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RE4 Project

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

D7.1 Scaled-up processes	
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[3] Draft, Revised, Final

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ACRONYMS & ABBREVIATIONS

CDW	Construction Demolition Waste
Fi / Fo	First in – First out
HPC	High Performance Concrete
LCA	Life Cycle Analysis
LCC	Life Cycle Costing
SCC	Self-Compacting Concrete
WP	Work Package

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EXECUTIVE SUMMARY

The present document reports the activities carried out in Task 7.1, led by RINA-C third parties of STRESS with the collaboration of QUB, RISE, CETMA, Vortex, Creagh, CDE, STAM, and NTUST.
Task 7.1 **Inputs related to scaled-up processes** is included into the context of Work Package 7 **"Life-cycle and HSE analysis and certification/standardization strategy definition"**.
This report has the purpose to provide the input for LCA and LCC activities related to the processes developed in WP5 and WP6.
Starting from the input provided by the partners in charge to produce the RE^4 components for the demo buildings the data about up-scaled processes are reported.
In particular for each product's families analysed, namely concrete sandwich panels, ventilated façade for refurbishment, wood fibres insulating panels, the following information are reported the:

- design;
- production flow;
- main features of the products;
- unitary operations involved;
- available data on energy and materials flows and streams;
- block flow diagram.

D7.1 includes the following main sections:

- Introduction to the deliverable, task propose, deliverable as well as relevant Work Package/task input/output (Chapter 1);
- Pilot Plant for sandwich panels (Chapter 2);
- Ventilated façade for refurbishment (Chapter 3);
- Pilot plant for insulating panel (Chapter 4);
- Conclusion and recommendations (Chapter 5).

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1 Introduction

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 7.1, led by STRESS with the collaboration of QUB, RISE, CETMA, Vortex, Creagh, CDE, STAM, and NTUST, which provided the needed information. Task 7.1 **Inputs related to scaled-up processes**, 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 2019) of the project.

The main goal of this task is to gather information related to the processes developed in WP5 and WP6 in order to better execute the LCA. In particular, each partner developing a specific technology will provide:

- Industrial data regarding competing state-of-the art products, to be utilized as a benchmark;
- Conceptual design of the RE^4 processes scaled-up at industrial scale, including materials and energy balances, equipment list and lay out, process flow diagrams.

1.1 Deliverable structure

D7.1 includes one dedicated section for each of the product's families analysed, namely: RE^4 concrete sandwich panels, RE^4 extruded tiles to be used in ventilated facades, and RE^4 timber facade panels. Each session contains the design, the production flow, the main features of the products, the unitary operations involved, the available data on energy and materials flows and streams as well as the block flow diagram.

1.2 Relevant Work Package/task input/output

The activities performed in T7.1 and the results presented in D7.1 build 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 characterization 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 T7.1, as mentioned, will be used in the other task of WP7 and in particular in Tasks 7.2, 7.3 and 7.4. In addition, some of 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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2 Pilot Plant for RE[4] concrete sandwich panels

Creagh facilities in Toomebridge have in total 12 individual factories that produce all the concrete products mentioned above, including steel fixing, bespoke concrete products and stairs factories where the RE[4] concrete products will be manufactured. The main production line for bespoke concrete elements has an area of 120x18m^2 and comprises 12 tilting and vibrating heated tables and a mould manufacturing area.


Figure 1: Creagh main factory in Toomebridge, Northern Ireland with tilting and vibrating heated tables.

RE[4] concrete façade sandwich panels for warm and cold climate will be produced in the Creagh existing facilities. The facilities are fully operational to produce the RE[4] elements and do not need any modifications of production lines to produce the RE[4] elements besides the manufacturing of wooden moulds to shape each concrete element[4]. The wooden moulds will not affect the consumptions and the operation of the plant with the exception of the dimensions, shape and any openings.

The same procedures of traditional products are applicable for the products developed under the RE[4] project with additional attention given when it comes to receiving, storing and handling CDW aggregates at Creagh facilities. All CDW aggregates are supplied to Creagh by CDE who sourced the materials from a recycling plant in Scotland (Brewsters Bros., Ltd[5]). The CDW are handled in similar way to natural aggregates and two bays were created at Creagh yard to stockpile CDW aggregates, one for the 04/10mm and another for the 0/04mm aggregates; while due to the small amount the 10/20mm aggregates were delivered and kept in 1-ton bags.

After trials and previous experiences dealing with CDW aggregates the following steps should be guaranteed to ensure there is no safety or quality issues with the materials:

- Aggregates are to be sourced in bulk to guarantee there is less variability in the supply and ease handling.

[4] The main issue of the scale up is the management of CDW in terms of re-arrangement of space in the factory for sorting, storage and handling of CDW

[5] 1 Information about the CDW plant can be found in: https://www.bbc.co.uk/news/uk-scotland-edinburgh-east-fife-45259931 ; and https://www.brewsterbros.com/

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- On delivery the materials should be inspected to ensure they meet acceptance criteria, including inspection for the existence of hidden contaminants
- Aggregates should be stored for 2 days undercover before use to allow them to drain.
- Stored piles of aggregates are to be turned / mixed by shovel prior to be placed in the batching plant bins to avoid segregation.
- Aggregate bins must be thoroughly cleaned and inspected by
- Materials Manager prior to a new material being placed
- CDW aggregates only can be placed in vibrating bins to avoid segregation and getting stuck to the bin walls.

During products of concrete, all aggregates are to be inspected daily by the batcher man for contamination prior to use.

Sieve analysis of aggregates is to be completed and recorded for each batch of CDW material delivered to ensure it meets supplier specification. These are to be compared to the sample batches for consistency.

Figure 2: Bays created at Creagh to stockpile the CDW aggregates (04/10mm on the left and 0/4mm on the right).

Two sandwich panels are being developed in RE^4 project:

- A **loadbearing sandwich panel** with a "traditional" section constituted by a structural concrete layer with 150 mm (inner layer), an insulation layer with variable thickness (in RE^4 it is utilised 100 mm of PIR insulation - adequate for **cold climates**) and a 80 mm architectural concrete layer (external / outer layer) where different finishes can be applied – in RE^4 a standard smooth concrete finish will be applied (Figure 3 – Left).
- A **non-loadbearing sandwich panel** with a section constituted by a structural concrete layer of 120 mm (inner layer), an insulation layer with variable thickness (in RE^4 it is utilised 60 mm of PIR insulation - adequate for **warm climates**) and an 40 mm architectural concrete layer (external / outer layer) where different finishes can be applied – in RE^4 a standard smooth concrete finish will be applied (Figure 3 –Right).

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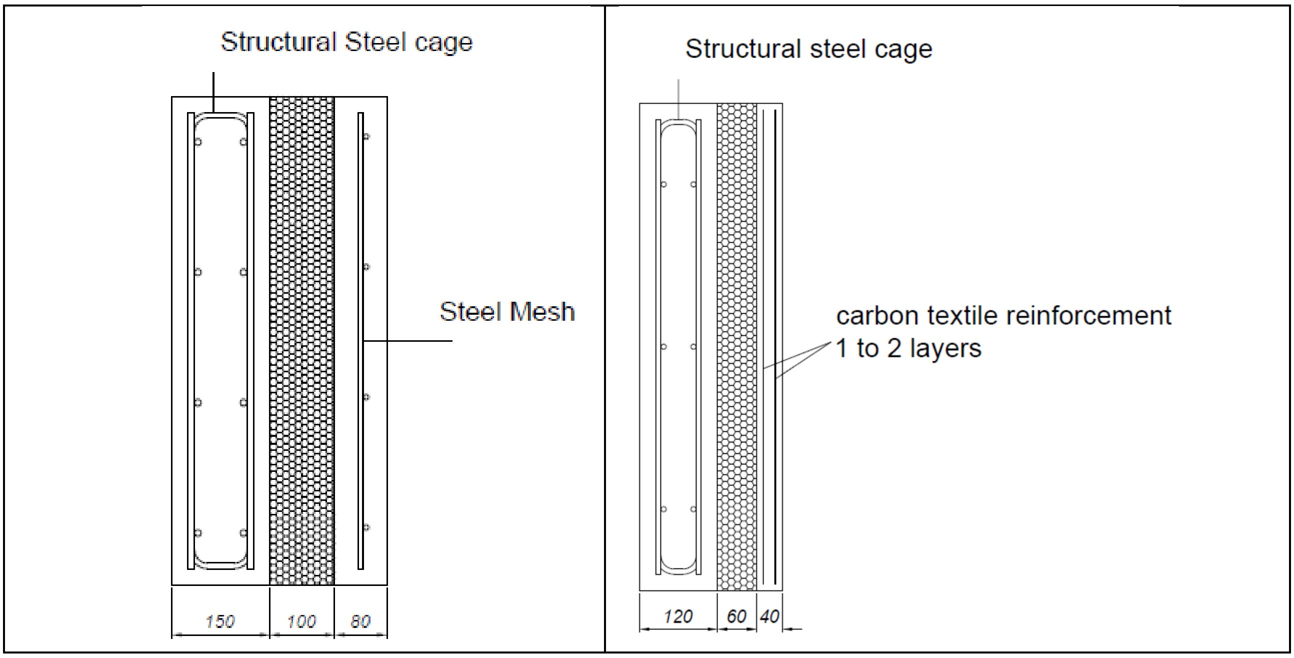

Figure 3: Sections of the sandwich panels developed in the RE4. Left: Loadbearing for cold climate; Right: Non-loadbearing for warm climate

A description of Creagh facilities is reported in Deliverable 6.1, while the plant main features for the RE4 concrete sandwich panels production are reported in Table 1, while the production steps list in Table 2.

Country and Location site	Toomebridge, Northern Ireland		
Total area of the site / factory (plant)	200,000/2,200	**m²**	
Plant capacity	$20x10^3$	**tonnes/year**	
	variable	**pieces/day**	
Yearly operation time	265	**days/year**	
Effort	variable	**men/piece**	
Product dimensions	Length	**Variable**	**m**
	Width	**variable**	**m**
	Thickness	**variable**	**m**

Table 1: Sandwich panels plant main features

N°	Name of the process	Maintenance	Operative personnel
1	*Steel reinforcement preparation*	Y	2
2	*Mould and Insulation Preparation*	Y	2
3	*Batching*	Y	1
4	*Pouring, steel and insulation placement*	Y	3
5	*Finishing and Curing*	Y	**1**
6	*Demoulding and lifting*	Y	**1**

Table 2: RE4 concrete sandwich panels production main steps

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Below a description of each process step:

1. **Steel reinforcement preparation:** steel bars and steel meshes are cut, bent and welded to form the shape specified by the structural engineer and in accordance with detailed drawings. In the external face of the panel a steel mesh or carbon fibre mesh (in the case of the non-loadbearing) are employed.
2. **Mould and Insulation preparation:** moulds are prepared for each panel. The sandwich panels are bespoke products and individual moulds are prepared for different designs (i.e. panels with different overall dimensions, windows and doors openings as well as other fixtures such lighting and plumbing). The base of the mould is a heated steel tilting bed and each panel mould is prepared by setting up wooden shutters in that steel base to give the desired form of the panel as per detailed drawings. The face / base mould is prepared by scrapping and cleaning any debris from previous casting and applying mould release oil. The steel mesh or carbon textile of the outer face is placed and set-up with appropriated cover spacers and fixtures. At this step, insulation is also cut to size and holes made to insert the pin connectors that link the outer and inner layers.
3. **Batching:** the concrete is batched at an *in-site* concrete batching plant. Here, all materials are firstly fed into a planetary 1 m^3 mixer which are then mixed with water and admixtures. All quantities are controlled by a computer and measured automatically by a series of sensors / scales fitted in the conveyors and silos that supply the batching plant. This batching plant is also fitted with moisture probes for measuring humidity in the aggregates and consequently computerised adjustment of the water dosage is accomplished. Once mixed, the concrete is discharged into a lorry that transports the concrete to the factory where the panels/elements will be cast, inside the factory the lorry discharges the concrete into a 2 m^3 skip which is moved close to the mould by an overhead bridge crane.
4. **Pouring, steel and insulation placement:** the casting / pouring must be done in two stages because the sandwich panels are composed by two layers of concrete with an insulation layer in between. Firstly, the external layer is poured then the insulation and connecting pins are immediately installed while the concrete is still fresh. Once the steel cage of the internal leaf is mounted as well as any other fixtures the 2nd pour is done. The two pours are usually separated by 1 to 3 hours and 100 mm concrete cube specimens are taken at the time of the casting for quality control proposes.
5. **Finishing and curing:** as soon as the concrete starts to harden and consistency is adequate the inner layer is manually or mechanically trowelled depending on the level of finish required. The panels are left to cure in the heated tables for approximately 16 hours before demoulding and lifting.
6. **Demoulding and lifting**: after 1 day, the panel is demoulded, lifted and transported to an adjacent factory where the final finishes and inspections are done before the panel is signed off

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and sent to site. Before lifting the strength of the concrete is verified by the means of compressive strength tests on two concrete cubes.

The sandwich panel production steps are depicted in the scheme reported in Figure 4, while the overall production and quality procedures flow chart is Figure 5.

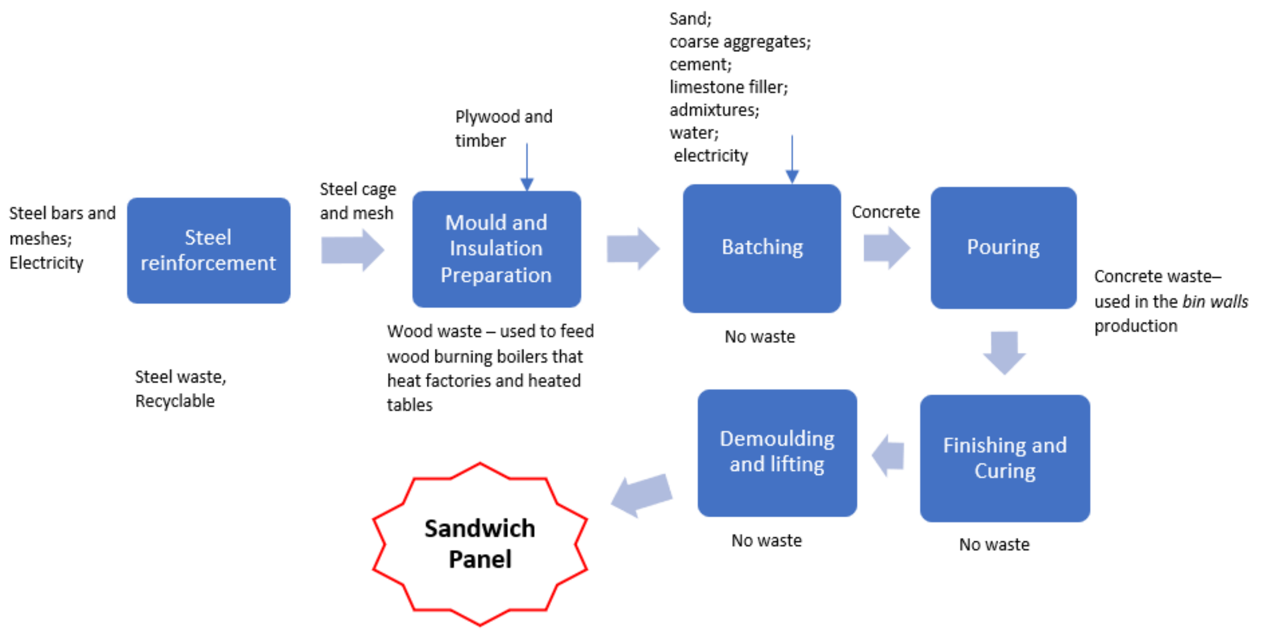

Figure 4: Sandwich panel production steps flowchart

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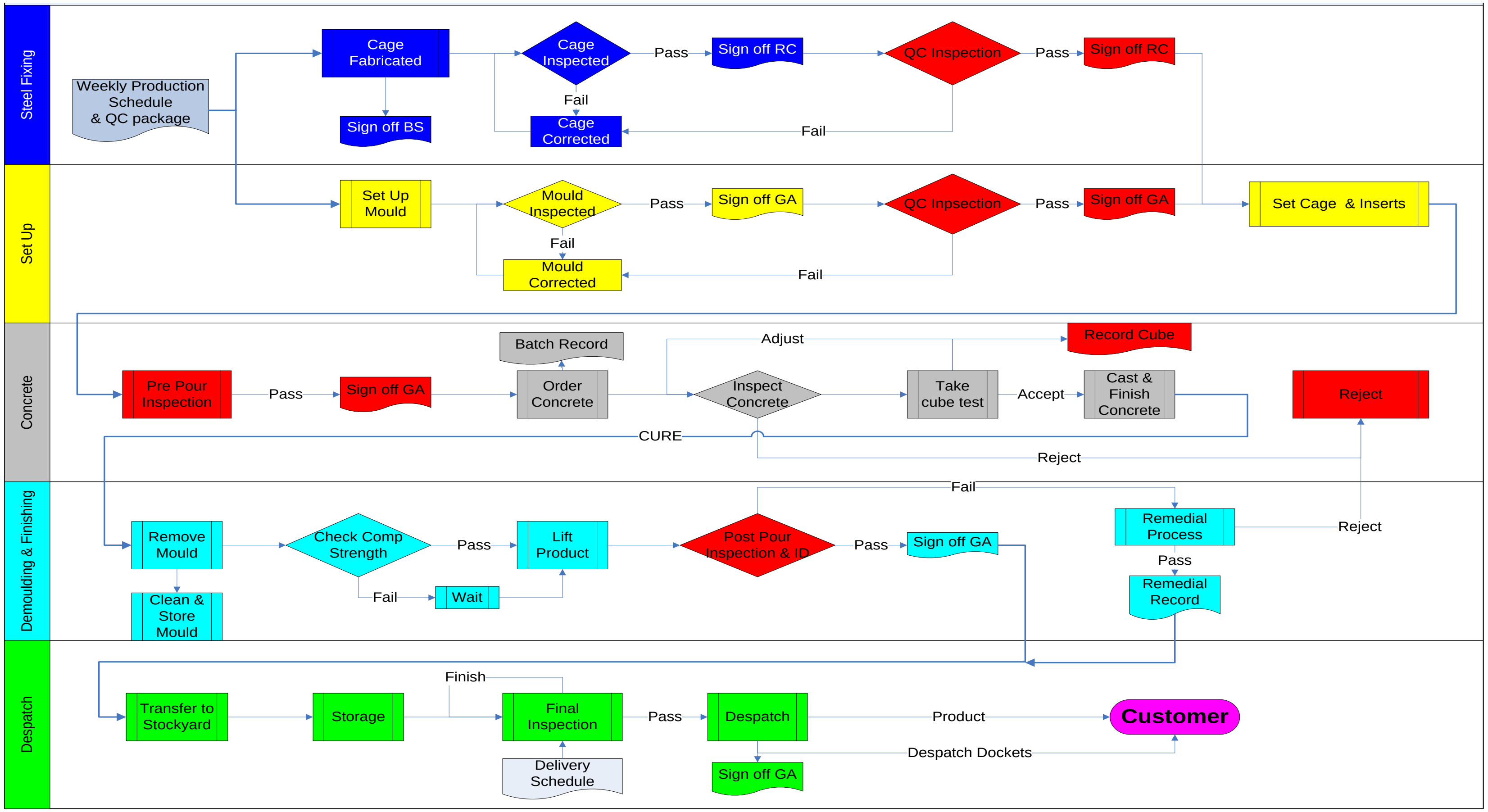

Figure 5: Overall production and quality procedures flow chart

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2.1 Process step n.1: Batching – Concrete production

This chapter summarizes the process step batching for the production of the concrete. Technical data and assumptions for this step are listed in Table 3.

Technical data and assumption		
Efficiency	95	%
Temperature	Ambient	°C
Duration of the process step (if feasible)	0,08 to 0,16	h

Table 3: Sandwich panel concrete production technical data and assumptions

According to the type of panel, loadbearing and non-loadbearing, a different mix design is manufactured.

To produce 1 m^2 of loadbearing sandwich panel, 0,23 m^3 of Self-Compacting Concrete (SCC) is necessary; for loadbearing sandwich panel concrete materials input and output are listed in Table 4 and Table 5 , respectively and the equipment is reported in Table 6.

Inputs – concrete for loadbearing panel		
Electricity	0,7[1]	kWh
Sand 0-2	124	kg
Sand 0-4	53	kg
CDW aggregate 4-10	176	Kg
Cement 42.5N CEM I	106	kg
Limestone filler	41	kg
Admixtures	1,8	kg
Water	46	L

[1] 5 min of mixing per 1m^3 of concrete

Table 4: loadbearing sandwich panel concrete production inputs

Outputs – concrete for loadbearing panel		
Intermediate Product - Concrete	0,23 / 548	m^3/kg

Table 5: loadbearing sandwich panel concrete production outputs

Equipment – concrete for loadbearing panel	Units	Characteristics	
Batching Plant equipped with 1m^3 planetary mixer	1	37	kW
		Ambient	°C

Table 6: loadbearing sandwich panel concrete production equipment list

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To produce 1 m^2 of non-loadbearing sandwich panel, 0,12 m^3 of SCC + 0,04 m^3 of High Performance Concrete (HPC) are necessary; for non-loadbearing sandwich panel concrete materials input and output are listed in Table 7 and Table 8, respectively and the equipment list is reported in Table 9.

Inputs – concrete for non- loadbearing panel		
Electricity	0,95[1]	kWh
Sand 0-2	75	kg
Sand 0-4	45	kg
CDW aggregate 4-10	120	Kg
Cement 42.5N CEM I	75	kg
Limestone filler	22	Kg
Fly Ash	6,6	Kg
Silica Fume	2,4	Kg
Admixtures	1,5	kg
Water	30	L

[1] 10 min of mixing per 1m^3 of concrete

Table 7: non - loadbearing sandwich panel concrete production inputs

Outputs – concrete for non- loadbearing panel		
Intermediate Product – SCC Concrete	0,12 / 285	m^3/kg
Intermediate Product – HPC Concrete	0,04 / 95	m^3/kg

Table 8: non - loadbearing sandwich panel concrete production outputs

Equipment – concrete for non- loadbearing panel	Units	Characteristics	
Batching Plant equipped with 1m^3 planetary mixer	1	37	kW
		Ambient	°C

Table 9: non - loadbearing sandwich panel concrete equipment list

2.2 Process step n.2: overall production (without concrete)

For the overall production process for 1 m^2 of sandwich panel, technical data and assumptions are reported in Table 10, while materials input and output are listed in Table 11 and Table 12, respectively and the equipment is reported in Table 13.

Technical data and assumption - sandwich panel overall production		
Efficiency	95	%
Temperature	Ambient/ 25[1]	°C
Duration of the process step (if feasible)	20	h

[1] Air temperature inside the factory / average temperature of the heated beds

Table 10: Overall sandwich panel production technical data and assumptions

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Inputs - sandwich panel overall production		
Electricity	2.0	kWh
Gas oil	0.94	L
Diesel	0.7	L
Steel (loadbearing panel / non-loadbearing panel)	18/12	kg
Carbon textile reinforcement (only for non-loadbearing)	1 to 2	m2
PIR Insulation	1	m2
Timber for moulds (estimated)	17	kg

Table 11: Overall sandwich panel production inputs

Outputs - sandwich panel overall production		
Waste timber (used to heat factories)	17	kg
Waste concrete	1-5	%
Waste steel	~1-3	%
Sandwich panel	1	m2

Table 12: Overall sandwich panel production outputs

Equipment - sandwich panel overall production	Units	Characteristics	
Moulds Heated tables	$1m^2$	No.12 14x4	m2
		25	°C
Overhead bridge crane	1	12 ton capacity	…
Concrete Lorry	500m[1]	$5m^3$ capacity	m
Moulds - Heated tables	$1m^2$	No.12 11x4 m^2	
Concrete skip	1	2 m^3 capacity	…
Table tools: saws, steel bending machinery	N.A.		
Hand tools: drills, saws, grinders hammers, etc.	N.A.		

[1] *Return distance from factory to batching plant*

Table 13: Overall sandwich panel production equipment list

An example of the output (i.e. sandwich panel) is depicted in Figure 6.

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Figure 6: Picture of sandwich panel

2.3 Sandwich panels BLOCK FLOW DIAGRAM AND PLANT LAYOUT

Figure below reports Plant layout of heated beds TF1 (Toome Factory no.1) factory where the concrete sandwich panels are produced.

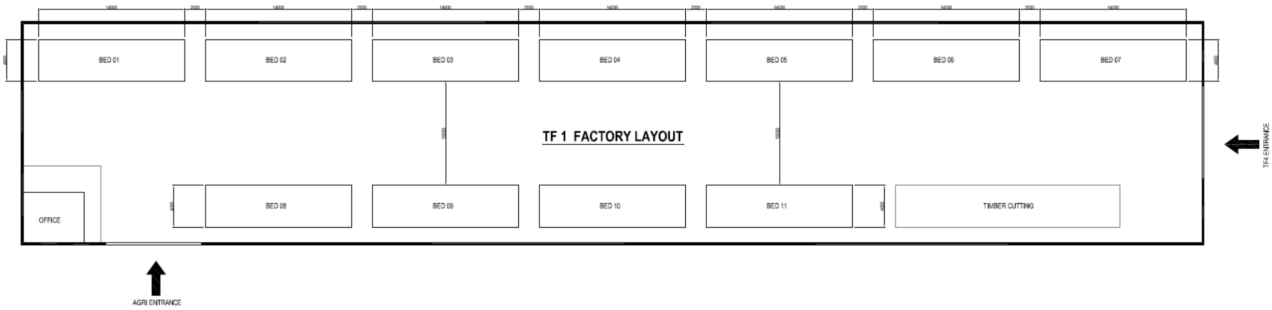

Figure 7: Plant layout of heated beds TF1 factory

While the following sub-chapters report the energy and mass balances and block flow diagram for the production of 1 m^2 of loadbearing and non-loadbearing sandwich panels for RE^4 project as well as for benchmark. The information of RE^4 products starts from the information reported in the previous chapter, while the information related the benchmark products were provided directly by the company and summarized.

2.3.1 Loadbearing Sandwich Panels

Table 14 lists the energy and mass balances of the Benchmark non-loadbearing sandwich panels, while and Figure 8 depicts the block flow diagram.

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BENCHMARK LOADBEARING SANDWICH PANEL			
Input	Electricity	2,71	kWh El.
	Virgin sand (0/2 mm)	69	kg
	Virgin sand (0/4 mm)	133	kg
	Virgin aggregate (6/14 mm)	184	kg
	Admixture content	0,76	kg
	Limestone Filler	28	kg
	Cement	97	kg
	Tap water	45	L
	Gas oil	0,94	L
	Diesel	0,7	L
	Steel	18	kg
	PIR Insulation	1	m^2
Output	Loadbearing sandwich panel	1	m^2

Table 14: Benchmark Loadbearing sandwich panel production line energy and mass balances

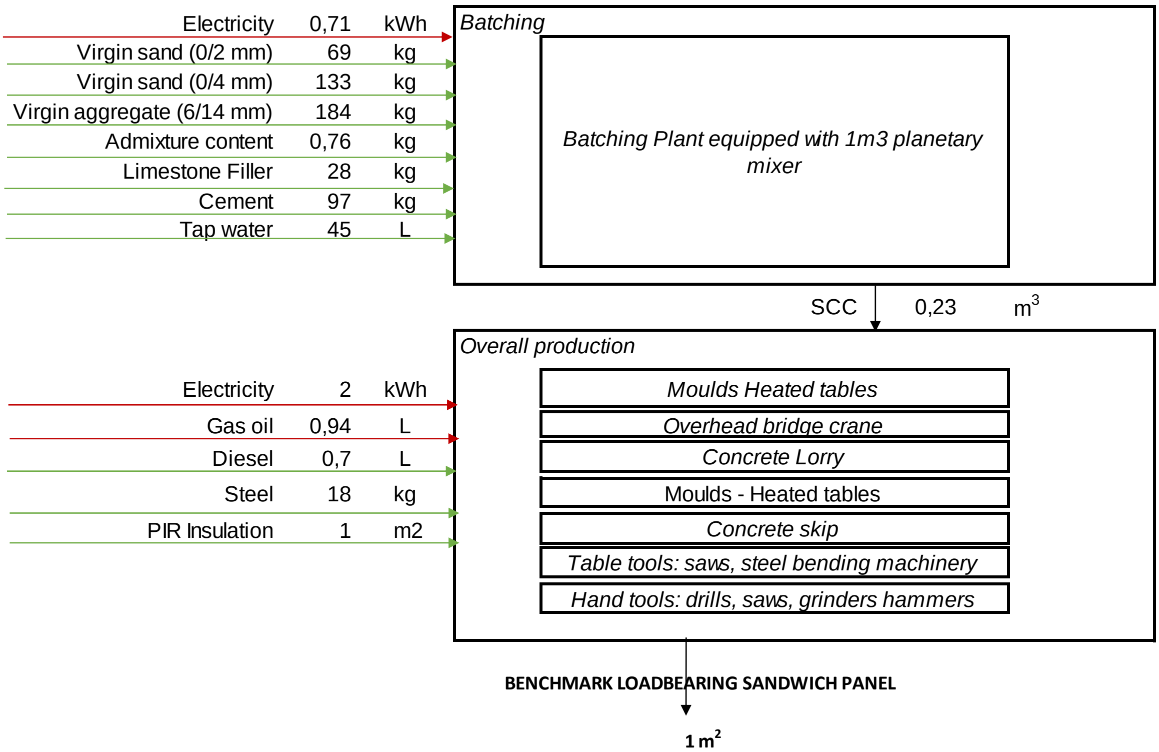

Figure 8: Block Flow Diagram of Benchmark loadbearing sandwich panel production line

Analogously, the energy and mass balances and the block flow diagram for RE[4] loadbearing sandwich panel are reported in Table 15 and Figure 9, respectively.

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RE^4 Loadbearing Sandwich Panel			
Input	Electricity	2,71	kWh El.
	Sand 0-2	124	kg
	Sand 0-4	53	kg
	CDW aggregate 4-10	176	kg
	Cement 42.5N CEM I	106	kg
	Limestone filler	41	kg
	Admixtures	1,8	kg
	Water	46	L
	Gas oil	0,94	L
	Diesel	0,70	L
	Steel	18	kg
	PIR Insulation	1	m^2
	Timber for moulds	17	kg
Output	Loadbearing sandwich panel	1	m^2

Table 15: RE^4 Loadbearing sandwich panel production line energy and mass balances

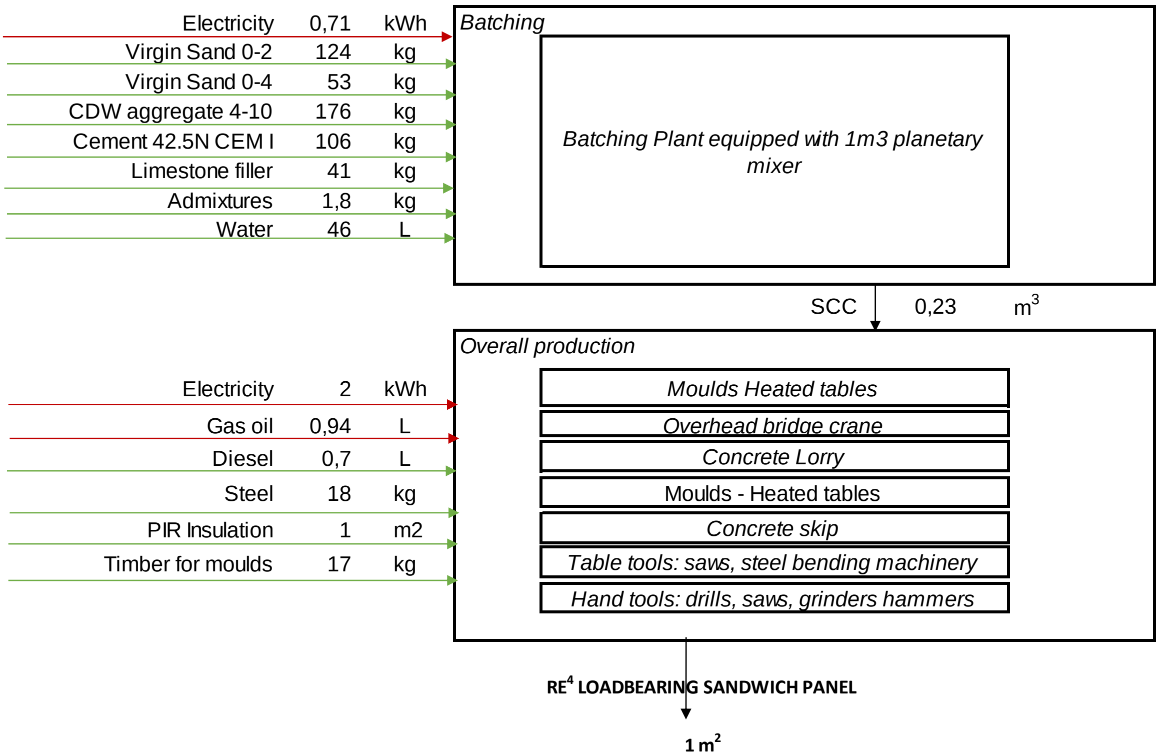

Figure 9: Block Flow Diagram of RE^4 loadbearing sandwich panel production line

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2.3.2 Non-Loadbearing Sandwich Panel

Table 16 lists the energy and mass balances of the Benchmark non-loadbearing sandwich panels, while Figure 10 depicts the block flow diagram.

BENCHMARK NON- LOADBEARING SANDWICH PANEL			
Input	Electricity	2,95	kWh
	Virgin sand (0/2 mm)	69	kg
	Virgin sand (0/4 mm)	133	kg
	Virgin aggregate (6/14 mm)	184	kg
	Admixture content	0,76	kg
	Limestone Filler	28	kg
	Cement	97	kg
	Tap water	45	kg
	Gas oil	0,94	L
	Diesel	0,7	L
	Steel	18	kg
	PIR Insulation	1	m2
Output	Non- Loadbearing sandwich panel	1	m^2

Table 16: Benchmark non-Loadbearing sandwich panel production line energy and mass balances

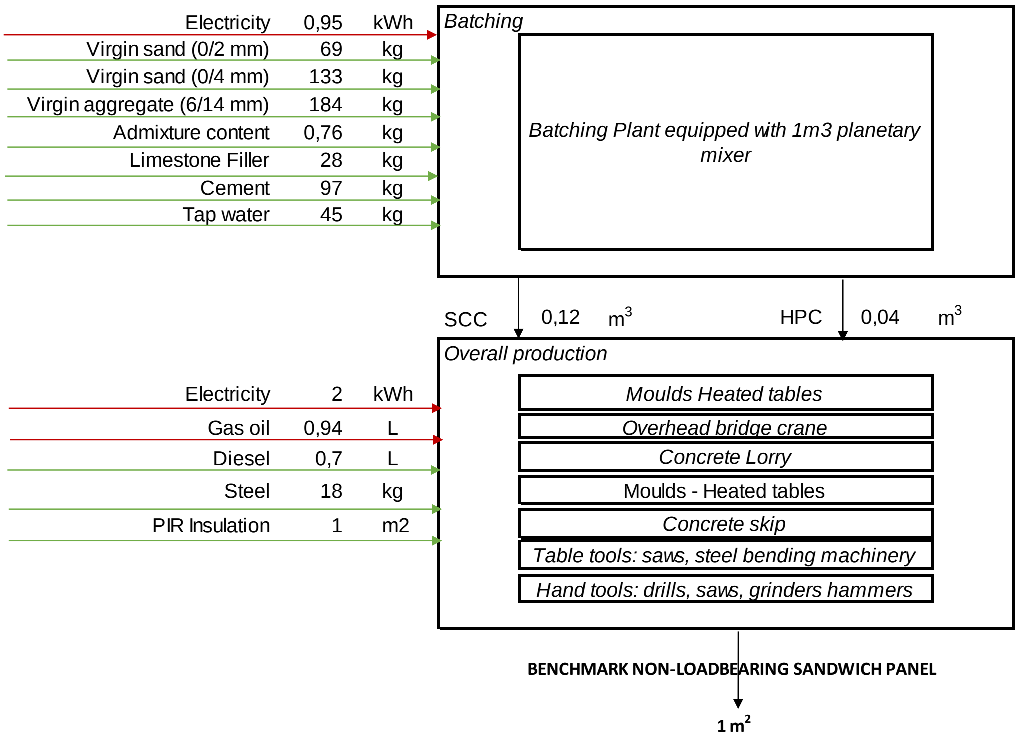

Figure 10: Block Flow Diagram of Benchmark non-loadbearing sandwich panel production line

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Analogously, the energy and mass balances and the block flow diagram for RE[4] non-loadbearing sandwich panel are reported in Table 17 and Figure 11, respectively.

RE[4] Non- Loadbearing Sandwich Panel			
Input	Electricity	2,95	kWh
	Sand 0-2	75	kg
	Sand 0-4	45	kg
	CDW aggregate 4-10	120	kg
	Cement 42.5N CEM I	75	kg
	Limestone filler	22	kg
	Fly Ash	6,6	kg
	Silica Fume	2,4	kg
	Admixtures	1,5	kg
	Water	30	L
	Gas oil	0,94	L
	Diesel	0,7	L
	Steel	12	kg
	Carbon textile reinforcement	1,5	m^2
	PIR Insulation	1	m^2
	Timber for moulds	17	kg
Output	Non- Loadbearing sandwich panel	1	m^2

Table 17: RE[4] Non-Loadbearing sandwich panel production line energy and mass balances

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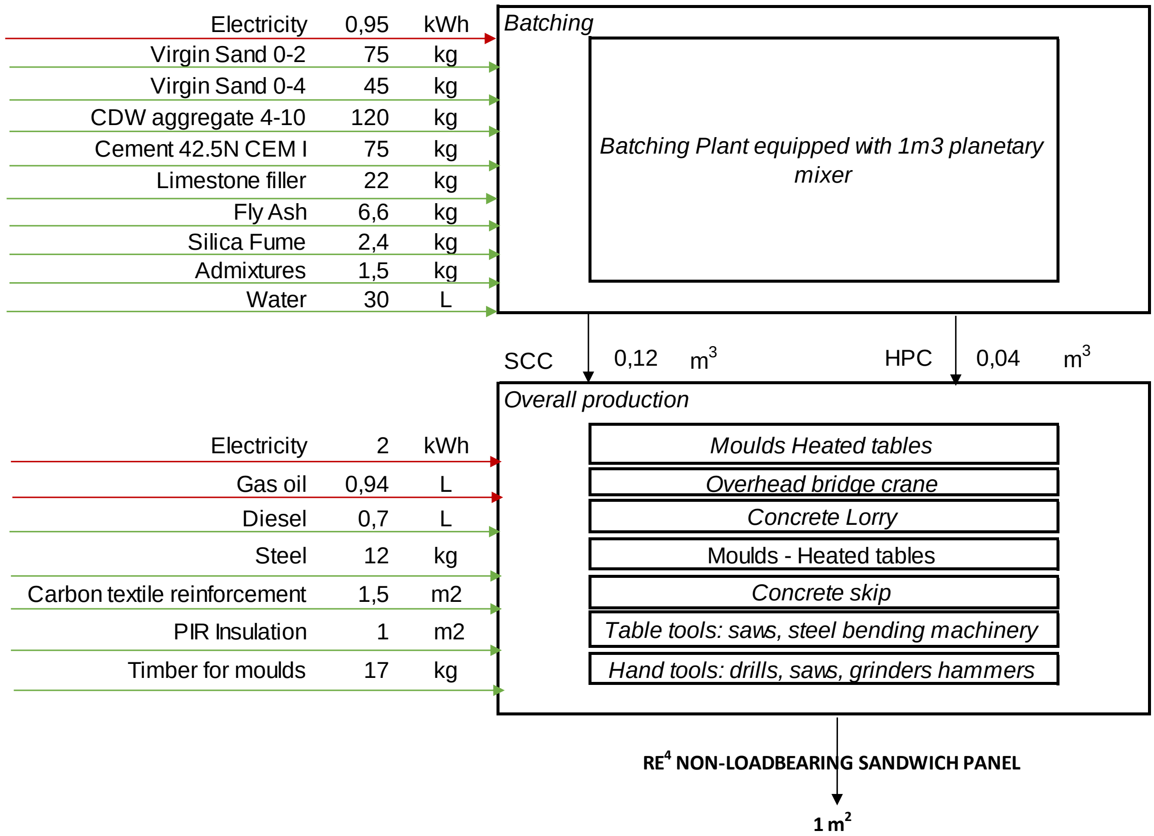

Figure 11: Block Flow Diagram of RE[4] non-loadbearing sandwich panel production line

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3 Pilot plant for RE4 extruded tiles to be used in ventilated façade

Within the Vortex facility will be produced the extruded components of the ventilated façade for RE4 project using the CDW aggregate in the 0-2 mm fraction, sorted according to the methodologies implemented in WP2, in lieu of virgin sand, commonly used for the manufacturing process of **extruded façade panels**.

The **RE4 extruded façade panels** is composed mainly by RE4 extruded tiles (Figure 12 - Figure 13) integrating high ratios of CDW-derived aggregates. This system is a complete refurbishment, light-weight and dry fixed system to upgrade the external appearance and the insulation of an existing building simply, effectively and for life. To produce the RE4 extruded tiles integrating high ratios of CDW-derived aggregates it is possible to adapt a current operational process, implemented by the Swedish company Marmoroc AB, which is the owner of the patented Marmoroc™ system.

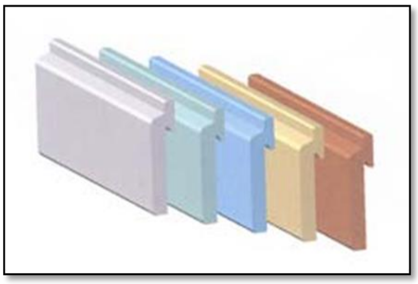

Figure 12: RE4 extruded tiles tiles

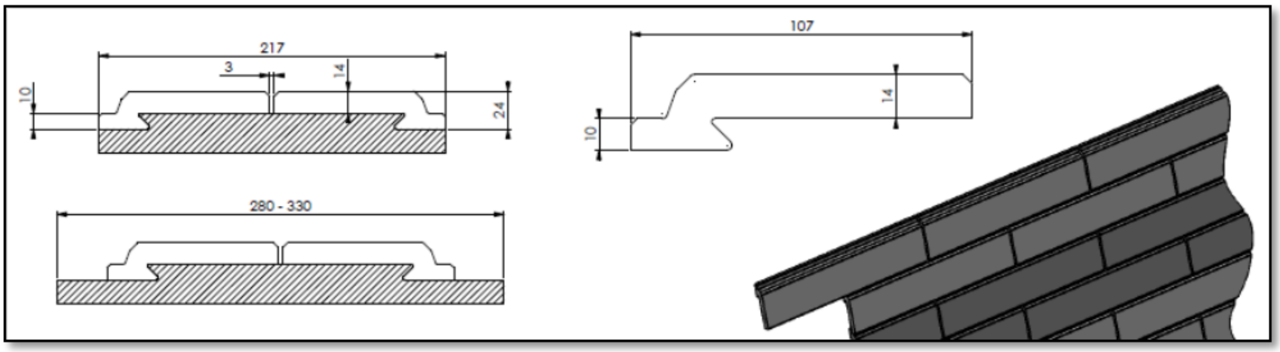

Figure 13: RE4 extruded tiles width and thickness

The system is made of pre-cast concrete facing tiles installed on steel mounting rails without mortar, glue or nails that allows the installation in every period of the year.

Thanks to the application of suitable steel components, an insulating layer can be introduced between the RE4 extruded tiles and the existing wall of the building, in order to have a ventilated and well-insulated layer. The fixing system is depicted in Figure 14.

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The insulation panels are of commercial type (not supplied by Vortex within the RE^4 project). Fixing system is a Marmoroc AB patent and will be provided by Vortex through Marmoroc AB.

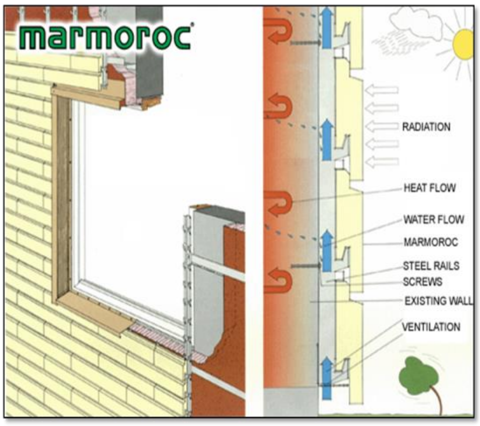

Figure 14: Marmoroc fixing system

The plant main features for RE^4 extruded tiles production are reported in Table 18, while the production steps list in Table 19. Data are referred to a generic plant.

Country and Location site	Potentially world (Eastern Europe and Russia more likely)		
Total area of the site	1500 (50 x 30)	**m^2**	
Plant capacity	~ 40.000	**kg/day**	
	38.400	**pieces/day**	
Yearly operation time	250	**days/year**	
Effort		**men/piece**	
Product dimensions	Length	**0,3 or 0,6**	**m**
	Width	**Figure 3**	**m**
	Thickness	**Figure 3**	**m**

Table 18: RE^4 extruded tiles plant main features

N°	Name of the process	Maintenance	Operative personnel
1	*Batching*	Y	1
2	*Extrusion*	Y	1 (shared with Racking)
3	*Racking*	Y	1 (shared with Extrusion)
4	*Curing*	Y	-
5	*DeRacking*	Y	-
6	*Depalleting*	Y	-
7	*Packing*	Y	1
8	*Strapping*	Y	-
9	*Palletizing*	Y	1 or 2

Table 19: RE^4 extruded tiles production main steps

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Below a description of each process step:

1. **Batching**: Sand, in the 0-2 mm fraction, together with Portland cement and water enter the planetary mixer, and after a mixing phase fresh concrete is discharged on a conveyor belt. The mixer may be equipped with a humidity probe for water dosing correction according to sand humidity. The duration of the cycle is of approximately 4 minutes including the skip hoist waiting phase.
2. **Extrusion**: Fresh concrete feeds the extruder through an overhead hopper. The tiles are formed by extrusion-pressure process of concrete on die-cast aluminium pallets. The extruder consists of a steel bench fitted with a series of anti-wear steel guides for the moulds to run on, a continuous pusher unit, an extrusion head and an automatic flying cutter. The mould bed, under the action of the propulsion chain, passes through the extrusion head, which consists of a rectangular heavy duty steel box containing a stirrer and a shaping roller, both driven by a motor gear box. A shaped slipper is mounted at the exit of the rectangular box. The cement-based mixture is fed automatically into the box where its level automatically controlled. The stirrer prevents the material from forming bridges and guarantees a uniform feeding of material under the roller. The shaped roller presses the mixture on to the aluminium moulds and pushes it towards the shaped slipper, which causes the material to be extruded between the moulds and the slipper itself. The continuous stream of extruded material is then divided into lengths which correspond to the separations between the moulds by means of a cutter, fitted with a blade which has the same profile of the RE^4 extruded tiles. The cutter is automatically activated by a pneumatic mechanism. A central insert in the slipper and a wheel blade mounted at the exit of the slipper after the insert divide the flow of concrete.
3. **Racker:** wet extruded tiles are conveyed to an elevator, stacked and then accommodated with their rack inside the curing area.
4. **Curing:** it may take place inside a rotational rack structure (Rotary system) or inside a series of adjacent chambers (Matrix system). The curing area is thermally insulated to minimize heat losses, heated to promote cement hydration, with air properly circulated to ensure consistent curing conditions. Various temperature and humidity probes and exhausting fans, heat-exchangers are strategically located inside the curing area.
5. **Deracker**: Stacked dry tiles are picked up from the curing area, lowered from stacked to in-line configuration and conveyed to the next step of the process. The system works on a Fi / Fo (First in – First out) logic.
6. **Depalleter:** Dry tiles are separated from their aluminium pallets. Pallets are diverted back to the extruder for a new extrusion cycle, while dry tiles are conveyed to the next step of the process.
7. **Packing:** Dry tiles are packed with a device capable to form packs of #10 tiles.
8. **Strapping:** Strapped packs are double strapped.

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

9. **Palletizing**: Packs are diverted to a grouping conveyor where a robot with automatic gripper load packs onto the wooden pallets dispensed by pallet dispenser.

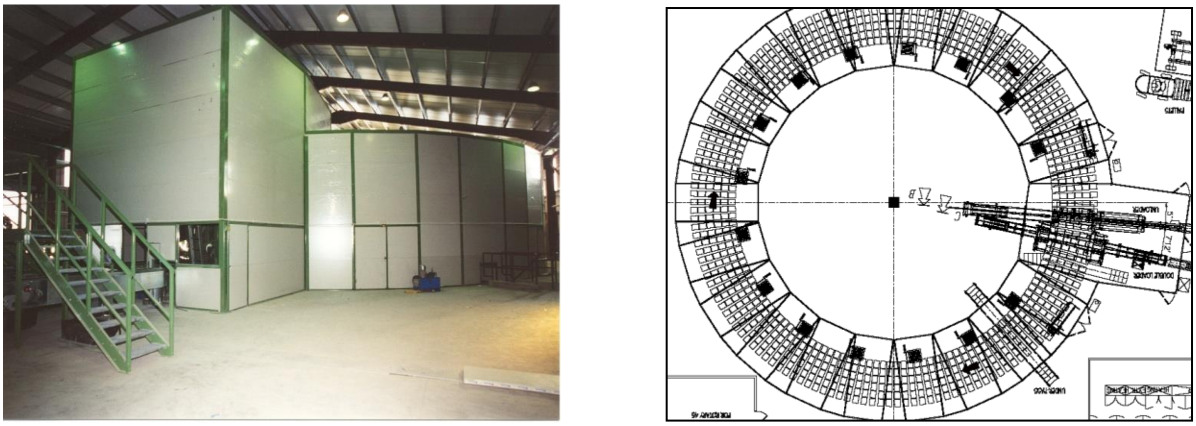

Figure 15 : Boxed curing area with Rotary system.

The overall mechanical efficiency is approximately 85%, spread over an 8 hours shift and for the overall process.

The RE[4] extruded tiles production steps are depicted in the scheme reported in Figure 16.

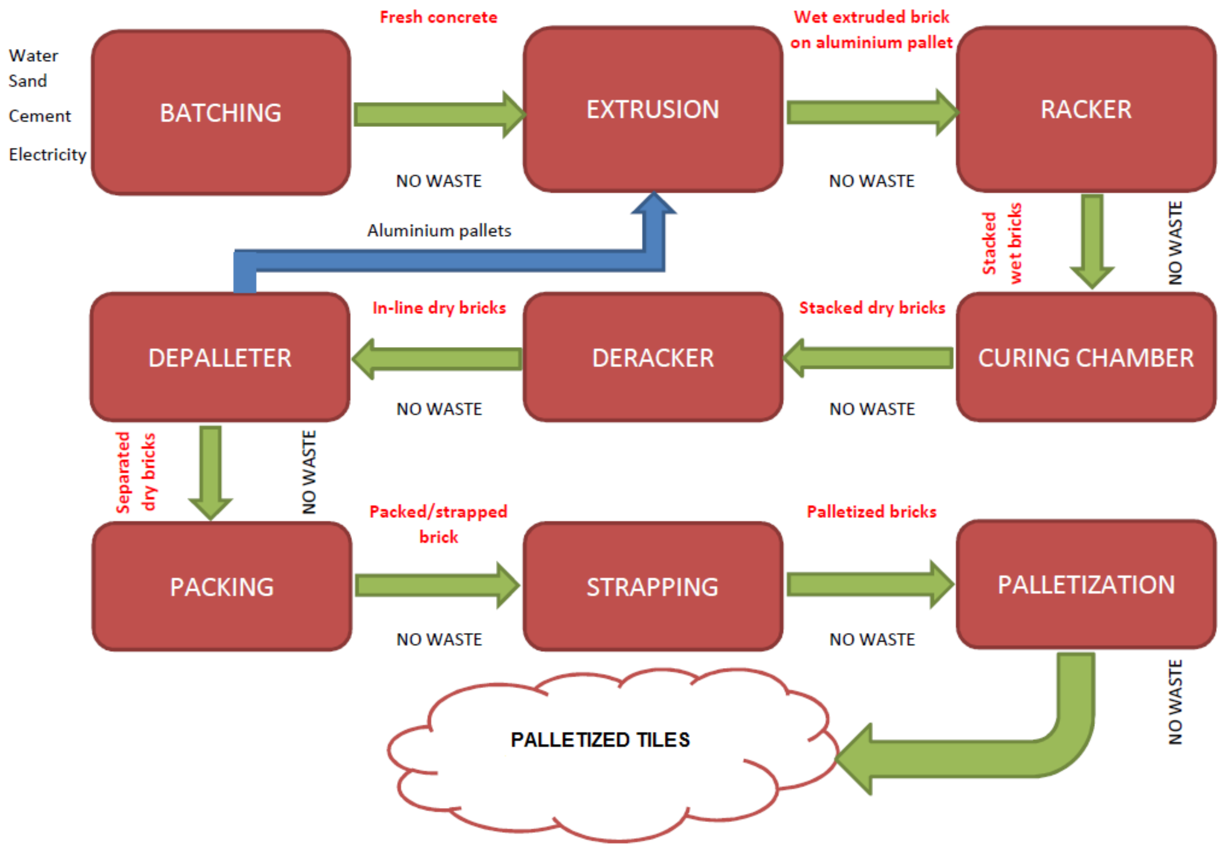

Figure 16: RE[4] extruded tiles production steps flow chart

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The technical data and assumptions considered for the material and energy balance each step and for equipment sizing are reported. Moreover, materials, water and energy inputs and output of each step are reported.

3.1 Process step n.1: BATCHING

For batching step technical data and assumptions are reported in Table 20, while materials input and output are listed in Table 21 and Table 22, respectively and the equipment list is reported in Table 23.

Technical data and assumption - batching		
Efficiency	95	%
Temperature	+5 ÷ + 40	°C
Duration of the process step (if feasible)	4	mins

Table 20: RE^4 extruded tiles Batching technical data and assumptions

Inputs - batching		
Power	42	kW
Water	147	L
Sand	1284	kg
Cement	369	kg

Table 21: RE^4 extruded tiles Batching Input

Outputs - batching		
Water	None	L
Waste	None	...
Intermediate Product: fresh concrete	1800	kg

Table 22: RE^4 extruded tiles Batching Output

Equipment- batching	Units	Characteristics	
Skip	1	5,5	kW
Mixer	1	36	kW
Discharge system	1	1,5	kW

Table 23: RE^4 extruded tiles Batching equipment list

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3.2 Process step n.2: EXTRUSION

For extrusion step, technical data and assumptions are reported in Table 24, while materials input and output are listed in Table 25 and Table 26, respectively and the equipment list is reported in Table 27.

Technical data and assumption - extrusion		
Efficiency	95	%
Temperature	+5 ÷ +40	°C
Duration of the process step (continuous process)	40x2 tiles	min

Table 24: RE^4 extruded tiles Extrusion technical data and assumptions

Inputs - extrusion		
Power	23,5	kW
Water	None	L
Fresh concrete	~ 2,2	kg/un

Table 25: RE^4 extruded tiles Extrusion Input

Outputs - extrusion		
Water	None	L
Waste	None	
Intermediate Product: wet tile	~ 2,2	kg/un

Table 26: RE^4 extruded tiles Extrusion Output

Equipment - extrusion	Units	Characteristics	
Extruder	1	22	kW
Cutter	1	1,5	kW

Table 27: RE^4 extruded tiles Extrusion Equipment list

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3.3 Process step n.3: RACKER

For racker step, technical data and assumptions are reported in Table 28, while materials input and output are listed in Table 29 and Table 30, respectively and the equipment list is reported in Table 31.

Technical data and assumption - racker		
Efficiency	95	%
Temperature	+5 ÷ +40	°C
Duration of the process step (if feasible)	75	s

Table 28: RE4 extruded tiles racker technical data and assumptions

Inputs - racker		
Power	10,6	kW
Water	None	L
Wet tile	~ 2,2	Kg/un

Table 29: RE4 extruded tiles racker input

Outputs - racker		
Water	None	L
Waste	None	
Intermediate Product: wet tile	~ 2,2	Kg/un
Water	None	L

Table 30: RE4 extruded tiles racker output

Equipment - racker	Units	Characteristics	
Loading conveyor	1	1,5	kW
Stacker	1	6,1	kW
Hydraulic power unit	1	3	kW

Table 31: RE4 extruded tiles racker equipment list

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

3.4 Process step n.4: CURING

For curing step, technical data and assumptions are reported in Table 32, while materials input and output are listed in Table 33 and Table 34, respectively and the equipment list is reported in Table 35.

Technical data and assumption - curing		
Efficiency	95	%
Temperature	+40÷ +45	°C
Duration of the process step (if feasible)	5	h

Table 32: RE[4] extruded tiles curing technical data and assumptions

Inputs - curing		
Power	12,49	kW
Heat	237	kW
Water	None	L
Wet tile	~ 2,2	Kg/un

Table 33: RE[4] extruded tiles curing Input

Outputs - curing		
Water	None	L
Waste	None	…
Hardened tile	~ 2,1	Kg/un

Table 34: RE[4] extruded tiles curing output

Equipment - curing	**Units**	**Characteristics**	
Hot water boiler	1	5	kW
Air heater	5	1,1	kW
		Tin = 80 Tout = 65	°C
Pump	5	0,25	kW
Exhaust air blower	2	0,37	kW

Tin = temperature of water entering the air heater

Tout = temperature of water leaving the air heater

Table 35: RE[4] extruded tiles curing equipment list

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3.5 Process step n.5: DERACKER

For deracker step, technical data and assumptions are reported in Table 36, while materials input and output are listed in Table 37 and Table 38, respectively and the equipment list is reported in Table 39.

Technical data and assumption - deracker		
Efficiency	95	%
Temperature	+5 ÷ +40	°C
Duration of the process step (if feasible)	300	s

Table 36: RE4 extruded tiles deracker technical data and assumptions

Inputs - deracker		
Power	9,5	kW
Water	None	L
Hardened tile	~ 2,1	Kg/un

Table 37: Marmoroc ™ deracker inputs

Outputs - deracker		
Water	None	L
Waste	None	
Intermediate Product: hardened tile	~ 2,1	Kg/un

Table 38: RE4 extruded tiles deracker outputs

Equipment - deracker	Units	Characteristics	
Loading conveyor	1	1,5	kW
Lowerator	1	4	kW
Hydraulic power unit	1	4	kW

Table 39: RE4 extruded tiles deracker equipment list

3.6 Process step n.6: DEPALLETER

For depalleter step, technical data and assumptions are reported in Table 40, while materials input and output are listed in Table 41 and Table 42, respectively and the equipment list is reported in Table 43.

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Technical data and assumptions - depalleter		
Efficiency	95	%
Temperature	+5 ÷ +40	°C
Duration of the process step (if feasible)	Continuous	h

Table 40: RE⁴ extruded tiles depalleter technical data and assumptions

Inputs - depalleter		
Power	3	kW
Water	None	L
Hardened tile	~2,1	Kg/un

Table 41: RE⁴ extruded tiles depalleter input

Outputs - depalleter		
Water	None	L
Waste	None	
Intermediate Product: hardened tile separated from pallet	~2,1	Kg/un

Table 42: RE⁴ extruded tiles depalleter output

Equipment - depalleter	Units	Characteristics	
Depalleter	1	3	kW

Table 43: RE⁴ extruded tiles depalleter equipment list

3.7 Process step n.7: PACKING-STRAPPING

For packing-strapping step, technical data and assumptions are reported in Table 44, while materials input and output are listed in Table 45 and Table 46, respectively and the equipment list is reported in Table 47.

Technical data and assumptions - packing-strapping		
Efficiency	95	%
Temperature	+5 ÷ +40	°C
Duration of the process step (if feasible)	Continuous	h

Table 44: RE⁴ extruded tiles packing-strapping technical data and assumptions

Inputs - packing-strapping		
Power	35	kW
Water	None	L
Spare hardened tile	~2,1	Kg/un

Table 45: RE⁴ extruded tiles packing-strapping inputs

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Outputs - packing-strapping		
Water	None	L
Waste	None	
Intermediate Product: packed tiles (6 pcs)	~ 12,6	Kg/un

Table 46: RE4 extruded tiles packing-strapping outputs

Equipment - packing-strapping	Units	Characteristics	
Packer	1	35	kW

Table 47: Marmoroc ™ packing-strapping equipment list

3.8 Process step n.8: PALLETIZATION

For palletization step, technical data and assumptions are reported in Table 48, while materials input and output are listed in Table 49 and Table 50, respectively and the equipment list is reported in Table 51.

Technical data and assumptions - palletization		
Efficiency	95	%
Temperature	+5 ÷ + 40	°C
Duration of the process step (if feasible)	Continuous	h

Table 48: RE4 extruded tiles palletization technical data and assumptions

Inputs - palletization		
Power	20	kW
Water	None	L
Packed tiles	~ 12,6	Kg/un

Table 49: RE4 extruded tiles palletization inputs

Outputs - palletization		
Water	None	L
Waste	None	
Intermediate Product: palletized tiles (504 pcs)	~ 1058	Kg/un

Table 50: RE4 extruded tiles palletization outputs

Equipment - palletization	Units	Characteristics	
Palletizer	1	20	kW

Table 51: RE4 extruded tiles palletization equipment list

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3.9 Process step 9: WRAPPING

For wrapping step, technical data and assumptions are reported in Table 52, while materials input and output are listed in Table 53 and Table 54, respectively and the equipment list is reported in Table 55.

Technical data and assumption - wrapping		
Efficiency	95	%
Temperature	+5 ÷ +40	°C
Duration of the process step (if feasible)	Continuous	h

Table 52: RE[4] extruded tiles wrapping technical data and assumptions

Inputs - wrapping		
Power	11	kW
Water	None	L
Palletized tiles	~ 1058	Kg/un

Table 53: RE[4] extruded tiles wrapping inputs

Outputs - wrapping		
Water	None	L
Waste	None	
Intermediate Product: wrapped tiles	~ 1058	Kg/un

Table 54: RE[4] extruded tiles wrapping outputs

Equipment - wrapping	Units	Characteristics	
Wrapper	1	11	kW

Table 55: RE[4] extruded tiles wrapping equipment list

The output product is the intermediate tiles, this product leaves the plant as it is with its standard dimensions and, subsequently, installed with other components in the façade. The overall system is depicted in Figure 17.

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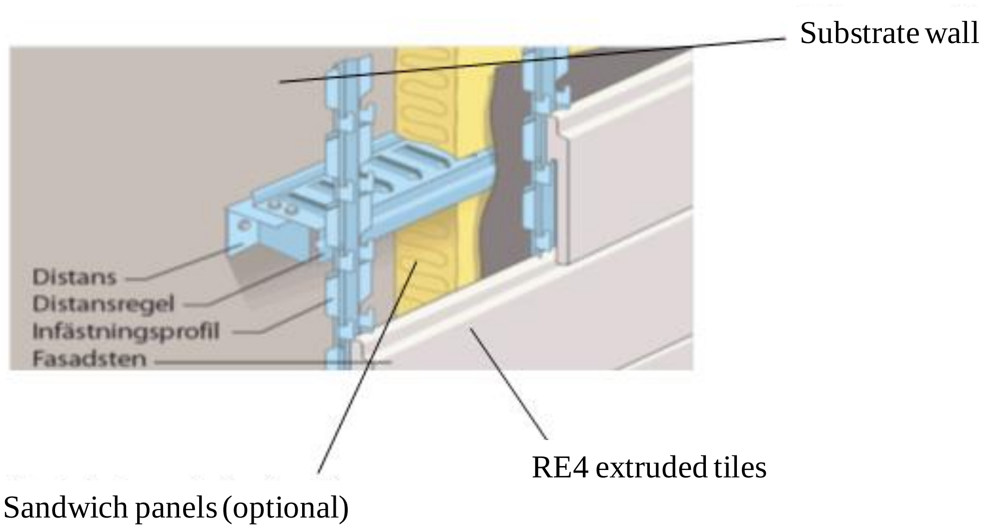

Figure 17: Overall façade system

3.10 RE4 extruded tiles BLOCK FLOW DIAGRAM AND PLANT LAYOUT

Figure 18**Error! Reference source not found.** depicts the plant layout and block flow diagram of the extruded façade tile production.

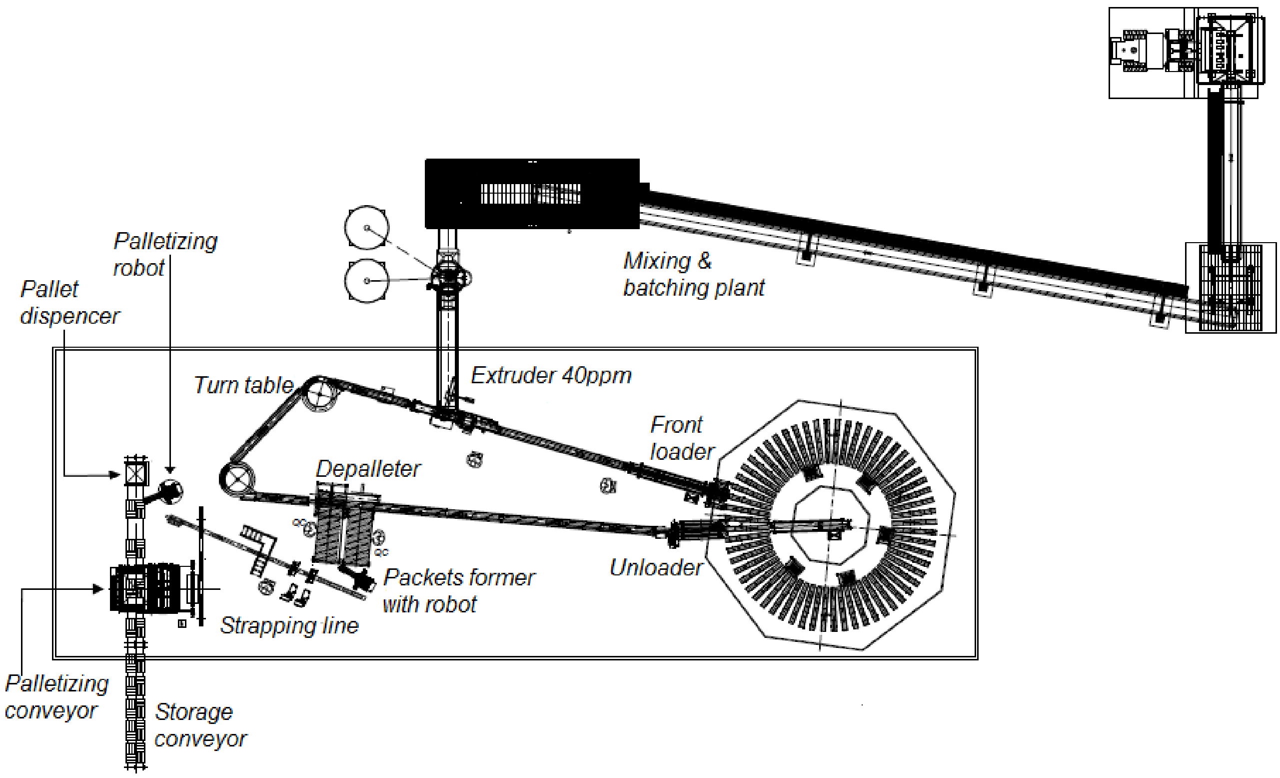

Figure 18: Extruded façade tile production line Plant layout

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While the energy and mass balances and block flow diagram for the production of 1 benchmark extruded tiles at industrial scale were calculated and listed in Table 56 and Figure 19, respectively.

Benchmark - Extruded façade tile production line			
Input	Electrical Power	65,04	kWh El.
	Heat	237,00	kWh Th.
	Dolomite	1,64	kg
	Cement	0,4	kg
	Water	0,18	kg
	Pigment, iron oxide based	0,01	kg
	Lime reducing agent	0,002	kg
	Soap	0,002	kg
Output	Benchmark extruted tile	2,1	kg
	Waste	0	kg

Table 56: Benchmark Extruded façade tile production line energy and mass balances

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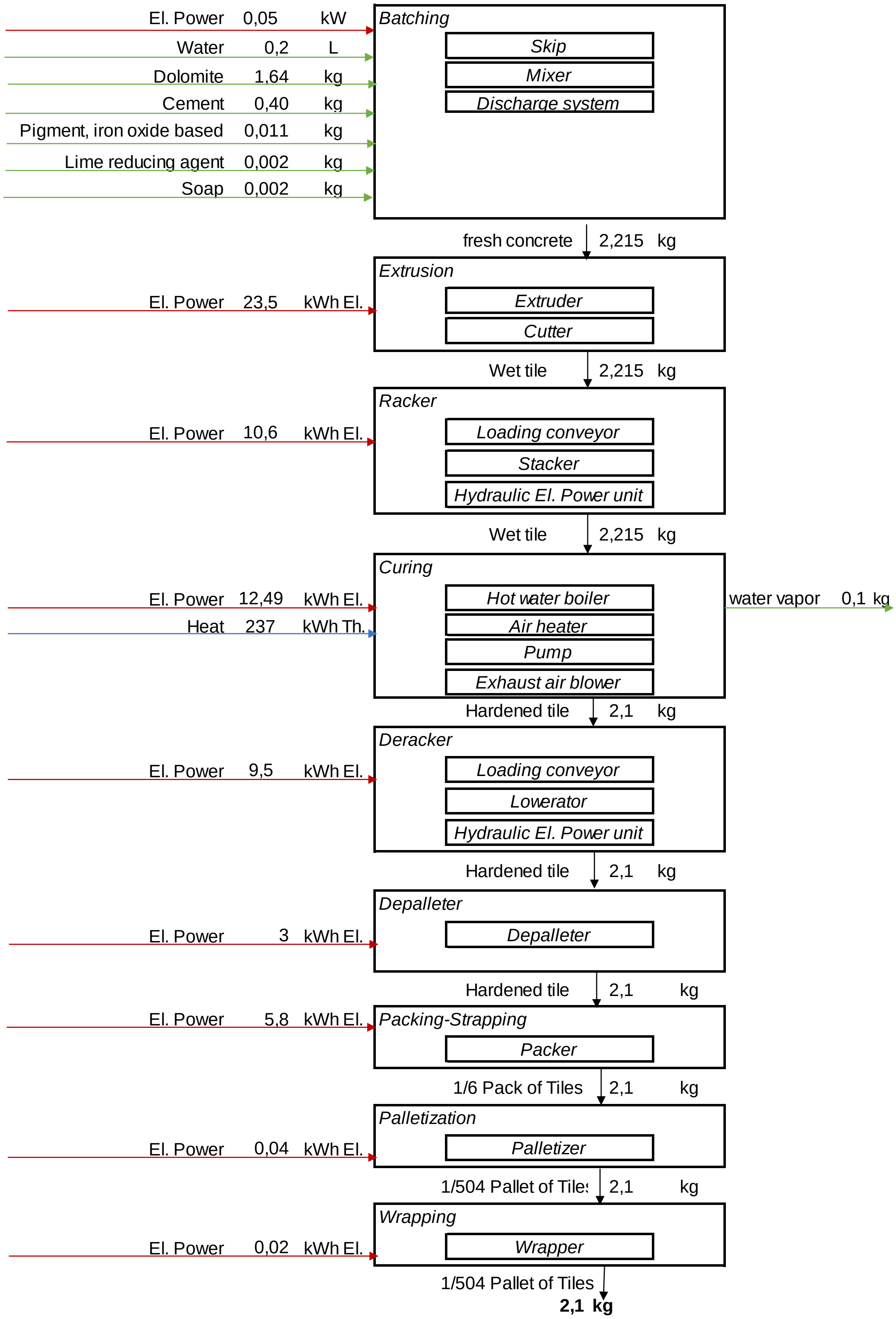

Figure 19: Block Flow Diagram of benchmark Extruded façade tile production line

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Table 57 reports energy and mass balances for RE^4 extruded tiles and Figure 20 the block flow diagram.

Extruded façade tile – mass and energy balances			
Input	Electrical Power	65,04	kWh El.
	Heat	237	kWh Th.
	Water	0,18	L
	Sand	1,57	kg
	Cement	0,45	kg
Output	Marmoroc™ Tile	2,1	kg
	Waste	0	kg

Table 57: RE^4 Extruded façade tile production line energy and mass balances

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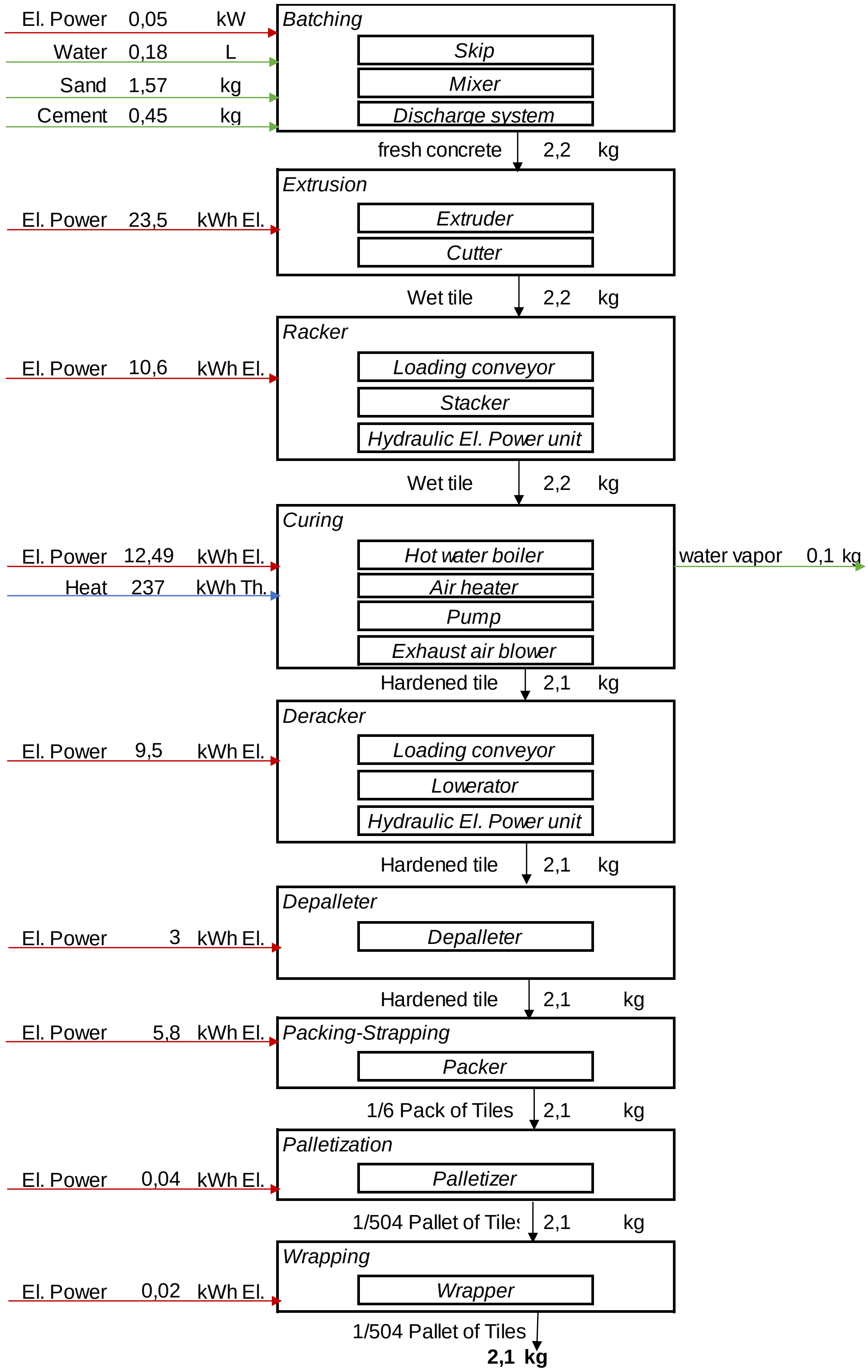

Figure 20: Block Flow Diagram of RE[4] Extruded façade tile production line

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4 Pilot plant for RE⁴ timber façade panel

RE⁴ timber façade panels were not originally foreseen to be analysed within the task but due to the high relevance of the product, the production process was included in the investigation. However, as within the RE⁴ consortium no partner has the expertise to perform an industrial upscaling of the timber panel production process, only preliminary information are reported.

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.

Timber used for the production of the previous elements was obtained from different construction sites, where timber roofs have been dismantled, by means of a winch, and transported by truck to the final manufacturing site.

Before dismantling, the timber is assessed against the possible presence of wood preservatives. If no wood preservatives or other harmful substances or fungi are found, beams, columns and flooring boards are dismantled from existing buildings. The harvested material is brought to a saw mill, cleaned, planed and cut into lamellas, after removal of possible fittings.

The final prefabricated panel will be assembled by carpenters in a carpenter's workshop, using screws and other fasteners to enable reversible connections.

Earth plaster will be applied in the workshop: RE⁴ earth plaster is made from CDW sand and virgin clayey soil (binder).Only a final thin coat will be applied on site.

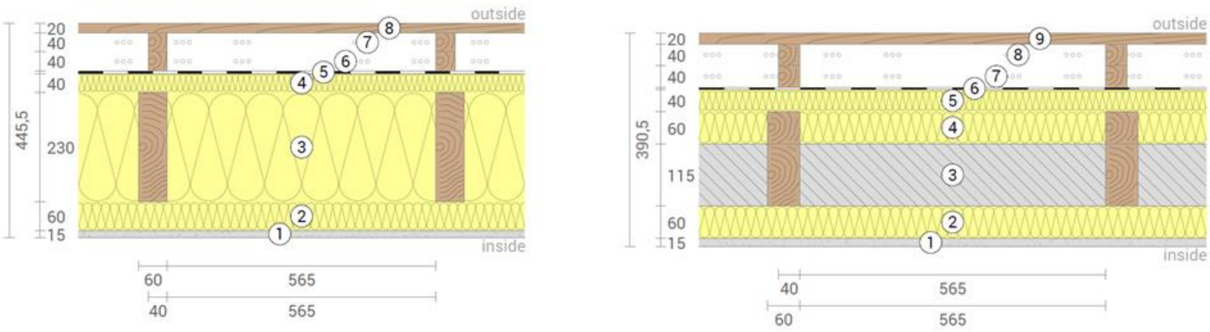

Figure 21: RE⁴ façade panel for cold climate (left) and warm climate (right)

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Table 58: RE4 timber façade panel for cold 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
3a	Infill insulation sawdust + clay (89%)	230	100% wooden fibres from the processing CDW timber, 100% clay from CDW recycling 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) Commercial product
5	Breather membrane sd=0.5	0.05	3-layered membrane, made of tear-resistant, vapour permeable PP spun bonded film Commercial product
6	Rear ventilated level	40	40 mm x 40 mm RE4 CDW spruce battens
7	Rear ventilated level	40	40 mm x 40 mm RE4 CDW spruce battens
8	Larch	20	100% timber battens from RE4 CDW (except fixage)
Total		445	

Table 59: RE4 timber façade panel for warm climate, layer composition (Solution a)

	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/m^3	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/m^3"- 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

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6	Breather membrane sd=0.5	0.05	3-layer 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 60: RE4 timber façade panel for warm climate, layer composition (Solution b)

	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), 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		300	

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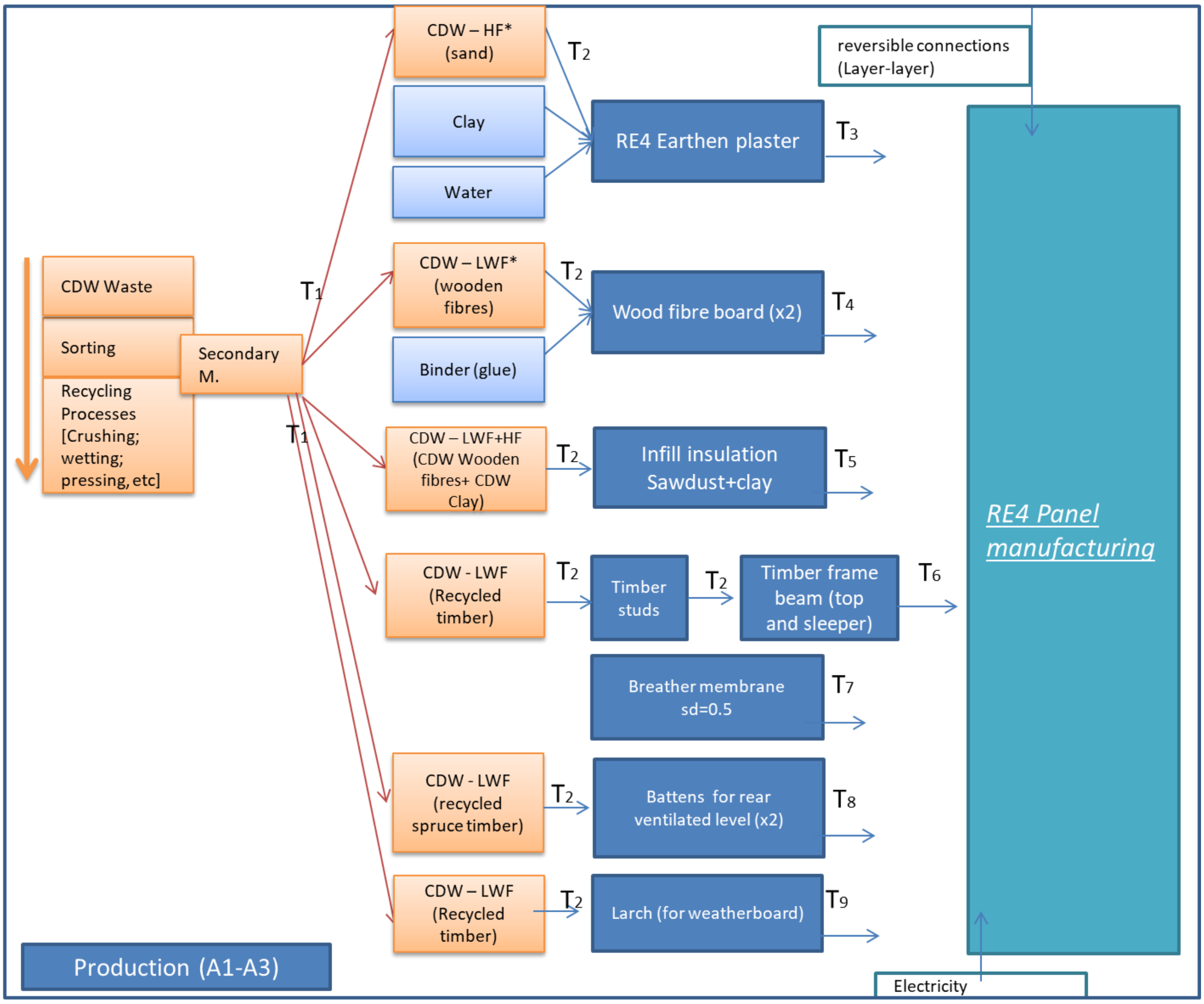

Figure 22: Production process for timber façade panel for cold climate *LWF=Lightweight Fraction; *HF=Heavy Fraction

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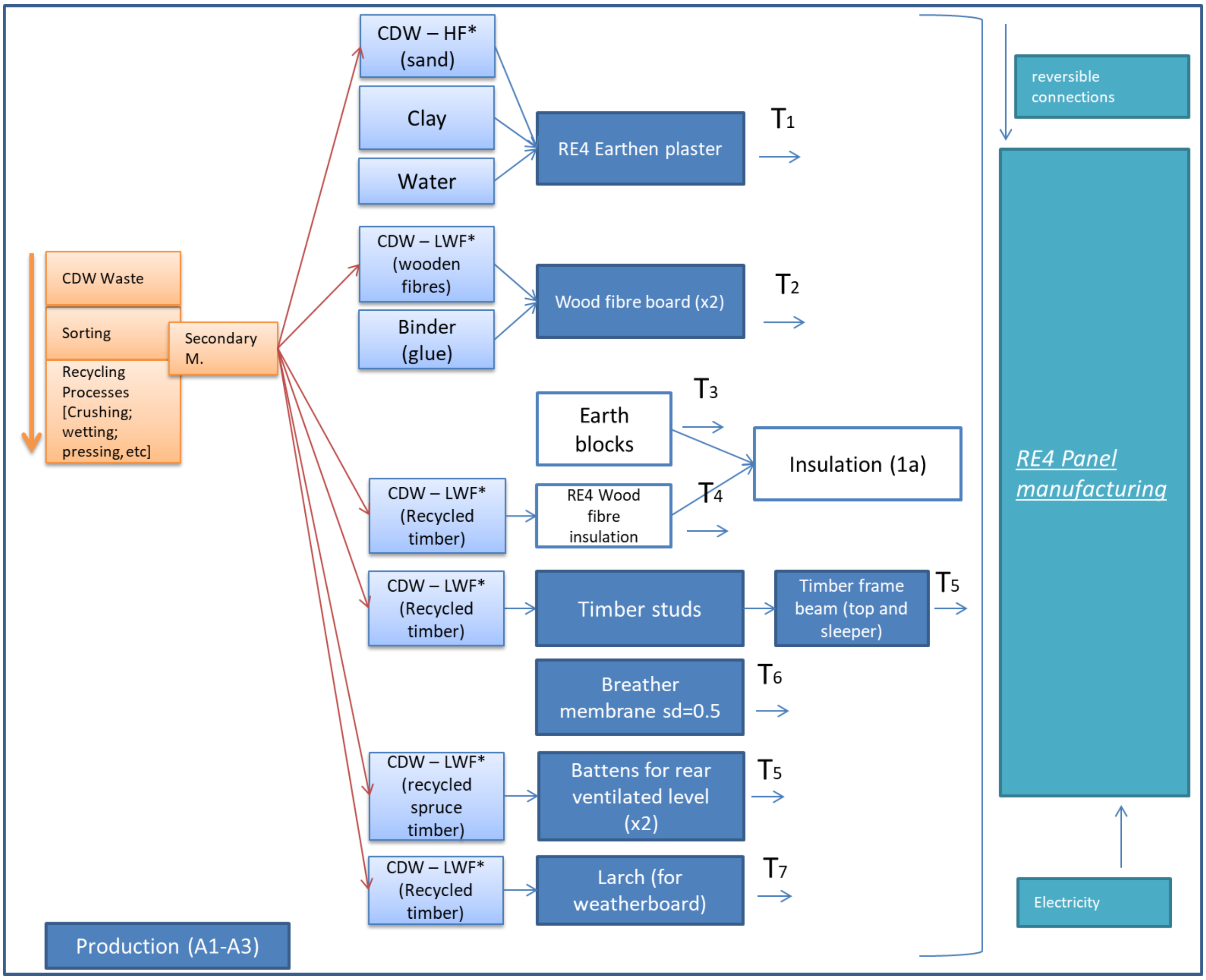

Figure 23: Production process for timber façade panel for warm climate (Solution a) *LWF=Lightweight Fraction; *HF=Heavy Fraction

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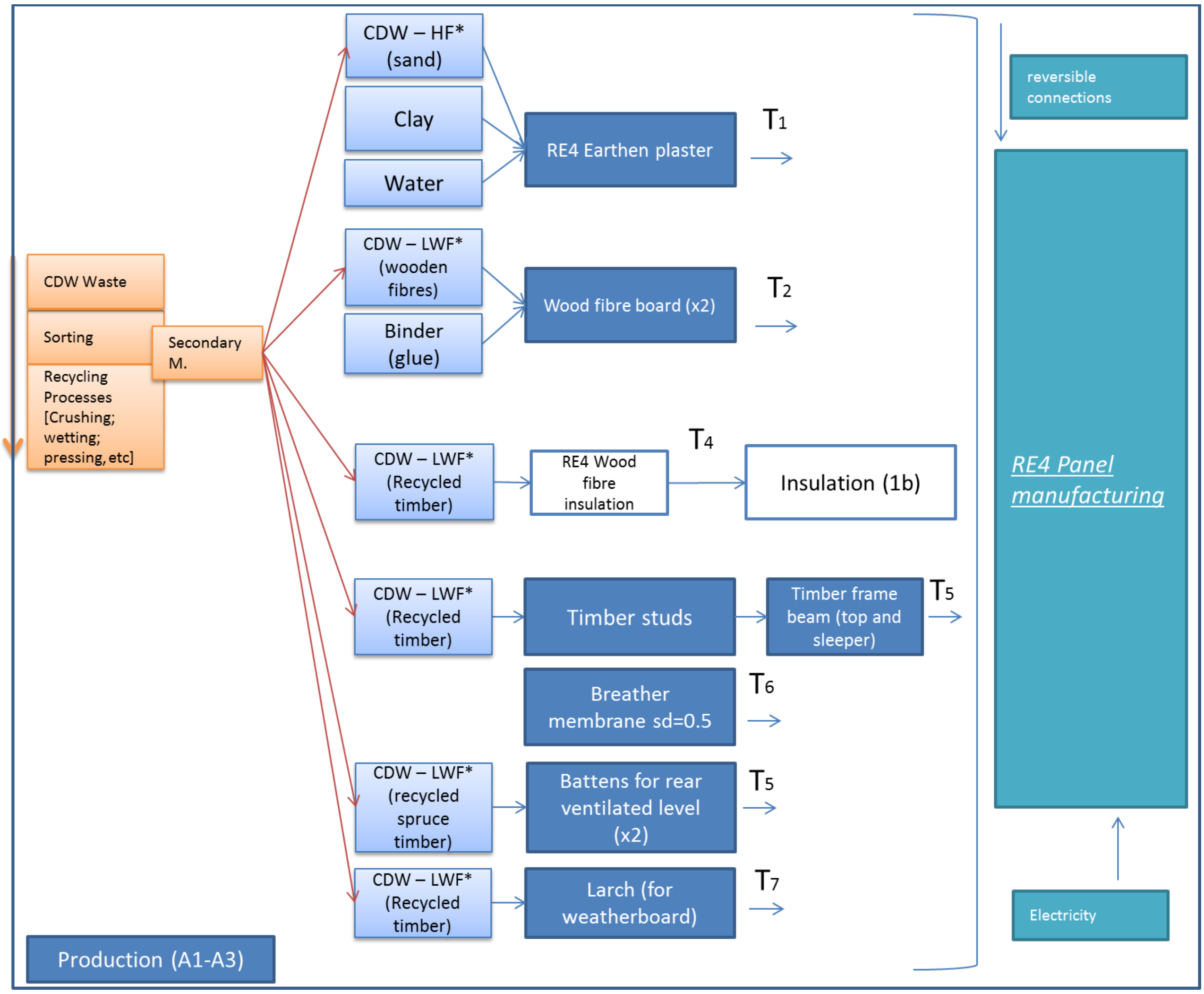

Figure 24: Production process for timber façade panel for warm climate (Solution b) *LWF=Lightweight Fraction; *HF=Heavy Fraction

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For the purpose of this deliverable, only the information related to the production of the wood fibre panels are reported, since they are being tested within CETMA facilities.

Wood fiber panels is produced by a dry process, which is considered less energetically expensive than the traditional wet process. The mineralization process allows fibers to became inert and fire resistant and consists in inserting the fibers in a hermetic container, where the process will be optimized in terms of soaking liquid to be used and pressure levels. Mineralized fibers are then coated with suitable resin, bound together under pressure and in temperature to form a stable, resistant, compact and durable structure.

Implementing CETMA equipment with a new autoclave system (double in volume respect to the one already present) and considering mineralized wood panels of 500 kg/m^3 density and 0.06 m thickness, the productivity would be of about 2 m^2/day.

First trials on the pilot line were carried out in order to verify that the upscale process does not present unexpected problems due to the use of industrial machinery and the bigger quantities of CDW material. For this reason, the lab scale process has been repeated as main steps of production, with a recalibration of times.

N°	Name of the process	Maintenance	Operative personnel
1	*Sieving*	Y	-
2	*Soaking*	Y	1 (shared with Draining)
3	*Draining*	Y	1 (shared with Soaking)
4	*Fibers distribution*	N	1
5	*Moulding*	Y	-
6	*Panel Removing*	N	1

Table 61: Production main steps

Below a description of each process step:

1. **Sieving**: the material needs to be sieved in a 4 mm mesh sieve, in order to eliminate the pieces of wood bigger than the chosen dimension for the panels and with such a shape that could not be intertwined.
2. **Soaking**: wood pieces are soaked in water.
3. **Draining**: the soaked material is them roughly drained by the water.
4. **Fibers distribution**: the material is organized in the mould in order to fill completely the available space.
5. **Moulding**: the material is kept under pressure and at stable temperature: the filled mould is introduced in hydraulic press and then kept under pressure and in temperature. The process requires steps at two different temperatures (160°C and 120°C).

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6. **Demoulding**: after being cooling down to room temperature the mould is moved out from the machinery and opened. The panel is then removed from the mould.

4.1 Process steps input and output

Into the present subchapter, the material and energy flows table are currently reported in an aggregated and simple way, as mentioned at the beginning this section.

Technical data and assumption - Wood fiber panels		
Efficiency	N.A.	%
Temperature	+5 ÷ + 40	°C
Duration of the process step (if feasible)	N.A.	mins

Table 62: Wood fiber panels technical data and assumptions

Inputs - Wood fiber panels		
Power	N.A.	kW
Water	None	L
CDW wood fibres	6,08	kg
Glue	0,32	kg

Table 63: Wood fiber panels Input

Outputs - Wood fiber panels		
Water	None	L
Waste	N.A.	...
Intermediate Product: Wood fiber panels	6,4	kg

Table 64: Wood fiber panels Output

Equipment- Wood fiber panels	Units	Characteristics	
Sieving	1	N.A.	kW
Soaking and draining	1	N.A.	kW
Moulding	1	N.A.	kW

Table 65: Wood fiber panels equipment list

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5 Conclusions and recommendations

The objective of WP7 is to analyse the environmental, economic and social impacts of the innovative solutions developed within RE^4 project, reducing time to market and contributing to improve market and social acceptance.
Within the document, the upscaled processes are analysed on the basis of the information provided by the involved partners and will serve as a basis for the sustainability activities to be carried out for LCA, LCC and SLCA analyses.

This deliverable reported one dedicated section for each of the product's families analysed, namely: R^{E}4 concrete sandwich panels, RE^4 extruded tiles to be used in ventilated facades, RE^4 timber façade panels. Each session contains the design, the production flow, the main features of the products, the unitary operations involved, the available data on energy and materials flows and streams as well as the block flow diagram.

The results reported in this deliverable will be used in the other task of WP7 and in particular in Tasks 7.2, 7.3 and 7.4. In addition, some of 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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6 References

- Deliverable 6.1: "Production. Conditioning, manufacturing and quality control. Safe production guideline" - RE^4 project (GA 723583)
- Deliverable 7.2: "Framework for LCA/LCCA/S-LCA"- RE4 project (GA 723583)
- Inventory analysis and boundary limits of LCA and LCC for timber façade extracted from the draft of Deliverable 7.3: "Inventory" - RE^4 project (GA 723583)
- Questionnaires provided by VORTEX on 07/01/2019 for extrusion process
- Questionnaires provided by CREAGH/RISE on 18/02/2019 for concrete façade component

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