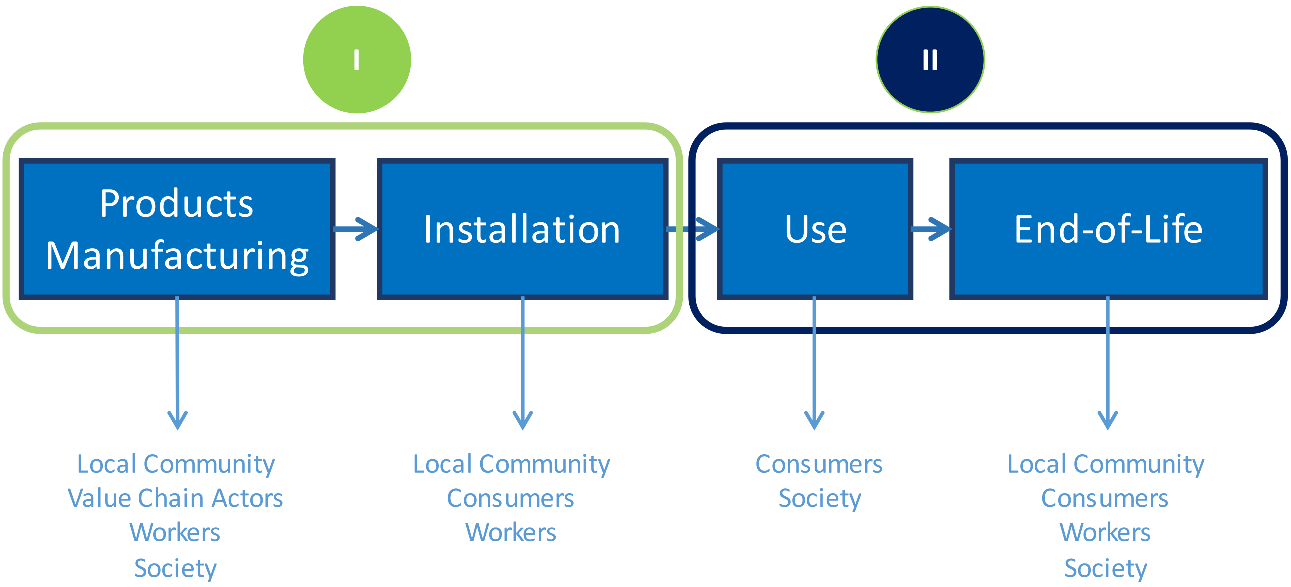



**Figure 12 – Stakeholder for the different phases**

More in detail, the local community, understood as a resident population in the regions where the production, installation and final dismantling take place, being influenced by the manufacturing, installation and disposal sectors present in the territory, has been considered as a stakeholder. In fact, these sectors can represent important realities from an occupational point of view and their behaviour can influence the living conditions of citizens in various ways. Similarly, considering that the welfare assessment of workers employed in these sectors can give interesting information about the social impact of the project, they have also been considered as stakeholders in the phases mentioned above. In particular, questionnaires were sent directly to the partners responsible of manufacturing & installation activities, to evaluate the impact of the standard and RE$^4$ solution within their companies and their own impact related also to the value chain and the society (for the manufacturing phase), beyond stakeholder mentioned above.
In addition, consumers have been considered by S-LCA as stakeholder in all phases of the life cycle from installation to dismantling. For the use phase, specific sub-categories (topics of interest) have been included, relating, for example, to the comfort perceived within the building through the use of concrete or timber panels. Finally, regarding the end-of-life phase, its impact has been assessed

also on the society, a category that includes organizations ranging from the micro level (local authorities) to the macro level (national bodies, associations) that interact directly or indirectly with the whole system analysed. In Table 34, the sub-categories are highlighted, among those provided for by the guidelines of the UNEP / SETAC approach for the S-LCA, which have been taken into consideration for the different phases of the life cycle. Those, however, considered negligible compared to a phase, are not included in the study. Since the UNEP / SETAC approach has been made to meet the success and sector expectations, the proposed sub-categories are not blocked. For the use phase, RINA, while applying the approach recommended by the guidelines, has added two sub-categories (Comfort and Easiness to use).

**Table 34 – Stakeholders and Identified Sub-Categories for the different life cycle phases (Source: UNEP/SETAC Life Cycle Initiative with RINA add-ons).**

| Stakeholder | Sub- Categories | Production (A1-A3) | Installation (A4 - A5) | Use (B1- B7) | End of Life (C1 – C4) |
|---|---|---|---|---|---|
| Local Community | Delocalization and migration | ✓ | | | |
| | Community engagement | | | | ✓ |
| | Cultural heritage | | | | |
| | Respect of indigenous rights | | | | |
| | Local employment | ✓ | ✓ | | ✓ |
| | Access to immaterial resources | | | | |
| | Access to material resources | ✓ | | | ✓ |
| | Safe and healthy living conditions | ✓ | ✓ | | ✓ |
| | Secure living conditions | ✓ | | | ✓ |
| Value Chain Actors | Fair competition | ✓ | | | |
| | Respect of intellectual property rights | ✓ | | | |
| | Supplier relationships | ✓ | | | |
| | Promoting social responsibility | ✓ | | | |
| Consumers | Health and safety | | ✓ | ✓ | |
| | Feedback mechanism | | ✓ | ✓ | |
| | Consumer privacy | | | | |

| Stakeholder | Sub- Categories | Production (A1-A3) | Installation (A4 - A5) | Use (B1- B7) | End of Life (C1 – C4) |
|---|---|---|---|---|---|
| | Transparency | | | ✓ | |
| | End of life responsibility | | | | ✓ |
| | *Comfort* | | | ✓ | |
| | *Easiness to use* | | | ✓ | |
| Workers | Freedom of association & collective bargaining | ✓ | ✓ | | ✓ |
| | Child labour | ✓ | ✓ | | ✓ |
| | Fair salary | ✓ | ✓ | | ✓ |
| | Working hours | ✓ | ✓ | | ✓ |
| | Forced labour | ✓ | ✓ | | ✓ |
| | Equal opportunities/discrimination | ✓ | ✓ | | ✓ |
| | Health and safety | ✓ | ✓ | | ✓ |
| | Social benefits/social security | ✓ | ✓ | | ✓ |
| Society | Public commitments to sustainable issues | ✓ | | ✓ | ✓ |
| | Prevention and mitigation of armed conflicts | | | | |
| | Contribution to economic development | | | | |
| | Corruption | ✓ | | | ✓ |
| | Technology development | ✓ | | | ✓ |

### 6.3.5 Indicators (specific for SLCA)

Several indicators are used to determine the status of the different sub-categories. These indicators are identified by the UNEP / SETAC indications and adapted by RINA for the specific objective of the RE[4] project; afterwards they will be assessed through the search for information on the performance status for the proposed intervention solutions and compared with the performance reference points (using the various sources recommended by the UNEP / SETAC). Through information, qualitative or semi-quantitative, found for each indicator, it is possible to evaluate the performances of the sectors or companies involved in the different phases of the life cycle of the product / service analysed. In particular, each subcategory is assigned a colour, corresponding to a certain level of an evaluation scale that goes from "Very good performance" to "Very poor performance". Each colour is associated with a specific rating, to allow the quantification of impacts. The performance evaluation scale is shown in Table 35.

**Table 35** – Performance Rating Scale

| Performance Evaluation | Colour | Rating |
|---|---|---|
| Very Good Performance | | 1 |
| Good Performance | | 2 |
| Satisfactory Performance | | 3 |
| Inadequate Performance | | 4 |
| Poor Performance | | 5 |
| Very Poor Performance | | 6 |

To achieve the most unbiased results, social evaluation is based on international standards as a reference point, such as the ILO work standards, ISO 26000 standards and the OECD guidelines for Multinational Enterprises.

### 6.3.6 Impact Categories (specific for SLCA)

Following the UNEP / SETAC guidelines for the S-LCA, the relationships between the different indicators and impact categories, which better identify the social issues that are to be evaluated, must be analysed. In particular, the impact categories considered in this study are the following:

- Working Condition, WC;
- Health and Safety, HS;
- Human Rights, HR;
- Socio-economic repercussions, SER;
- Indigenous rights including cultural heritage, IR;
- Governance, G.

The relations between subcategories and impact categories are analysed through the symbols presented in

Table 36.

**Table 36 – Relation between subcategories and impact categories**

| Subcategories and Impact Categories | |
|---|---|
| - | no impacts |
| ✓ | strong relationship between subcategory and impact category |
| (✓) | weak relationship between subcategory and impact category |

These symbols allow to define whether the performances related to the introduction of RE[4] products with construction and demolition wastes, have a positive or negative impact on each impact category and if they bring benefits also compared to their standard versions made by virgin materials. Therefore, according to these reports, the overall impact of the sub-categories is assessed, using the chromatic evaluation scale and the associated factors for the quantification of impacts. The impact assessment scale is shown in Table 37.

**Table 37** – Impact Rating Scale

| Impact Assessment | Colour | Rating |
|---|---|---|
| Positive Effect | | 1 |
| Lightly Positive Effect | | 2 |
| Indifferent Effect | | 3 |
| Lightly Negative Effect | | 4 |
| Negative Effect | | 5 |
| Very Negative Effect | | 6 |

# 7. FRAMEWORK FOR WEIGHTING SUSTAINABILITY

As mentioned in the introduction section, once the individual impacts (i.e. environmental, economic and social) of the solutions will be quantified, an integration of all impacts in one single indicator will be provided. As matter of fact, STRESS and RISE have elaborated a simple methodology for the integration of the results. This methodology will be applied on the solutions where the LCA, LCC and SLCA will be performed: Timber façade panel and Concrete façade panel (warm climate). The application of this methodology will be presented step by step in D7.4: "LCA/LCCA analysis". In more details, the methodology will consider both the results of D7.4 and D7.5 related to the LCA, LCC and S-LCA analysis, respectively.

## 7.1 Shortest Column Method

Main target of this method is a global evaluation of LCA, LCC and S-LCA results.
In mode details, through the method it will be possible to homogenize the three different impacts, providing a single score. The first step is related to the collection of the results of the three analyses, considering a numerical value:

- ✓ the result of SLCA is a value (from 1 to 6) , 1 for very good and 6 for bad;
- ✓ the result of LCC is a financial value expressed in €
- ✓ the result of LCA are expressed by different environmental indicators reported in section 4.4.1; however some LCIA methods (i.e. Impact 2002+) it will be possible obtain a single numerical value (points); generally the score is directly proportional to the impacts.

The proposed methodology is described in the follow considering 4 generic products: A, B, C and D.
In Table 38, a summary of the LCA, LCC and SLCA results are showed:

| Product | LCA (points) | LCC (€) | SLCA (value) |
|---|---|---|---|
| A | 44 | 125 | 2 |
| B | 36 | 104 | 4 |
| C | 69 | 97 | 5 |
| D | 83 | 84 | 3 |

**Table 38 – LCA, LCC, SLCA results_ Example**

- The first step consists in the homogenization of the results; 6 will be attributed to the worst judgment and the other values are appropriately scaled in the range 0 – 6. Since for the SLCA, the results are already presented in this way, the homogenization will be considered for the LCA and LCC results. In particular, for the LCA, 6 will be attributed to product D (i.e. 83) and in the LCC to product B (i.e. 104). The results of this step are summarize for each product in Table 39.

| Product | LCA | LCC | SLCA |
|---|---|---|---|
| A | 3,2 | 6,0 | 2,0 |
| B | 2,6 | 5,0 | 4,0 |
| C | 5,0 | 4,7 | 5,0 |
| D | 6,0 | 4,0 | 3,0 |

**Table 39 – Homogenization of LCA, LCC, SLCA results_ Example**

- In second step all the results will be summed, according to the definition of LSCA. The SLCA results are presented in Table 40.

| Product | LCA | LCC | SLCA | LCSA |
|---|---|---|---|---|
| A | 3,2 | 6,0 | 2,0 | **11,2** |
| B | 2,6 | 5,0 | 4,0 | **11,6** |
| C | 5,0 | 4,7 | 5,0 | **14,6** |
| D | 6,0 | 4,0 | 3,0 | **13,0** |

**Table 40** – SLCA results

- The final step is related to the interpretation of the results;
  The results will be presented through histogram graphs, as depicted in Figure 13:
  - for each product the contribution of each impact (LCA, LCC and SLCA) will be identified;
  - the best sustainable solution will be selected (product A), corresponding to the solution with a lower score.

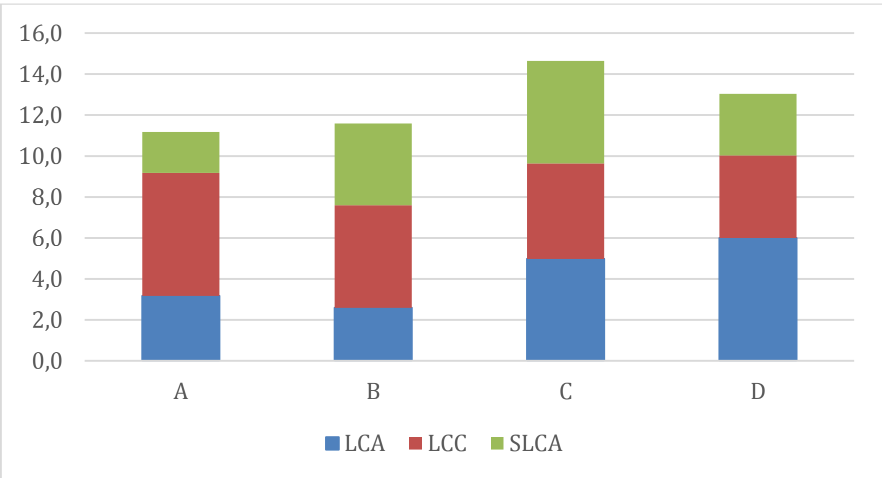



**Figure 13 – SLCA results**

Apart from challenges with regard to indicators and weighting issues, LCSA has to deal with the trade-off between validity and applicability. The inherent complexity of an approach that is supposed to allow a valid measurement of the sustainability performance is a challenge for decision-makers. Therefore, effective and efficient ways to present LCSA results will be considered. This is a prerequisite for the communication of LCSA results to the non-expert audience of real world decision-makers in public and private organizations.

## 8. CONCLUSION AND RECOMMENDATIONS

The objective of WP7 is to analyse the environmental, economic and social impacts of the innovative solutions developed within RE$^4$ project, defining new strategies for a 360° sustainability evaluation. Within the document the first phase of the sustainability methodologies such as LCA, LCC and SLCA, namely goal and scope, has been defined. Indeed the elements to be compared (RE$^4$ and conventional solutions) along with the functional unit, system boundary has been described. Moreover an overview of the sustainability methodologies, has been also presented. In detail, the sustainable performance of six innovative RE$^4$ building elements containing construction and demolition waste CDW compared with common reference elements on the European market will be assessed.

The LCA and LCC analysis will be performed on all elements. Instead, the SLCA will be performed on only two elements: Concrete and Timber façade panels. On these two elements, the methodology accounted for the integration of all the results, according to a Life Cycle Sustainability Assessment approach, will be also applied. The results reported in this deliverable will be used in the other tasks of WP7 and in particular in Tasks 7.3 and 7.4. In addition, all the outputs of WP7 will be transferred to WP6 for the manufacturing and testing of the prefabricated elements prototypes in order to monitor and validate their energy and sustainability performance.

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