H2020-NMBP-ST-IND-2018-2020-GA 958218

PLUG-AND-USE RENOVATION WITH ADAPTABLE LIGHTWEIGHT SYSTEMS

PLURAL

D6.2
Assembly methodology for PnU kits

Version: 1.1

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958218

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Terms, definitions, and abbreviated terms

AA	Activated Alumina
AHU	Air Handling Unit
BRIMEE	Cost-effective and sustainable Bio-Renewable Indoor Materials with high potential for customisation and creative design in Energy Efficient buildings
CEN	CENELEC
EMC	Equilibrium Moisture Content
EN ISO 16000	Indoor air — Part 1: General aspects of sampling strategy
HEPA	high-efficiency particulate air
HVAC	Heating Ventilation and Air-Conditioning
IAQ	Indoor Air Quality
ISO	International Organization for Standardization
PnU	Plug and Use
PS	Potassium Silicate
RETROKIT	RetroKit - Toolboxes for systemic retrofitting
RH	Relative Humidity
SG	Silica Gel
VOC	Volatile Organic Compounds
WHO	World Health Organization

TABLE 1: ACRONYMS

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1 Publishable summary

Assembly is more than putting parts together. Assembly is the capstone process in manufacturing. It brings together all the upstream processes of design, engineering, manufacturing, and logistics to create an object that performs a function. A great deal is known about the unit processes that are required to fabricate and inspect individual parts. With the invention of the assembly line in the early 1900s, assembly in manufacturing transformed into a much more productive, efficient, and safer operation. The part being manufactured moves along a semi-automated system from workstation to workstation and each station performs a specific task along the line. Advances in manufacturing technology as well as computer aided tracking throughout each process has allowed manufacturers to increase their overall throughput over the years while decreasing their rework or scrap operations. In return, the manufacturer could reinvest the savings for future projects.

Moving a step forward, this report aims to present the basic assembly steps for each PLURAL PnU kit and highlight the main parameters infusing their assembly process, taking into consideration the PnU kit versatility, flexibility, and adaptability to the demo building's requirements.

Briefly, this report aims to:

a) Present the assembly methodology for each PnU kit to be manufactured for installation at the project's demonstration buildings. D6.2 is the outcome of T6.2: Assembly methodology and planning and should be read in conjunction with *D6.1 – Manufacturing methodology of PLURAL kits*;
b) Identify the Quality Assurance Protocols for each Working Station involved;
c) Identify and present essential parameters of the production such as:
    a. Processes duration per Working Station;
    b. Required materials and use of resources per Working Station;
    c. Auxiliary equipment used per Working Station;
    d. Energy use and any other auxiliary means of auxiliary to the assembly process parameters.

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2 Introduction

"*Manufacturing*" is determined as *"the creation or production of goods with the help of equipment, labor, machines, tools, and chemical or biological processing or formulation"*[1] and has been extensively described in *D6.1 - Manufacturing methodology of PLURAL kits*. The *"Assembly"* process is determined as *"a manufacturing process (often called a progressive assembly) in which parts (usually interchangeable parts) are added as the semi-finished assembly moves from workstation to workstation where the parts are added in sequence until the final assembly is produce"*[21]. Moving a step forward, this report aims to present and record the basic assembly steps for each PLURAL PnU kit and highlight the main parameters infusing the Assembly process, taking into consideration the PnU kits' versatility, flexibility, and adaptability to the demo building's requirements.

Deliverable D6.1 - Manufacturing methodology of PLURAL kits presented the overall LEAN (6σ) methodology of the manufacturing process developed for the PLURAL PnU kit manufacturing. Additionally, the data included in the deliverables of *WP2 - Selection of technologies – Integration – Design of PnU kits*, and *WP4 - Optimization of PnU components – prototyping – testing,* established the assembly process that the manufactures followed for the PnU kits manufacturing for each demo building.

The current D6.2 report aims to:

a) Present the assembly methodology for each PnU kit to be manufactured for installation at the project's demonstration buildings. D6.2 is the outcome of T6.2: Assembly methodology and planning and should be read in conjunction with *D6.1 – Manufacturing methodology of PLURAL kits*;
b) Identify the Quality Assurance Protocols for each Working Station involved;
c) Identify and present essential parameters of the production such as:
    a. Processes duration per Working Station;
    e. Required materials and use of resources per Working Station;
    f. Auxiliary equipment used per Working Station;
    g. Energy use and any other auxiliary means of auxiliary to the assembly process parameters.

The main key factors that were taken into consideration for the establishment of the Assembly methodology were:

a. *Planning*
   Aiming to reduce assembly time, human resources involvement and eventually costs.
b. *Materials*
   Use of manufacturing-compliant materials which determine manufacturing processes and means, materials management and quality control.
c. *Processes*
   Know – understand – adjust the manufacture process to reduce costs.
d. *Standards*
   Use of standard / commercial parts or components, resulting to cost reduction, while improving inventory management and time-to-market conditions.

It must be noted that this report is under Public Dissemination Status. Therefore, essential information which considered by the manufacturers as "*Sensitive",* such as Cost Analysis, Manufacturing Drawings, Bill of Materials, Quality Assurance Plan, etc. has not been included in the current report but will be presented in *Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly (M36)* which is a confidential deliverable.

Finally, it should be highlighted that each assembly line has different characteristics and requirements and this is depicted in the analysis performed for each PnU kit.

[1] https://en.wikipedia.org/wiki/Manufacturing
[2] https://en.wikipedia.org/wiki/Assembly_line

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3 SmartWall – Assembly Process

3.1 Assembly Process Analysis

Assembly Process is always the outcome of the manufacturing methodology based on certain actions and activity tasks undertaken during the manufacturing steps, as extensively presented in *Deliverable D6.1 - Manufacturing methodology of PLURAL kits*. Furthermore, in *Deliverable D4.4 – PnU kit porotypes addressing the 3 demo site requirements* the assembly process followed for the manufacturing of the SmartWall prototype installed in the Living Lab of the NTUA was presented in detail.

As a result of the aforementioned deliverables the assembly process of SmartWall systems proved to be an one-time-product manufacturing process, constantly evaluating the single component-parts during the construction flow, leading to the conclusion that the "*100% Inspection Method*" with customized manufacturing and inspection processes to be applied before and after every manufacturing step and to each working station involved to the assembly process, is the most appropriate assembly method for SmartWall systems.

Taking into account the particular needs of the VVV demo building where the SmartWalls will be installed, as presented in the *Deliverables D7.1 – Preliminary Design* and *D2.7 – Final stage complete design of PnU kits,* the assembly methodology for a <u>*typical SmartWall panel @ 2.50m (h) x 1.20 (l) x 0.17m (w) incorporating a window @1.00m (h) x 1.20m (l), roller blinds and its toolbox*</u>, is presented in the paragraphs below, under the following notice:

Due to the "Public" status of the current Deliverable and the sensitivity of the information of the Assembly Process, all data, information and drawings classified as "Confidential" or covered under IPR statuses are presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly (M36).

3.1.1. Prerequisites (prior assembly process commencement)

Step Description: Prerequisites
Tasks' description: As per *Table 2*
Equipment: PC
Auxiliary equipment: Plant's crane
Carrying trailer
Vacuum hoover
Cleaning equipment

Manufacturing Step	Actions
Drawings inspection for mistakes & omissions	a. Visual inspection of drawings to determine any drawing's omissions. b. CAD inspection to determine if drawings comply with requirements. c. CAD inspection to determine if dimensions are correct. d. CAD inspection to determine if auxiliary systems are complying with units to be produced. e. 3D CAD or BIM inspection to determine any discrepancies on design and/or components and/or materials.
Check availability of raw materials	a. Check CAPEX system (storage software if any) in any for materials availability. b. Visual quantification of raw materials.
Raw materials quality check – handling – storage to the *Working Stations*	a. Visual inspection to determine that the raw materials will be used would be of a good quality, e.g., undamaged and without defects etc. b. Clean with appropriate means all materials to be used for manufacturing. c. Use appropriate handling equipment for their transportation to the designated working stations. d. Store them to the designated working stations as per manufacture instructions.

TABLE 2: PREREQUISITES FOR SMARTWALL ASSEMBLY PROCESS

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3.1.2. Working Station WS1

Manufacturing Step:	#1
Step Description:	Steel frame manufacturing
Tasks' description:	***Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly***
Main equipment:	Bench steel cutting machine Bench drilling machine MIG welding machine Portable steel grinder
Auxiliary equipment:	Plant's crane Carrying trailer Hand tools Vices & clamps Digital spirit level Digital angle's meter
Main materials:	Steel hollow rectangular beams Eye nuts M24
Consumables:	Grinding disks Cleaning material & soft clothes Welding flux wire Drill beads

3.1.3. Working Station WS2

Manufacturing Step:	#2
Step Description:	Frame's fire protection
Tasks' description:	***Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly***
Main equipment:	Paint room Air brush painter Power crane Oven - drier
Auxiliary equipment:	Compressed air Carrying trailer Hand tools Carrying wheels
Main materials:	Primer coating Water-based intumescent Basecoat
Consumables:	Soft wool brushes Soft wool rollers Cleaning trowel Nitrous solvent Cleaning materials Soft clothes Paper sheets for protective covering Adhesive tape

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3.1.4. Working Station WS3

Manufacturing Step:	#3
Step Description:	Sub-frames combination
Task description:	Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly
Main equipment:	Air powered screw/bolts driver Bolt's tensiometer
Auxiliary equipment:	Plant's crane Carrying wheels Hand tools Vices & clamps Digital spirit level Digital angle's meter Magnifying glasses with led light
Main materials:	Heat breaker combination fixing Heat breaker threaded holes fixings Stainless steel flat head screws
Consumables:	Cleaning material Soft cloth

3.1.5. Working Station WS4

Manufacturing Step:	#4
Step Description:	Cladding installation
Tasks' description:	***Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly***
Main equipment:	Air powered screw/bolts driver Portable grinder Oven- drier
Auxiliary equipment:	Plant's crane Carrying wheels Cutting knives Scrapers Hand tools
Materials:	Cement board Gypsum plasterboard Gypsum board screws Galvanized steel drywall corned bead
Consumables:	Fiber tape for boards joints Joints filler (putty) Sandpapers

3.1.6. Working Station WS5

Manufacturing Step:	#5
Step Description:	Opening's covering installation ***(****applicable only to units with integrated window or balcony door – if not proceed to WS7)*
Tasks' description:	***Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly***
Main equipment:	Air powered screw/bolts driver

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	Portable saw cutter
	Portable grinder
	Clamps
Auxiliary equipment:	Plant's crane
	Hand tools
	2" brush
	Steel roller
	Cutter knives
	Scrapers
	Digital spirit
	Digital angle's meter
Materials:	OSB boards
	Self-Drilling stainless steel screws
	Cork sheet
	Self-drilling low profile wafer screws
	Marble sill
	Cement boards
	Gypsum board screws
	Galvanized steel drywall corned bead
	Mechanical ventilation system on windows frame
	Window or door
	Windows' supporting brackets
Consumables:	Universal acrylic sealant
	Construction adhesive
	Cleaning material
	Fiber tape for boards joints
	Joints filler (putty)
	Sandpapers
	Soft clothes & sponges

3.1.7. Working Station WS6

Manufacturing Step:	#6
Step Description:	Blinds box installation *(applicable only to units with integrated window or balcony door – if not proceed to WS7)*
Tasks' description:	***Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly***
Main equipment:	Air powered screw/bolts driver
Auxiliary equipment:	Plant's crane
	Carrying trailer
	Hand tools
	Digital spirit level
	Digital Angle's meter
Materials:	Wire (cables)
	Flexible metallic tube
	Installation boxes
	ATEX Zone 1 junction boxes
	Thread Nylon Cable Glands
	Cable brackets
	Self-Drilling stainless steel screws
	Self-drilling low profile wafer screws

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	Roller blinds
	Roller blinds' supporting brackets
Consumables:	Universal acrylic sealant
	Cleaning material
	Soft cloth

3.1.8. Working Station WS7

Manufacturing Step:	#7
Step Description:	Insulators installation
Tasks' description:	Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly
Main equipment:	Portable steel grinder
Auxiliary equipment:	Plant's crane
	Carrying trailer
	Hand tools
	Cutting knives
	Trowel
Materials:	Rock-wool
	Fiber net
	VIP panel
	Thermal thin paste
	M24 rods
	Self-Drilling stainless steel screws
	Galvanized steel drywall corned bead
Consumables:	Adhesive tape
	Sandpapers
	Cleaning material
	Soft clothes & sponges

3.1.9. Working Station WS8

Manufacturing Step:	#8
Step Description:	Fan-coil installation *(applicable only to units with integrated fan-coil – if not proceed to WS9)*
Tasks' description:	Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly.
Main equipment:	n/a
Auxiliary equipment:	Plant's crane
	Carrying trailer
	Hand tools
	Digital spirit level
Materials:	Fan-coil unit
	Fan-coil's anti-vibration rubber pads
	Fan-coil's mounting screws
	Flexible metallic tube
	Thread Nylon Cable Glands
	Cable brackets
	Self-drilling low profile wafer screws
	Ball valve
	Female tube connectors

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	Flexible tube
	Flexible drainage tube
	GASTITE connection fitting F-M
	Heavy duty steel clamp
Consumables:	PTFE sealing tape
	Cleaning material
	Soft cloth

3.1.10. Working Station WS9

Manufacturing Step:	#9
Step Description:	Toolbox installation *(applicable only to units with integrated toolbox – if not proceed to WS10)*
Tasks' description:	Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly.
Equipment:	n/a
Auxiliary equipment:	Plant's crane
	Hand tools
	Digital spirit level
	Tensiometer
	Multimeter
	Geiger meter
Materials:	Custom made casing box
	Custom made box cover
	Steel screws M8
	Steel nuts M8
	3D printed custom made horizontal supporting brackets.
	Primer coating
	Fire protection coating
	Wires (Cables) on various sizes
	Flexible metallic tubes on various sizes
	Flexible metallic tubes
	Cable brackets
	Self-drilling low profile wafer screws
	Adhesive tape with PVC rubber
	AMscope
	Temperature & humidity sensors
	Smoke detector
	Thread Nylon Cable Glands
	Circuit Breaker rail mount type C various capacities
	Din rail for circuit breakers
	Rail mount interface connectors
	PVC terminals insulated ring connectors.
	M4 stainless steel screws
	BlazeCut T series tube
	Flexible heavy-duty tube
Consumables:	Insulation plastic tape
	Adjustable stripes
	Cleaning material
	Soft cloth

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3.1.11. Working Station WS10

Manufacturing Step:	#10
Step Description:	Finishes installation.
Tasks' description:	Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly
Equipment:	Air powered screw/bolts driver Portable saw cutter Portable grinder Oven-drier
Auxiliary equipment:	Plant's crane Carrying trailer Hand tools Soft roll brush Roller Knife cutter Digital spirit level Digital angle's meter Multimeter Geiger meter
Materials:	Horizontal air intake suction duct Horizontal air exhaust duct Inlet air grill Outlet air grill Stainless Steel Water Pipe Faucet Decorative Cover Maintenance hatch - custom made Self-drilling low profile wafer screws Cement boards Gypsum board screws Self-Drilling stainless steel screws Installation box Power socket Blind rollers switch Cover for switches / sockets Inlet power supply 220V (caravan type) USB cable Type A AMS nano-primer AMS nano-coating exterior AMS nano-coating interior
Consumables:	Joints filler (putty) Sandpapers Industrial lubricant Cleaning material Adhesive tape Fiber tape for boards joints 40mm Soft clothes & sponges

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3.1.12. Quality Control Station (Q.C.S.)

In order to complete the assembly process. a series of inspection actions / tests to all of its components should be performed, as presented in the *Deliverable D4.5 - PnU kit prototype property and performance characterization* and will be further analyzed in *D6.3 - Quality Assurance Plan – manufacturing / assembly.*

Briefly, the inspection actions / tests performed at a designated area of the plant (Q.C.S.) at the completion of SmartWall systems manufacturing, are:

Visual tests

- Measurements' confirmation;
- SmartWall panel aesthetics;
- Surface observation / defects on paint, cracks, flakes etc.;
- Sealant check defects on windows, sealant, sills, edges, bead.

Mechanical tests

- Anchoring system (bottom and top hinges of the frame);
- Power outlet's condition e.g. firmly secured on the board, loose screws, etc.;
- PV panel mounting rail to be firmly secured on the frame;
- Window's frame to be securely attached on the frame;
- Window's hinges;
- Access panel locking system / unlocking system;
- AMscope casing to be firmly attached on the frame;
- Air pressure test for leakages on the fan-coil pipework.

Electrical tests

- Power inlet / outlet's voltage & current;
- Fan-coil voltage & current;
- PV panels voltage & current;
- Battery voltage & current;
- Circuit breakers testing;
- Line continuity tests;
- Earthing testing, and
- Emergency cut-off mode.

Operational tests

- Window operation (open / close / tilt);
- Fan-coil control panel operation;
- AMscope operation;
- Electrical operation of the roller blinds;
- Blinds mechanical (without power supply) operation.

IR thermography

- To window's / opening's joints and sill;
- To SmartWall panels' joints and interlocking system.
- E/M components for overheating, leakages etc.

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3.2 Assembly Process – additional data

3.2.1. Assembly Process Duration

The overall Assembly Process for the SmartWall panels that will be manufactured for their installation at VVV's demonstration building is based on the following assumptions:

a) The total number of SmartWall panels which need to be manufactured is limited, in total thirty-three (33), from which twenty-two (22) are "blank type" panels and eleven (11) "composite panels" with fan-coils and toolboxes.
b) Production plant's capacity.
Due to the fact that SmartWall panels production is limited and will be operated in a plant where the usual windows' production by BGTC is continuous, the availability of area for the SmartWall production is limited to 250m^2.
c) Production line is not automated but is manually operated and all manufacturing tasks require manual interaction with the workforce.
d) There would be no limitations on plant's human resources (workforce) and or plant's facilities.
e) Some minor arrangements required in terms of relocating basic equipment and machinery need for SmartWall production, which have been resolved prior production's commencement.

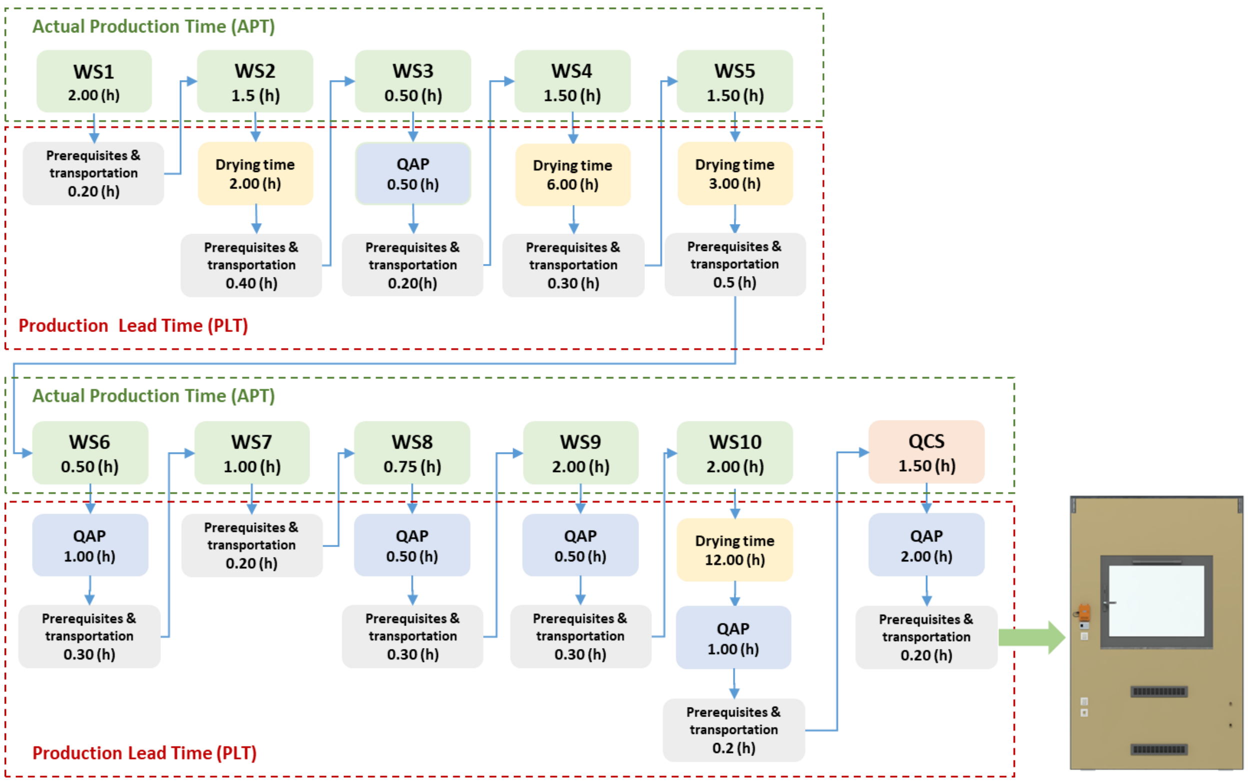

FIGURE 1: ASSEMBLY PROCESS DIAGRAM

Figure 1 illustrates the Assembly Process diagram in a very simple form, based on the aforementioned assumptions, as well as all the relevant data included in *Deliverables D4.5 - PnU kit prototype property and performance characterization* and *D6.1 - Manufacturing methodology of PLURAL PnU kits.*

While the role and functionality of each WS has been described in the previous C*hapter: Assembly Process Analysis*, this diagram provides additional data related to the Assembly Process and could be analyzed as following:

Actual Production Time (APT)

The Actual Production Time (APT) is clearly defined *in ISO - 22400-2:2014 Automation systems and integration — Key performance indicators (KPIs) for manufacturing operations management — Part 2: Definitions and descriptions*[3], as part of the overall Assembly Process, is a Key Performance Indicator (KPI) where identifies the working time needed for machining or processing or assembling parts to a completed product.

As KPI is merely used, in order to arrange, control and optimize work and workloads by allocating plant and machinery, as well as, human resources on the productive tasks of the Assembly Process. This KPI does not take into consideration any additional activities might be required for the overall product's production or any lead time among production tasks which are subject of the Production Lead Time (PLT) KPI and will be analysed in the next paragraph of the current report.

From the diagram of *Figure 1,* the Actual Production Time (APT) for SmartWall systems assembly per panel type, is clearly identified by incorporating only the "productive WS" (green dotted line) and can be summarized in the following *Table 3*.

Actual production type (h)	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10	QSC
Blank type panel	**2.00**	**1.50**	**0.50**	**1.50**	**x**	**x**	**1.00**	**x**	**x**	**2.00**	**0.75**
Panel with fan-coil & AMscope	**2.00**	**1.50**	**0.50**	**1.50**	**1.50**	**0.50**	**1.00**	**0.75**	**2.00**	**2.00**	**1.50**

TABLE 3: ACTIVE PRODUCTION TIME PER PANEL TYPE

By the data of *Table 3,* the overall Actual Production Time for the overall SmartWall systems that will be installed in VVV's demo building, is as following:

- "Blank type panels": **9.25(h)** per item x **22** items = **203.50 hours**
- "Composite panels": **14.75(h)** per item x **11** items = **162.25 hours**
- Total Actual Production Time: **365.75 hours (app. 48.78 working days)***

** Working day equals to 7.5 working houts*

Production Lead Time (PLT)

As mentioned on the previous *paragraph – Actual Production Time (APT),* any delay or lag between and/or among the productive tasks, even if this lag is subject and/or part of the Assembly process, is defined as Production Lead Time (PLT).

Production Lead Time is a very crucial factor to the Assembly process as influences the scheduling and/or planning of the overall activities / tasks and in many cases determines the working flow sequence as well as the production capacity. This is a condition that also applies in the SmartWall manufacturing / assembly process. *Table 4* describes and analyses the lagging time among the WS.

	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10	QSC
Prerequisites (h)	0.10	0.20	0.10	0.20	0.20	0.10	0.10	0.10	0.20	x	x
Drying time for coatings (h)	x	1.00	x	x	x	x	x	x	x	12.00	x
Drying time for fillers, plasters, pastes, etc. (h)	x	x	x	6.00	3.00	x	x	x	x	x	x
QAP processes (h)	x	x	0.50	x	x	1.00	x	0.50	0.50	1.00	2.00
Transportation among WSs (h)	0.10	0.20	0.10	0.10	0.30	0.20	0.10	0.20	0.10	0.20	0.20
Overall lagging time (h)	**0.20**	**1.40**	**0.70**	**6.30**	**3.50**	**1.30**	**0.20**	**0.80**	**0.80**	**13.20**	**2.20**

TABLE 4: AVERAGE DURATION LAGS PER CAUSE ON EACH WS FOR SMARTWALL PANEL PRODUCTION

[3] https://www.iso.org/standard/54497.html

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Important conclusions could be extracted from *Table 4*, related to the overall duration of the Assembly Process, as following:

- The most time consuming (lagging) WSs (yellow cells in *Table 4*), are:
  a. WS10 @ 13.20 (h),
  b. WS4 @ 6.30 (h) and
  c. WS5 @ 3.50 (h).
- At the aforementioned WSs the common factor which determines their lagging time is the "*Drying time*" of plaster (WS4), coatings (WS10) and glue (WS5).
- WS4 and WS5 are considering as more crucial WSs in the Assembly Process as they are approximately in the middle of the production workflow and their working capacity is influencing a series of other WSs which are dependent on the completion of the tasks executed in those two WSs (WS4 & WS5).
- While WS5 is used on very few items (eleven), as it deals with the *"openings installation"*, WS4 is used for all SmartWall panels manufacturing, impacting the workflow capacities to all afterwards production tasks.
- Despite the fact that WS10 has the longest lagging time among all other WSs, this lagging time is less of importance that WS4 as its successor is the Quality Control Station which is the final task of the Assembly Process.
- In WS2 (grey cells on *Table 4*) is involved "drying time" lag but this time is manageable and its impact to its succession tasks is by far less important than WS4 & WS5.

<u>Assembly Process Duration (APD)</u>

"KPI Production Capability"

The definition of "*KPI Production Capability*" as per *ISO - 22400-2:2014 Automation systems and integration — Key performance indicators (KPIs) for manufacturing operations management — Part 2: Definitions and descriptions* is based on the following assumptions:

- The addition of Actual Production Time (ADT) and Production Lead Time (PLT) determines the Assembly Process Duration (APD) per unit and per WS, as highlighted with grey cells in *Table5*, which is the overall duration required for the production of a single SmartWall unit on each WS based on the physical properties and characteristics of each unit to be produced.
- For the production of SmartWall systems for VVV demonstration building:
  a. "Blank type panels": **22** items
  b. "Composite panels": **11** items

Optimal case scenario

The *"Production Capability"* per WS per swift (yellow cells on *Table 5*), meaning how many units can be produced in each WS per day's shift of 7.5 hours (*KPI Production Capability = (ADT + PLT = APD / 7.5h*)

SmartWall per unit	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10	QSC
Actual Production Time (APT)	2,00	1,50	0,50	1,50	1,50	0,50	1,00	0,75	2,00	2,00	1,50
Production Lead Time (PLT)	0,20	1,40	0,70	1,30	2,00	1,30	0,20	0,80	0,80	4,20	2,20
Assembly Process Duration (APD) per WS per unit	**2,20**	**2,90**	**1,20**	**2,80**	**3,50**	**1,80**	**1,20**	**1,55**	**2,80**	**6,20**	**3,70**
Production Capability per swift	***3,41***	***2,59***	***6,25***	***2,68***	***2,14***	***4,17***	***6,25***	***4,84***	***2,68***	***1,21***	***2,03***

TABLE 5:" KPI PRODUCTION CAPABILITY CASE I"

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Interpreting *Tables 5* data, to a schedule of works and a sequence of workflows among the WSs, the overall duration (optimal case) of the Assembly Process, is as following:

	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10	QSC
Start day	**1**	4	8	9	13	23	16	26	27	17	28
Finishing day	10	16	22	23	25	26	28	29	32	45	**49**

TABLE 6: WORK FLOW PER WS IN PRODUCTION DAYS CASE I

From *Table 6* is clear, that:

- The Assembly Process Duration in this optimal scenario, is forty-nine (**49)** working days.
- **Not** all WSs could start on the same day as are all dependant to their predecessor.
- "Blank type" panels skip WS5, WS6, WS8 and WS9, as those WS's tasks are related to openings, fan-coil and toolboxes installations.
- This condition (22 items skipping those WSs) is allowing to reduce lags occurring from WS7 due to "drying time" required, as WS7 could be fed directly (for at least the 22 "blank type" units) by WS4, independently the production status of WS5 & WS6.
- Same condition applies for WS10 which can be fed directly for the "blank type" panels by WS7.

Case scenario with increased lag time

In order to understand the importance of Production Lead Time (PLD) a similar production scenario but without the use of the oven-drier used to minimise the lag of "drying time", is presented in *Table 7*.

SmartWall panels per unit	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10	QSC
Actual Production Time (APT)	2,00	1,50	0,50	1,50	1,50	0,50	1,00	0,75	2,00	2,00	1,50
Production Lead Time (PLT)	0,20	1,40	0,70	6,30	3,50	1,30	0,20	0,80	0,80	13,20	2,20
Linear Modelling Assembly Process Duration (LMAPD)	**2,20**	**2,90**	**1,20**	**7,80**	**5,00**	**1,80**	**1,20**	**1,55**	**2,80**	**15,20**	**3,70**
Production capability per swift	***3,41***	***2,59***	***6,25***	***0,96***	***1,50***	***4,17***	***6,25***	***4,84***	***2,68***	***0,49***	***2,03***

TABLE 7:" KPI PRODUCTION CAPABILITY CASE II"

In this case, the only differences from the "optimal case scenario" is to setup the "drying time" to the time needed for physical drying of the plasters and coatings @ 20°C within the plant facility (red figures in *Table 7*). From this table is clear that the KPI "Production Capability" decreased as following:

- WS4: from 2.68 to 0.96 **(-178,87%)**
- WS5: from 2.14 to 1.50 **(-42.86%)**
- WS10: from 1.21 to 0.49 **(-145.16%)**

Trying to identify the schedule and sequence of workflows with the new KPI, in this case the best possible scenario for the production of SmartWall panels would be as in *Table 8*:

	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10	QSC
Start day	**1**	4	8	8	16	21	19	23	24	24	30
Finishing day	10	16	22	44	23	24	45	27	27	91	**96**

TABLE 8: WORK FLOW PER WS IN PRODUCTION DAYS CASE II

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Two main conclusions can be derived from *Table 8*:

a. the Assembly Process Duration (APD) has been increased from **49** to **96** working days, corresponding to **95,92%** increase of the overall assembly process duration, and
b. the percentage of reduction on the KPI Production Lead Time (PLD) does not numerically correspond to the overall assembly time presented in *Table 8*. This occurs because, based on the KPIs obtained from *Table 8,* the calculation of workflow was focused to minimise as much as possible, the lag effect among WS4 and WS10.

   This was achieved by bringing forward the production of the "composite panels" to minimise lag time in WS8 and WS9 prior their move to WS10 (in which the higher lag time is recorded) and then add to the production workflow the "blank type" panels.

3.2.2. Assembly Process Efforts (workmanship)

From *Table 9*, the following conclusions can be extracted relating to the overal assembly efforts for the production of SmartWall systems for the VVV demo building:

- Complete efforts for the overall assembly process: **470.25 Mh (app. 62.75 working days*)**
- Average efforts per "Blank panel": **12.25 Mh (app. 1.65 working days*)**
- Average efforts per "Composite panel": **18.50 Mh (app. 2.47 working days*)**

* *Working day equals to 7.5 working houts*

.	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10	QSC
Technician (Mh)	1,5	0,5	0,5	1,5	1,5	0,5	1	0,75	2	2	1,5
Skilled labour (Mh)	0,5	1	0,25	0,5	0,25	0,25	1	0,25	0,5	0,25	0,25
Total (Mh) per WS	**2**	**1,5**	**0,75**	**2**	**1,75**	**0,75**	**2**	**1**	**2,5**	**2,25**	**1,75**
Total(Mh) per WS (overall production)	**66**	**49,5**	**24,75**	**66**	**19,25**	**8,25**	**66**	**11**	**27,5**	**74,25**	**57,75**

TABLE 9: ASSEMBLY EFFORTS FOR THE OVERALL PRODUCTION OF SMARTWALL SYSTEMS

Table 9 refers strictly to the efforts per WS and identifies the personnel directly involved in the Assembly Process. However, for the manufacturing of any product, personnel not directly involved to the actual assembly process is required, as their contribution plays a significant role for the smooth operation and completion of the manufacturing works. For SmartWall manufacturing the personnel non-directly involved in the Assembly Process is presented in *Table 10.*

Job Description	Units	Occupation*	Remarks
Plant manager	1	50.00%	Assigned also for BCTC normal windows production
M/E engineers	2	40.00%	
Safety Engineer	1	20.00%	
CAD Designers	1	30.00%	
Plant supervisor	1	50.00%	
Procurement officer	1	35.00%	
General duties workers	2	100.00%	Dedicated to SmartWall production
Administrative personnel	1	25.00%	General duties

TABLE 10: EFFORTS BY NON-DIRECTLY INVOLVED PERSONNEL DURING ASSEMBLY PROCESS

* *Percentage of occupation allocated to SmartWall Assembly Process*

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3.2.3. Assembly's Process Energy Demand

The energy required for the SmartWall Assembly Process per unit in each WS of the assembly line at the plant is analysed in *Table 11.*

Energy required	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10	QSC	Totals
Electric energy (kWh)	4,28	2,85	2,14	3,06	2,40	1,65	2,14	2,01	1,28	3,53	3,23	**28,54**
Crane's electric energy (kWh)	0,78	0,78	0,78	0,78	0,78	0,78	0,78	0,78	0,78	0,78	0,78	**8,58**
Lighting, oven & minor equipment electric energy (kWh) (chargers, testing devices, etc.)	1,28	0,96	0,88	3,02	3,16	0,72	1,04	1,44	1,20	5,36	2,40	**22,46**
Water (lt)	x	5,00	x	5,00	5,00	x	x	10,00	x	10,00	30,00	**65,00**
Compressed air (lt)	410,00	960,00	640,00	1220,00	280,00	180,00	220,00	180,00	220,00	2470,00	260,00	**7040,00**
Drying oven (lt)*	x	x	x	2,30*	x	x	x	x	x	4,60*	x	**6,90**

TABLE 11: ENERGY DEMAND PER WS FOR EACH SMARTWALL UNIT PRODUCTION

* *Diesel burner 100.000 Kcal/h @ 60°C. Drying time 45-60 minutes.*

3.3 Assembly Process Drawings

Extracts of the all the manufacturing drawings for all the types of the SmartWall panels that will be installed in VVV Municipality's demo building is presented in *ANNEX III – SmartWall* and a complete set of all the relevant drawings has been uploaded in digital form (3ds[4] format) in EMDESK portal *(EMDESK/Documents/ WP6/D6.2)* and due to their "Confidential" status will be included in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly.

NOTE: Assembly drawings are providing all the necessary detailing for manufacturing the SmartWall systems, though for their better understanding and use should be read in conjunction with the Assembly Process, as described in the previous paragraphs and the manufacturing guidelines provided in Deliverable D6.1 – Manufacturing Methodology of PnU kits.

3.4 Assembly Cost Analysis

All relevant Assembly Cost Analysis will be thoroughly presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly.

[4] https://en.wikipedia.org/wiki/Autodesk_3ds_Max

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4 Denvelops Comfort Wall Assembly Process

4.1 Assembly process analysis

The manufacturing process developed and described in D6.1 – Manufacturing methodology of the Plural PnU kits, in addition to the requirement information presented in D4.4 – PnU kit prototypes addressing the demo site requirements, generated the first result for the model assembly process. It was the manufacturing prototype for the Terrassa Demo Project, in which a first manufacturing methodology process (and assembly as well) was developed to achieve the objectives of these tasks.

In accordance with the well-known advantages of making industrialized building systems, this task confirmed that the detailed analytic process of the system's, design on both single and optimized components, in addition to the effective analysis of their assembly process in the chain manufacturing workstation system, is the best way to ensure that whole process can be improved 100% at any time whilst being made. From Denvelops' point of view, it is demonstrated that this strategy is the best to resolve the Denvelops Comfort Wall PnU, and of course to achieve the objectives related within the Plural Project.

According to the project organization, taking as incoming the tasks mentioned before, and the Tasks 7.1 Preliminary Design of the PnU and 2.7 Final stage complete design of the PnU, as specific design requirements, the next sections describe the assembly methodology for Denvelops Comfort Wall PnU kits.

In this sense and to specially generate a generic description studio case, it will be described a representative assembly case of single sequence, in which all the functional kits would be installed, ordered by the phases described below (corresponding to working stations). On the other way, since not all the sequences always include all the functionalities, the data of the project will be get in relation to 100% of the Demo Case project, otherwise, the assembly cost and times would not be realistic.

Due to the "Public" status of the current Deliverable and the sensitivity of the information of the Assembly Process, all those data, information and drawings classified as "Confidential" or are covered under IPR statuses, have been removed and will be presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly.

4.1.1. Prerequisites (prior assembly process commencement) Phase 1: DETAILED DESIGN

Step Description	WS / Detailed Desing
MAIN EQUIPMENT	3d informatic programs like AutoCAD, inventor, 3d solid, and many other.
AUXILIARY EQUIPMENTS	• Offices • Ventilation
SPECIFIC TECHNIQUES	3d drawing, small mockup / tests.
ENEREGY REQUIERED	Power supply 240V
CUT OFF POINT	New changes that need new approvals.
TASK DESCRIPTION	Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly

TABLE 12: DETAILED DESIGN RESOURCES

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4.1.2. Prerequisites (prior assembly process commencement) Phase 2: COMPONENTS PROVISION PROCESS

Step Description	WS / Components Provision Process
MAIN EQUIPMENT	• Office and management PC programs • Standards ordering sheet for the commands. • Standards sheets to follow the state of the command. • Tools for take measurements, and standards sheets for components reception.
AUXILIARY EQUIPMENTS	• Offices • Crane • Ventilation
SPECIFIC TECHNIQUES	• Management of provision components. • Quality control procedures to check the produced components at their reception.
ENEREGY REQUIERED	Power supply 240V
CUT OFF POINT	Delay in arrival of components
TASK DESCRIPTION	Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly

TABLE 13: PROVISION PROCESS RESOURCES

4.1.3. Prerequisites (prior assembly process commencement) Phase 3: COMPONENTS STORAGE

Step Description	WS / Components Storage
MAIN EQUIPMENT	• Forklift had pallet truck. • Barcode reader • Foam or wood protectors • Wood pallets
AUXILIARY EQUIPMENTS	• Offices • Crane • Storage auxiliary furniture • Ventilation
SPECIFIC TECHNIQUES	Storage informatic programs.
ENEREGY REQUIERED	Power supply 240V
CUT OFF POINT	Damages of components storage
TASK DESCRIPTION	Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly

TABLE 14: STORAGE PREREQUISITES RESOURCES

4.1.4. Phase 4: COMPONENTS PRODUCTION PROCESS

Workstation Isolation phase

Step Description	WS / Components Production Process
MAIN EQUIPMENT	• Forklift • Wood pallets • Table, cutter, measuring tape.

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	• Cutting Table
AUXILIARY EQUIPMENTS	• Offices • Crane • Production plan • Packaging tools • Ventilation
SPECIFIC TECHNIQUES	Cut isolation panels
ENEREGY REQUIERED	Power supply 240V
CUT OFF POINT	Mistake in result (dimensions or codifies)
MAIN MATERIALS	Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly
CONSUMABLES	Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly
TASK DESCRIPTION	Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly

TABLE 15: COMPONENTS PRODUCTION RESOURCES

4.1.5. Phase 5: FRAME ASSEMBLY PROCESS

Workstation Assembly stage A:

Step Description	WS / Frame Assembly Process
MAIN EQUIPMENT	• Hydraulic Rivet machine • Denvelops installing Connectors tool.
AUXILIARY EQUIPMENTS	• Factory • Crane • Forklift • Production plan • DEN Frame Easel Assembly • Safety dressing clothes
SPECIFIC TECHNIQUES	Production program (To indicate the operation is done).
ENEREGY REQUIERED	Power supply 240V
CUT OFF POINT	Find some components do not fit or damaged. Go again to components provision process
MAIN COMPONENTS	Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly
CONSUMABLES	Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly
TASK DESCRIPTION	Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly

TABLE 16: FRAME ASSEMBLY RESOURCES STAGE A

Workstation Assembly stage B:

Step Description	WS / Frame Assembly Process
MAIN EQUIPMENT	• Various hand tools
AUXILIARY EQUIPMENTS	• Factory • Crane • Forklift • Production plan • Safety dressing clothes

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SPECIFIC TECHNIQUES	Production program (To indicate the operation is done).
ENEREGY REQUIERED	Power supply 240V
CUT OFF POINT	Find some components do not fit or damaged. Go again to components provision process
MAIN COMPONENTS	Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly
CONSUMABLES	Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly
TASK DESCRIPTION	Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly

TABLE 17: FRAME ASSEMBLY RESOURCES STAGE B

Workstation Preassembly C) Window:

Step Description	*WS / Frame Assembly Process*
MAIN EQUIPMENT	• Various hand tools
AUXILIARY EQUIPMENTS	• Factory • Crane • Forklift • Production plan • Safety dressing clothes
SPECIFIC TECHNIQUES	Production program (To indicate the operation is done).
ENEREGY REQUIERED	Power supply 240V
CUT OFF POINT	Finding some components that do not fit or that gets damaged. Go again to components provision process
MAIN COMPONENTS	***Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly***
CONSUMABLES	***Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly***
TASK DESCRIPTION	***Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly***

TABLE 18: FRAME ASSEMBLY RESOURCES STAGE C) WINDOWS

Workstation Preassembly D) Louver:

Step Description	WS / Frame Assembly Process
MAIN EQUIPMENT	• Various hand tools
AUXILIARY EQUIPMENTS	• Factory • Crane • Forklift • Production plan • Safety dressing clothes
SPECIFIC TECHNIQUES	Production program (To indicate the operation is done).
ENEREGY REQUIERED	Power supply 240V
CUT OFF POINT	Fins some components do not fit or that gets damaged. Go again to components provision process
MAIN COMPONENTS	***Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly***
CONSUMABLES	***Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly***
TASK DESCRIPTION	***Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly***

TABLE 19: FRAME ASSEMBLY RESOURCES STAGE D) LOUVERS

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4.1.6. Phase 6: FRAMES STORAGE

Step Description	WS / Frames Storage
MAIN EQUIPMENT	• Various hand tools
AUXILIARY EQUIPMENTS	• Factory • Crane • Forklift • Production plan • Ventilation
SPECIFIC TECHNIQUES	• Production program (To indicate the operation is done). • Storage program. (To fill where it is)
ENEREGY REQUIERED	Power supply 240V
POSSIBLE FAILURES	As per F.Q.P
CUT OFF POINT	Find some components do not fit or that gets damaged. Go again to components provision process
TASK DESCRIPTION	***Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly***
MAIN MATERIALS	***Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly***
CONSUMABLES	***Complete analysis is presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly***

TABLE 20: STORAGE RESOURCES

4.1.7. Quality Control Station (Q.C.S.)

According to the Lean manufacturing production system application, in every workstation, and even in each component assembly, a self-quality control is already done. That's the reason why all assemblage operation tables described in this deliverable have been done adding a last column to explain which are the Factory quality procedures that must be performed at every production step. In spite these procedures are closely related to small actions or steps, further inspections actions must be performed to the frames, each of which considered as a single operational assembly result of the process. These inspections and tests were already presented – as a first approach- in Task 4.5 PnU kit prototype property and performance characterization. All these inspections in relation to the Work package 6 tasks will be developed with accuracy in task 6.3 Quality Assurance Plan. The most important tests and inspections that will be done in the assembly process are summarized as following:

Visual tests

- *Dimensional control of the finished frames.*
- Surface observation / defects on paint, cracks, flakes etc. identification.
- Assembled components inspection: tiles, connectors, loads lines and windows, wind bridges, wind loads, isolation, pv panels and unit ventilation.

Mechanical tests

- Assembled components test: tiles, connectors, loads lines and windows, wind bridges, wind loads, isolation, pv panels and unit ventilation.

Operational test

- Window operation (open / close / tilt).
- Louver operations (open / close)
- Louver railing wheels

Electrical tests

- UV voltage & current.
- PV panels voltage & current.

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4.2 Assembly Process – additional data

4.2.1 *Assembly Process Duration*

The duration of the assembly process for the Terrassa Demo is closely related to the capabilities of the Denvelops installations and workforce. It is important to describe them in terms of quantity and quality, to calculate the required time to produce the 42 sequences (154 frames) of the Demo Terrassa project. This are the main points about the Denvelops capabilities:

a) Production plant's capacity: Denvelops has an operational space of 320 m^2. This space allows to have up to 8 assembly areas, which means that space should not be a problem in terms of production capacity.
b) Denvelops doesn't have a big workforce, currently is composed by 3 people. In case of need, this workforce can be easily increased. This is possible because for the Denvelops Comfort Wall assembly and for the standard Develops projects as well, the required workforce doesn't need to be high qualified.
Besides in case of overwork in the factory, some of the production assembly phases can be subcontracted to outside handling companies, to leave the Denvelops workforce only occupied with the Plural project.
c) The designed Denvelops Comfort Wall solution has been done to achieve the standard Denvelops fabrication system, which is a manufacturing process always related to be a chain assembly of out coming finished components. For example, in the Denvelops Comfort Wall PnU the only components which demands a factory manipulation is the cutting of the isolation panels. This advantage implies that no special changes in the spaces or in the machinery of the company are required to carry out the fabrication of the panels.
d) The developed solution almost doesn't have drying time on the assembly of the components so that there are not death times to be calculated for the production times. This improves the assembly speed and the reliability of the data.

The next table presents the last updated information about the duration of the assembly. The assigned times for each task are strictly related to do the assembly. It also must be said that the assembly times assigned are a provision done considering that this is the first time such a large assembly will be done, so it is not yet an optimized data. This optimal data for the assembly process duration will be defined for the task 6.5 future industrialization of the PnU, once the experience of this assembly has been gained.

The next table shows the duration time of doing the assembly of the PnU per each fabrication phase, comparing the duration of doing one single unit or function against their proportion with project, and the second ones show the duration of doing all the functional units that the Demos project has.

HYBRID WALL DEMO TERRASSA PROJECT	Total time worker 1	Quantity and concept description	Qtt (Units)	Hours / Ut
Denvelops	748,70	309,47 m² of standard façade	309,47	2,42
Façade anchoring	17,76	309,47 m² of standard façade	309,47	0,06
Windows	108,29	29,00 units of windows	29,00	3,73
Louvers	212,63	29,00 units of louvers	29,00	7,33
Perimetral façade finishing	0,00	309,47 m² for standard façade	309,47	0,00
Balconies	1,00	6,00 units of balconies	6,00	0,17
Pv photovoltaics	30,75	50,00 units of tiles	50,00	0,62
Insulation	59,25	289,03 m² of isolated façade	289,03	0,21
Unit ventilation	12,10	6,00 units of UV	6,00	2,02
Packaging	81,55	369,88 m² of project facade	369,88	0,22
Transport	2,60	369,88 m² of project facade	369,88	0,01
Installation assistance	0,00	369,88 m² of project facade	369,88	0,00
Technical office	0,00	369,88 m² of project facade	369,88	0,00
Comercial office	0,00	369,88 m² of project facade	369,88	0,00
General cost	0,00	369,88 m² of project facade	369,88	0,00
TOTAL	**1274,63**	**369,88 m2 of project facade**	**369,88**	**3,44**

TABLE 21: ACTIVE PRODUCTION TIME PER UNITS AND PER PROJECT

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From this data can be defined the next ratios related to the assembly duration:

- Considering that the total amount of façades surfaces that will be installed in the Terrassa Demos is 369.88 m^2, the expected production time for each square meter is 1367,86 hours /369,88 m^2 = 3,69 h/m^2.
- Considering a work force of 3 people, working 8 hours x day, 20 days x month, the project should be able to be assembly in 2,84 months or in a total of 12 week approximately.
- The assembly process is a lineal assembly chain operated with 3 workmanship forces. The easiest to improve to speed would be to work with two assembly chain.

Assembly time	1274,63
Month days	20
Hours x day	7,5
Nº of workers	3
Project duration	2,83

According to the considerations of to the *ISO - 22400-2:2014 Automation systems and integration — Key performance indicators (KPIs) for manufacturing operations management — Part 2: Definitions and descriptions*, and all together related with the assembly process developed for the Denvelops Comfort Wall, in which there are no drying production times, the Actual Production Time (APT) could be considered the same as the Production Lead Time (PLT). As a result, the Assembly Process Duration (APD) is the same as the APT.

4.2.2 *Assembly Process efforts (workmanship)*

According to Table 22, the overal efforts for the assemby process is 1367,86 hours. These efforts would be strictly direct to do the assembly works, which can be done by askilled labour because there are not technical and dificult jobs.

However, in this type of works it is important to have skilled labour focused on how to organize, give information and control the project assembly and ensure the factory quality porcedures are respected. The relation of assitance for the assembly is presented in Table 22:

HYBRID WALL DEMO TERRASSA PROJECT	total time worker 1	total time technician support	Total project hours	Quantity and concept description	Qtt (Units)	Hours / Ut
Denvelops	748,70	162,95	911,65	309,47 m^2 of standard façade	309,47	2,95
Façade anchoring	17,76	3,29	21,05	309,47 m^2 of standard façade	309,47	0,07
Windows	108,29	28,11	136,39	29,00 units of windows	29,00	4,70
Louvers	212,63	44,93	257,56	29,00 units of louvers	29,00	8,88
Perimetral façade finishing	0,00	0,00	0,00	309,47 m^2 for standard façade	309,47	0,00
Balconies	1,00	0,19	1,19	6,00 units of balconies	6,00	0,20
Pv photovoltaics	30,75	5,69	36,44	50,00 units of tiles	50,00	0,73
Insulation	59,25	24,35	83,61	289,03 m^2 of isolated façade	289,03	0,29
Unit ventilation	12,10	5,57	17,67	6,00 units of UV	6,00	2,95
Packaging	81,55	15,10	96,65	369,88 m^2 of project facade	369,88	0,26
Transport	2,60	0,48	3,08	369,88 m^2 of project facade	369,88	0,01
Installation assistance	0,00	0,00	0,00	369,88 m^2 of project facade	369,88	0,00
Technical office	0,00	0,00	0,00	369,88 m^2 of project facade	369,88	0,00
Comercial office	0,00	0,00	0,00	369,88 m^2 of project facade	369,88	0,00
General cost	0,00	0,00	0,00	369,88 m^2 of project facade	369,88	369,88
TOTAL	**1274,63**	**290,67**	**1565,30**			

TABLE 22: ACTIVE ASSEMBLY EFFORTS PER LABOR TYPES

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4.2.3 *Assembly Process energy demand*

The energy required for the Denvelops Comfort Wall systems Assembly Process per each production phase and per unit of the assembly line is shown in Table 23.

	Energy demand hours			Energy demand Kw		
HYBRID WALL DEMO TERRASSA PROJECT	Electric light (Kw/h)	Electric crane (Kw/h)	Electric energy (Kw/h)	Electric light (Kw/h)	Electric crane (Kw/h)	Electric energy (Kw/h)
Denvelops	748,70	62,50	96,50	748,70	62,50	96,50
Façade anchoring	17,76	0,00	1,76	17,76	0,00	1,76
Windows	108,29	106,00	4,03	108,29	106,00	4,03
Louvers	212,63	0,00	6,75	212,63	0,00	6,75
Perimetral façade finishing	0,00	0,00	0,00	0,00	0,00	0,00
Balconies	1,00	0,00	0,00	1,00	0,00	0,00
Pv photovoltaics	30,75	0,00	0,50	30,75	0,00	0,50
Insulation	59,25	0,00	1,45	59,25	0,00	1,45
Unit ventilation	12,10	0,00	0,12	12,10	0,00	0,12
Packaging	81,55	0,00	25,67	81,55	0,00	25,67
Transport	2,60	2,60	0,00	2,60	2,60	0,00
Installation assistance	0,00	0,00	0,00	0,00	0,00	0,00
Technical office	0,00	0,00	0,00	0,00	0,00	0,00
Comercial office	0,00	0,00	0,00	0,00	0,00	0,00
General cost	0,00	0,00	0,00	0,00	0,00	0,00
TOTAL	1274,63	171,10	136,77	1274,63	171,10	136,77

TABLE 23: ENERGY DEMAND PER WS FOR EACH DENVELOPS COMFORT WALL UNIT PRODUCTION

4.3 Assembly Process Drawings

Extracts of the all the manufacturing drawings for all the types of the Denvelops Comfort Wall panels for the Terrassa Demo building is presented in *ANNEX II-Denvelops Comfort Wall* and a complete set of all the relevant drawings has been uploaded in digital form (3ds[5] format) in EMDESK *(EMDESK/Documents/ WP6/D6.2)*. Due to their "Confidential" status will be included in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly.

4.4 Assembly Cost Analysis

Similarly, to paragraph *3.3 Assembly Process Drawings,* all relevant Assembly Cost Analysis will be thoroughly presented in Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly.

[5] https://en.wikipedia.org/wiki/Autodesk_3ds_Max

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5 ConExWall Assembly Process

5.1 Assembly process analysis

The assembly process of the ConExWall system is mostly based on common manufacturing processes of the RDR. The manufacturing methodology was presented on the *Deliverable D6.1 – Manufacturing methodology of PLURAL kits*.

Furthermore, in *Deliverable D4.4 – PnU kit prototypes addressing the 3 demo building requirements* the assembly process was presented in detail for the manufacturing of the ConExWall prototype installed at the facility of SPF.

Taking into account the particular needs of the Kasava demo building, as presented in the *Deliverables D7.1 – Preliminary Design* and *D2.7 – Final stage complete design of PnU kits*, the assembly methodology for three typical types of ConExWall panels (wall panel type 1 – to be attached to existing wall, wall panel type 2 – stand-alone wall panel for 2nd storey, and roof panel), incorporating a window and a ventilation unit, is presented in the following sections, under the following notice:

Due to the "Public" status of the current Deliverable and the sensitivity of the information of the Assembly Process, all those data, information and drawings classified as "Confidential" or covered under IPR statuses, have been removed and will be presented in Deliverable D6.3 – Quality Assurance Plan – manufacturing/assembly.

5.1.1 *Prerequisites (prior to assembly process commencement)*

Before assembly process starts, two main prerequisites are to be completed as follows, visible also from the Figure 2.

- Detailed design and production documentation;
- Materials and components provision.

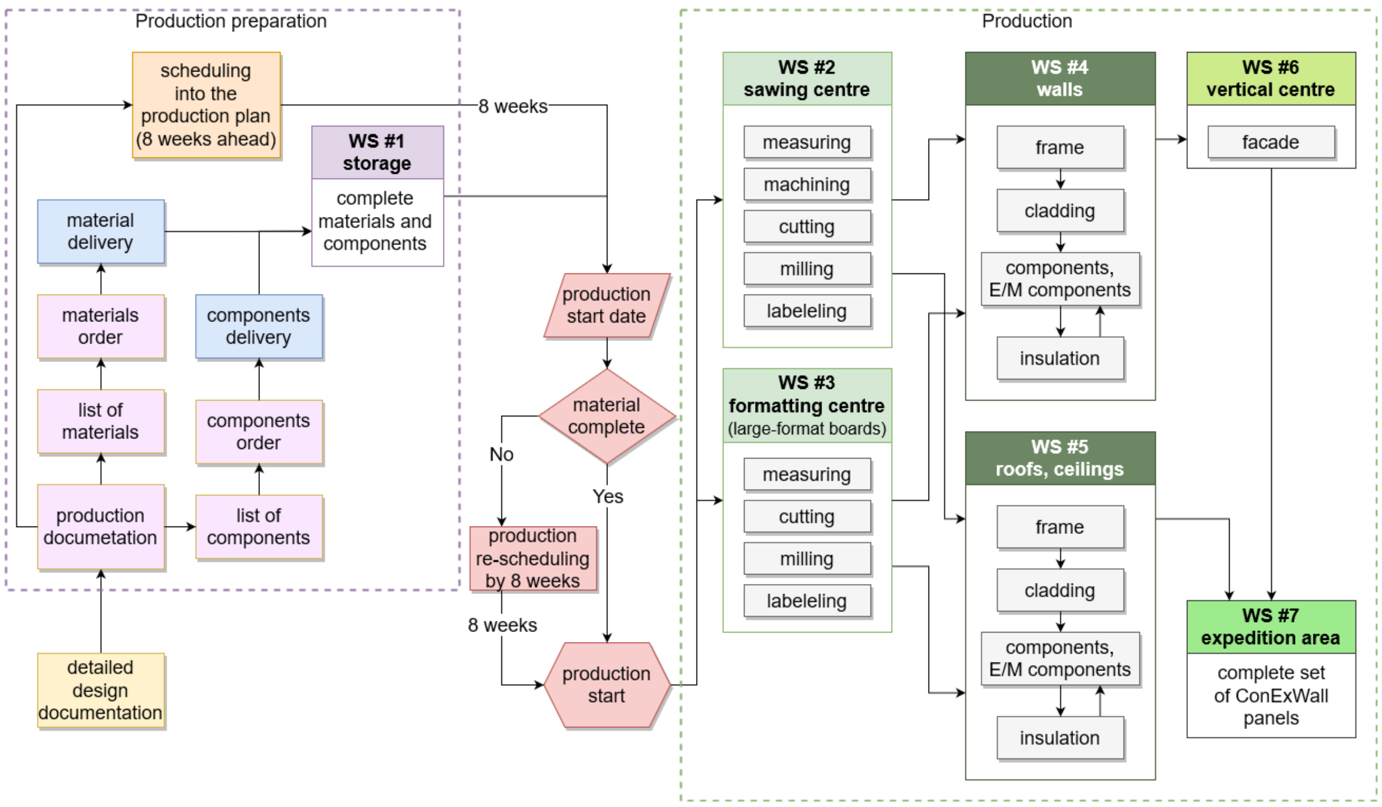

FIGURE 2: OVERVIEW OF THE PRODUCTION PREPARATION AND ASSEMBLY PROCESSES

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Detailed design and production documentation

Detailed design is a basis for the production documentation preparation. Once the production documentation is prepared, the assembly is scheduled into the production plan 8 weeks ahead. More information about detailed design and production documentation topics is provided in *Deliverable D6.1 – manufacturing methodology of PLURAL kits*.

Step description	Detailed design and production documentation
Main equipment	Computer, 3D CAD and/or BIM software (AutoCAD[6], Revit[6], Cadwork[7], etc.), other software
Auxiliary equipment	Offices
Specific techniques	2D and 3D drawing, small mock-up/tests
Cut off point	Changes that need approvals
Total duration	2 weeks
Task description	• Draw the detailed documentation in 3D • Check there are not interferences between components • Generate prevision regarding the size and the weight of the assemblies and pre-assemblies that will be needed, so that they can be done in the available factory space. Check maximum weight of the panels (RDR limits the panels to be below 2 tons). • Check/revise the whole process (metrics, position, …). From that point on every mistake will be real, not only digital • Proposition of small sample/mock-up/tests in case of doubts about the viability of a particular assembly proposed • Draw a 3D production documentation and generate list of all materials and components
Final result	• List of materials and components with complete specifications to be sent to providers • Plans of assembly needed for the production

TABLE 24: DETAILED DESIGN AND PRODUCTION DOCUMENTATION RESOURCES
(PREREQUISITES FOR CONEXWALL ASSEMBLY PROCESS)

Components provision and storage process

Production documentation is a prerequisite for components provision process. An integral part of the production documentation is a list of materials and components to be ordered and purchased. Those items are subsequently ordered by the manufacturer RDR, to be delivered into the plant storage (WS#1) within the 8 weeks, prior the assembly stage starts.

If any of the materials or components required for the manufacturing of the PnU kits is not delivered in time, prior the scheduled assembly starting date, the assembly process must be rescheduled for 8 weeks later. More information about components provision process is provided in *Deliverable D6.1 – Manufacturing methodology of PLURAL kits*.

Step description	Materials and components provision process
Main equipment	Computer, office and management computer programmes, ordering sheets, sheets for components reception, tools for measurements, barcode reader
Auxiliary equipment	Offices, storage, auxiliary furniture, crane, forklift
Specific techniques	Management of provision components, quality control procedures to check the delivered materials and components at their reception, storage informatic programmes
Cut off point	• Delay in arrival of materials/components • Damages of materials/components arrived or stored

[6] https://www.autodesk.com/
[7] https://www.cadwork.com

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Total duration	8 weeks
Task description	• Based on the list of materials and components to be ordered, choose and contact providers and define binding dates for delivery. • Receive and check in detail that dimensions, amount, and parameters (including humidity of wooden elements) correspond to the orders, visually inspect the materials and components for damage • Store and label the delivered materials and components • Fill the data that the component has been stored for assembly
Final result	• Stored and labelled materials and components (complete set) needed for the entire assembly phase

TABLE 25: MATERIALS AND COMPONENTS PROVISION PROCESS RESOURCES (PREREQUISITES FOR CONEXWALL ASSEMBLY PROCESS)

5.1.2 *Working station #2 and #3: Sawing and formatting centres*

Once the assembly phase commences, the materials stored in the storage area (WS#1) are transported by forklifts to the sawing centre (WS#2). Based on the Cadwork drawings, the Weinmann shortening saw[8] automatically machines, measures, cuts, mills, and labels the linear timber elements. It also creates mark lines for the timber positioning to compose the frame.

Formatted materials are then packed onto the pallets, sorted for individual panels production and labelled, and transported by forklifts to the next working station – the Weinmann production line area, consisting of (see the overview of the processes in Figure 3):

- WS#4 for wall components, and
- WS#5 for roof components.

In case that large-format boards are part of the materials delivery, they may be transported from storage (WS#1) to the large-format formatting centre (WS#3) where they are formatted to final panel formats. Then they are sorted and packed onto pallets and transported by forklifts to WS#4/WS#5.

Utilization of WS#3 is optional – the boards formatting can also be done directly at WS#4/WS#5 – and depends on the processes' setup and current WS#3 and WS#4 machines utilization.

[8] https://www.homag.com/en/products/house-construction

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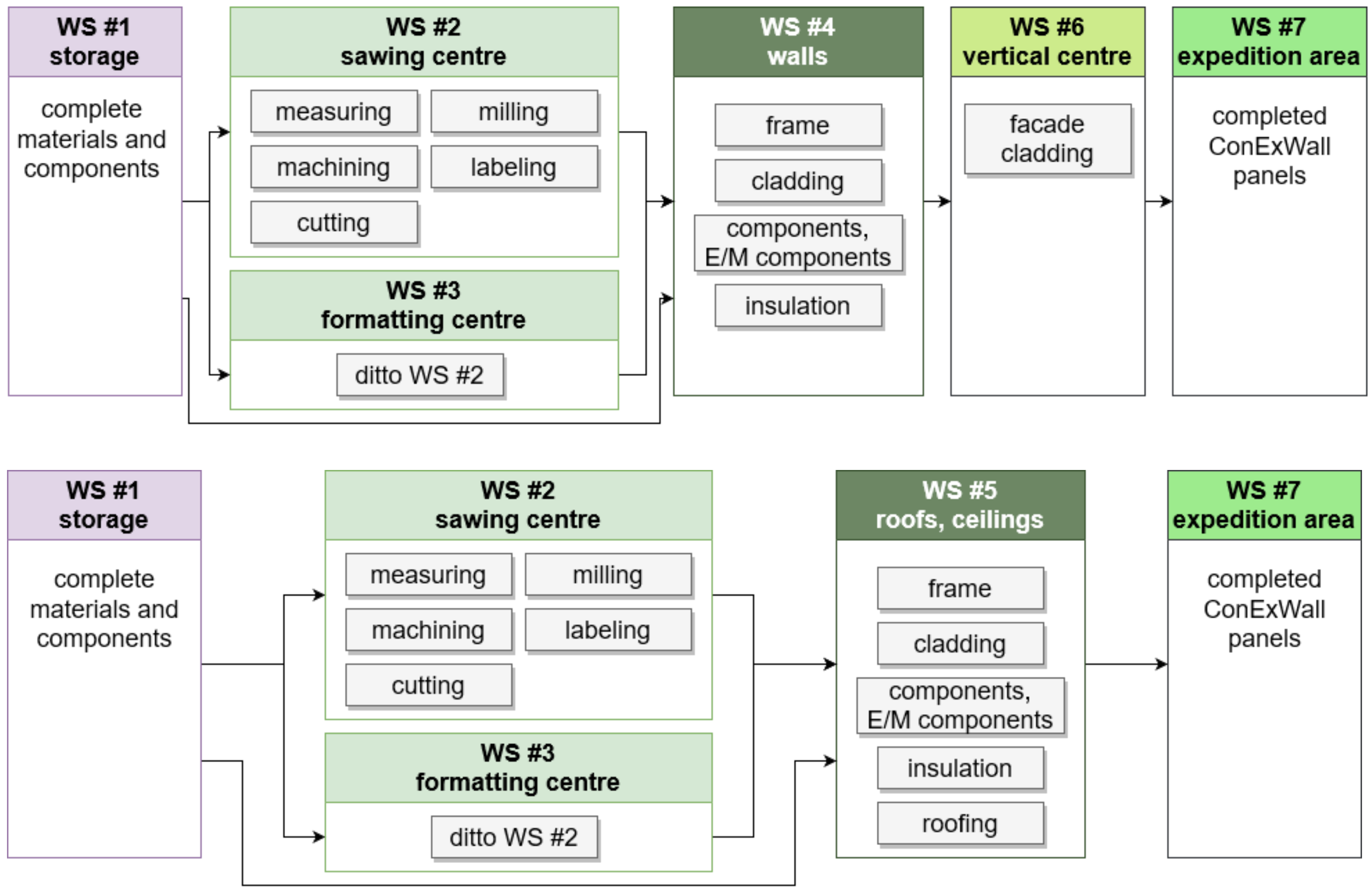

FIGURE 3: OVERVIEW OF ASSEMBLY PROCESSES AND WORKING STATIONS – WALL PANELS (TOP), ROOF PANELS (BOTTOM)

Step description	Sawing centre processes (WS#2)
Main equipment	Automatized sawing centre Weinmann[9], various hand tools
Auxiliary equipment	Forklift, production documentation (Cadwork files for machining, printed for quality check), bridge crane
Cut off point	Some material/components do not fit or get damaged → Go again to components provision process
Main materials	Timbers, laths, and other linear wooden elements
Consumables	Slitting wheels, milling wheels, marking material
Workmanship units	1–2 workers at WS
Total duration	20 minutes / materials for 1 average panel
Task description	• Measuring, cutting, milling, mark lines creating, labelling • Sorting, packing onto pallets sorted for individual panels, labelling
Final result	• Formatted, labelled, sorted, and packed materials and components for the panel assembly

TABLE 26: SAWING CENTRE RESOURCES (WS#2)

[9] https://www.homag.com/en/products/house-construction

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Step description	Formatting centre processes (WS#3)
Main equipment	Weinmann CNC shortening saw[10], CNC formatting saw Holzma[11], CNC centre Hundegger[12], various hand tools
Auxiliary equipment	Forklift, bridge crane, production documentation (Cadwork files for machining, printed for quality check)
Cut off point	Some material/components do not fit or get damaged → Go again to components provision process
Main materials	WS#3: large-format boards (OSB, wooden-fibre, cement-fibre, gypsum-fibre, etc.)
Consumables	Slitting wheels, milling wheels, marking material
Workmanship units	1–2 workers at WS
Total duration	20 minutes / materials for 1 average panel
Task description	• Measuring, cutting, milling, mark lines creating, labelling • Sorting, packing onto pallets sorted for individual panels, labelling
Final result	• Formatted, labelled, sorted, and packed materials and components for the panel assembly

TABLE 27: FORMATTING CENTRE RESOURCES (WS#3)

5.1.3 *Working station #4: Wall panel type 1 assembly*

In Table 28 and Table 29, the detailed processes and steps are described in terms of the assembly of wall panel type 1 at the WS#4. Figure 4 illustrates the composition layer's assembly tasks numbers. Wall panel type 1 is the one that is attached to the existing wall.

The materials and components necessary for the WS#4 processes are delivered from the WS#2 and WS#3 (formatted materials) and WS#1 (components), see Figure 3.

Step description	Wall panel type 1 assembly processes (WS#4)
Main equipment	Weinmann turning tables[13], Weinmann multifunction bridges[14], automated slider
Auxiliary equipment	Drills, screwdrivers, hammers, and other hand tools, staple gun, compressor
Cut off point	Delay due to specific techniques, related to ConExWall panels, in which the workers are not skilled → to prevent the risk of delay, increased manpower will be involved in the assembly process
Main materials	Timber members, boards, thermal insulations, heating system layers (soft thermal insulation, milled particleboards, metal/aluminium sheets, heating pipes), laths, diffusion foils, windows, ventilation unit cases incl. electrical wiring, plastic protecting tubes/goose necks, planks
Consumables	Staples, nails, screws, straps, washer-head screws, vapour barrier tapes, diffusion tapes, pipe clips, load slings
Workmanship units	4 workers at WS
Total duration	40 minutes / frame and boards assembly for 1 average panel 30 minutes / 1 typical window/door preparation 30 minutes / 1 typical window/door installation 20 minutes / ventilation unit case installation 40 min / insulation of 1 average panel

[10] https://www.homag.com/en/products/house-construction
[11] https://www.homag.com/en/products/cutting
[12] https://www.hundegger.com/en-us/machines
[13] https://www.homag.com/en/products/house-construction/assembly-tables
[14] https://www.homag.com/en/products/house-construction/multifunction-bridge

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	2 hours / heating system layers (for 1 average panel) 1 hour / auxiliary works (materials and components manipulation, etc.) 30 minutes / quality check of 1 average panel Total: 6:10 hours / 1 typical wall panel type 1
Task description	Assembly a ConExWall wall panel type 1, including a window and a ventilation unit case and wiring, prepared for ventilation unit installation. See more in Table 29.
Final result	Completed ConExWall panel type 1 prepared for installation, or semi-completed panel to be completed with façade at WS#6

TABLE 28: WALL PANEL TYPE 1 ASSEMBLY RESOURCES (WS#4)

no	Assembly task	Description, activities (wall panel type 1, WS#4)
1	Frame assembly	• Timber members for main structural frame are manually positioned on the Weinmann table, based on the documentation and mark lines, • Provisionally fixed with staples
2	Cladding board	• Cladding boards are positioned onto the frame from the step #1 (manipulated using a sucker) • The boards are fixed with staples to the frame #1
3	Cladding cutting	• The side laps of the cladding boards #2 are cut on shape (unless done at WS#3 in advance) and all openings (for windows/doors, ventilation unit case) are cut out (automatically by the Weinmann multifunction bridge, based on the imported drawings' documentation)
4	Turnover	• The composition is turned upside down by the Weinmann turning table
5	Thermal insulation	• Thermal insulation is manually positioned in between the frame #1 timber members
14	Window preparation	• Window frame is affixed with water vapour barrier tape from the interior side and diffusion tape from the exterior side (window head and reveal parts) • angle brackets are fixed to the window frame (will serve for fixing the window into the frame #1)
15	Window assembly into the frame	• Window is inserted into the frame #1 (into the opening cut out in #3) (manipulation with the window using a glass suction cup) • Window is fixed to frame #1 using the angle brackets already prepared in #14
16	Ventilation unit case assembly	• Ventilation unit case is inserted and fixed, using angle brackets or screws • The case is sealed from interior side by a vapour barrier tape
17	Turn to vertical position	• The composition is turned to vertical position by the Weinmann turning table
18	External thermal insulation	• Hard wooden fibre insulation boards are manually put against the structure and screwed to the frame #1 • Note: in case the ConExWall system is included in regular production, step #18 might be machined. For the single Kasava demo panels assembly, it would be inefficient to prepare a machinery programme for a single use only; a manual work is found more reasonable in this situation • Note2: the external thermal insulation boards will probably be a tongue-and-groove system which cannot be machined and a manual work is necessary, anyway
19	Diffusion foil	• Diffusion foil (weathering membrane) is positioned on the thermal insulation board #18 and provisionally fixed with small staples
20	Façade laths	• Façade laths are positioned on the diffusion foil and screwed into the frame #1
21	Turn to horizontal position	• The composition is turned to horizontal position (laths' side down) by the turning table
22	Plastic protecting tubes / goose necks	• If needed for the sake of electrical wiring, plastic protecting tubes/goose necks are mounted on the board #2 and fixed with pipe clips. The maximum diameter of tubes is 24 mm to prevent its damage during installation.
23	Soft insulation layer	• Soft wooden fibre insulation is laid on the board #2 (milled out where plastic protecting tubes are placed to avoid pressing the tube during installation)
24	Heating particleboard with steel/aluminium sheets for heating pipes	• Particleboards with milled grooves are laid on the top of the soft insulation layer #23. • Metal/aluminium sheets for heating pipes are inserted to the particleboard grooves, based on the drawing documentation
25	Heating pipes	• Heating pipes are inserted into the grooves of the particleboard from #24, based on the drawing documentation
26	Heating layers fixing	• The layers #23, #24 and pipes #25, are fixed by using straps and screwed with washer-head screws into the frame #1

note: tasks #6 to #13 are intentionally skipped to keep numbering of identical tasks among all types of panels

TABLE 29: WALL PANEL TYPE 1 ASSEMBLY TASK STEPS AT WS#4

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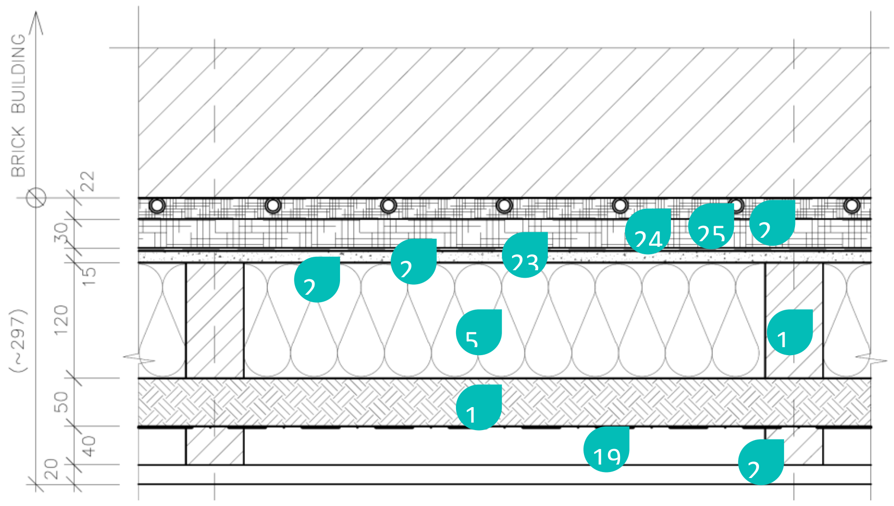

FIGURE 4: WALL PANEL TYPE 1 – COMPOSITION LAYER'S ASSEMBLY TASKS REFERRED TO IN TABLE 29

5.1.4 ***Working station #4: Wall panel type 2 assembly***

In the Table 30 and Table 31 are described the processes and manufacturing steps that lead to the wall panel type 2 assembly at the WS#4. Figure 5 illustrates the composition layer's assembly tasks numbers. This type of panel is intended for stand-alone installation (without existing wall) at some parts of 2nd storey of the Kasava demo building.

The materials and components necessary for processes at WS#4 are collected from the WS#2 and WS#3 (formatted materials) and WS#1 (components), see Figure 3.

Step description	Wall panel type 2 assembly processes (WS#4)
Main equipment	Weinmann turning tables, Weinmann multifunction bridges, automated slider
Auxiliary equipment	Drills, screwdrivers, hammers, and other hand tools, staple gun, nail gun, compressor
Cut off point	No cut off point expected. Except for the ventilation unit case installation, this kind of panel is a common RDR structure, thus no specific techniques are involved that might delay the assembly process. To prevent the risk of delay coming from ventilation unit installation case techniques, increased manpower will be involved in the assembly process.
Main materials	Timber members, boards, thermal insulations, laths, water vapour membranes, diffusion foils, windows, ventilation unit cases incl. electrical wiring, plastic protecting tubes/goose necks, planks
Consumables	Staples, nails, screws, vapour barrier tapes, diffusion tapes, load slings
Workmanship units	4 workers at WS
Total duration	50 minutes / frames and boards assembly for 1 average panel 1 hour / C-beams production 30 minutes / 1 typical window/door preparation 30 minutes / 1 typical window/door installation 20 minutes / ventilation unit case installation 50 minutes / insulation of 1 average panel 1 hour / auxiliary works (materials and components manipulation, etc.)

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	30 minutes / quality check of 1 average panel Total: 5:30 hours / 1 typical wall panel type 2
Task description	Assembly of a ConExWall stand-alone wall panel type 2, including a window and a ventilation unit case and wiring, prepared for ventilation unit installation. See more in Table 31.
Final result	Completed ConExWall stand-alone panel type 2 prepared for installation, or semi-completed panel to be completed with façade at WS#6

TABLE 30: WALL PANEL TYPE 2 ASSEMBLY RESOURCES (WS#4)

no.	Assembly task	Description, activities (wall panel type 2, WS#4)
1	Frame assembly	• Timber members for main structural frame are manually positioned on the Weinmann table, based on the documentation and mark lines, • Provisionally fixed with staples
2	Cladding board	• Cladding boards are positioned onto the frame #1 (manipulated using a sucker) • The boards are fixed with staples to the frame #1
3	Cladding cutting	• The side laps of the cladding boards #2 are cut on shape (unless done at WS#3 in advance) and all openings (for windows/doors, ventilation unit) are cut out (automatically by the Weinmann multifunction bridge, based on the imported drawings' documentation)
4	Turnover	• The composition is turned upside down by the Weinmann turning table
5	Thermal insulation	• Thermal insulation is manually positioned in between the frame #1 timber members
6	Water vapour barrier foil	• Water vapour barrier foil is laid on the thermal insulation #5
7	Laths	• Laths are positioned on vapour barrier foil and screwed/nailed to the frame #1
7a	Plastic protecting tubes / goose necks	• If needed for the sake of electrical wiring, plastic protecting tubes/goose necks are inserted between laths #7 and fixed to them with pipe clips
8	Thermal insulation	• Thermal insulation is manually put in between the laths #7
9	Interior cladding	• Interior gypsum-fibre board, or Interior system gypsum-fibre board equipped with heating pipes (where heating is designed as integral part of the panel type 2) is put on the laths #7 • The boards are fixed with staples to the laths #7
10	Cladding cutting	• The side laps of the cladding boards from #9 are cut on shape (unless done at WS#3 in advance) and all openings (for windows/doors, ventilation unit) are cut out (automatically by the Weinmann multifunction bridge, based on the imported drawings' documentation)
11	Turnover	• The composition is turned upside down by the turning table
12	C-beams	• C-beams are manually made from timbers 60x60 mm and OSB • The C-beams are positioned onto the board #2 • The C-beams and fixed with staples/nailed to the frame #1
13	Thermal insulation	• Thermal insulation is manually positioned in between the C-beams #12
14	Window preparation	• Window frame is affixed with water vapour barrier tape from the interior side and diffusion tape from the exterior side (window head and reveal parts) • angle brackets are fixed to the window frame (will serve for fixing the window into the frame #1)
15	Window assembly into the frame	• Window is inserted into the frame #1 (into the opening prepared in #3 and #10) (manipulation with window using a glass suction cup) • Window is fixed to the frame using the angle brackets prepared in #14
16	Ventilation unit case assembly	• Ventilation unit case is inserted and fixed, using angle brackets or screws • The case is sealed from interior side by a vapour barrier tape
17	Turn to vertical position	• The composition is turned to vertical position by the turning table
18	External thermal insulation	• Hard wooden fibre insulation boards are manually placed to the structure and screwed to the frame #1 • Note: in case the ConExWall system is included in regular production, step #18 might be machined. For the single demo Kasava panels assembly, it would be inefficient to prepare a machinery programme for a single use only; a manual work is found more reasonable in this situation • Note2: the external thermal insulation boards will probably be a tongue-and-groove system which cannot be machined and a manual work is necessary, anyway
19	Diffusion foil	• Diffusion foil is positioned on the thermal insulation board #18 and provisionally fixed with small staples
20	Façade laths	• Façade laths are positioned on the diffusion foil and screwed into the frame #1

TABLE 31: WALL PANEL TYPE 2 ASSEMBLY TASK STEPS AT WS#4

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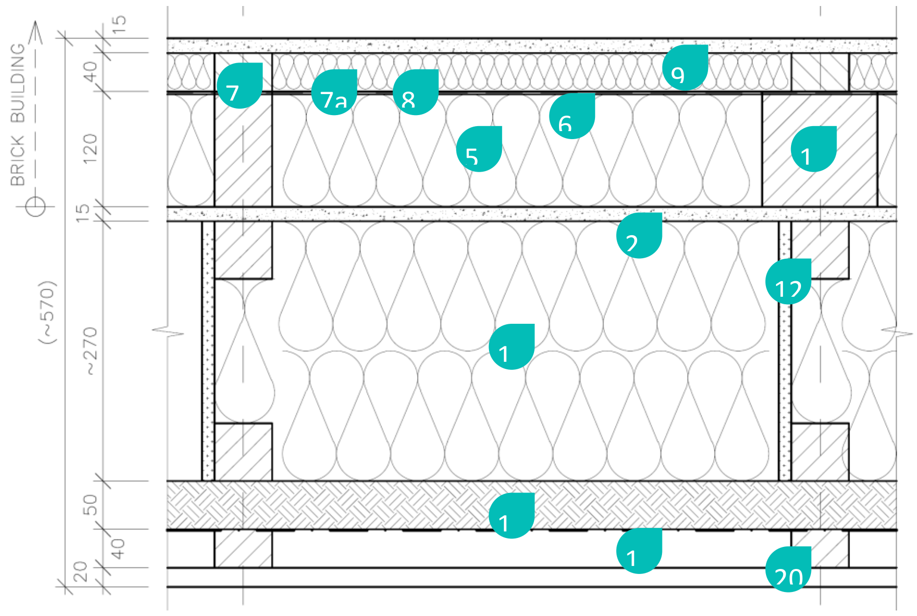

FIGURE 5: WALL PANEL TYPE 2 – COMPOSITION LAYER'S ASSEMBLY TASKS REFERRED TO IN TABLE 31

5.1.5 *Working station #5: Roof panel assembly*

Roof panels' assembly processes and manufacturing steps are described in Table 32 and Table 33. Figure 6 illustrates the composition layer's assembly tasks numbers. Roof panels' assembly usually takes place at WS#5; in some cases, it may also take place at WS#4.

The materials and components necessary for processes at WS#5 are delivered from the WS#2 and WS#3 (formatted materials) and WS#1 (components), see Figure 3.

Regarding the level of roof panel completion, the zinc sheet cladding is not included in the assembly process to prevent its damage during transportation and handling (the roofing will completely be laid on-site). As a consequence, and for the same transportation and safety reasons, neither PV panels are included in the assembly process. They will be installed on-site only after the roof panels installation is completed and zinc roofing laid.

Step description	Roof panel assembly processes (WS#5)
Main equipment	Weinmann turning tables, automated slider
Auxiliary equipment	Saws, drills, screwdrivers, hammers, and other hand tools, staple gun, nail gun, compressor
Cut off point	No cut off point expected (this kind of panel comes from a common RDR structure, thus no specific techniques are involved that might delay the assembly process)
Main materials	Timbers, boards, thermal insulations, laths, water vapour membranes, diffusion foils
Consumables	Staples, nails, screws, vapour barrier tapes, diffusion tapes, load slings
Workmanship units	4 workers at WS
Total duration	50 minutes / frames and boards assembly for 1 average panel 50 minutes / insulation of 1 average panel 1 hour / auxiliary works (materials and components manipulation, etc.) 30 minutes / quality check of 1 average panel Total: 3:10 hours / 1 typical roof panel
Task description	Assembly a ConExWall roof panel. See more in Table 33.
Final result	Completed ConExWall roof panel prepared for installation

TABLE 32: ROOF PANEL ASSEMBLY RESOURCES (WS#5)

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no.	Assembly task	Description, activities (roof panel, WS#5)
1	Rafters	• Rafters are manually positioned on the Weinmann table, based on the documentation • Provisionally fixed with staples
2	Cladding DHF board	• DHF (hardwood) cladding boards are positioned onto the rafters #1 • The boards are screwed to the rafters #1
3	Cladding cutting	• The side laps of the DHF cladding boards #2 are cut on shape (unless done at WS#3 in advance)
4	Turnover	• The composition is turned upside down by the turning table
5	Thermal insulation	• Thermal insulation is manually positioned in between the rafters #1
6	Water vapour barrier foil	• Water vapour barrier foil is laid on the thermal insulation #5
7	Laths	• Laths are positioned on vapour barrier foil and screwed/nailed to the rafters #1
7a	plastic protecting tubes / goose necks	• If needed for the sake of electrical wiring, plastic protecting tubes/goose necks are inserted between the laths #7 and fixed to them with pipe clips
8	Thermal insulation	• Thermal insulation is manually put in between the laths #7
9	Interior cladding	• Interior gypsum-fibre board is put on the laths #7 • The boards are fixed with staples to the laths #7
10	Cladding cutting	• The side laps of the cladding boards from #9 are cut on shape (unless done at WS#3 in advance)
11	Turnover	• The composition is turned upside down by the turning table
18	External thermal insulation	• Hard wooden fibre insulation boards are placed on the DHF board #2 and fixed with staples to the board #2
19	Diffusion foil	• Diffusion foil is positioned on the thermal insulation #18 and provisionally fixed with small staples
27	Roof laths	• Roof laths are positioned on the diffusion foil and screwed into the rafters #1
28	Wooden sheet	• Wooden sheet is put on laths #27 and screwed

Note: tasks #19 to #25 are intentionally skipped to keep numbering of identical tasks among all types of panels

TABLE 33: ROOF PANEL ASSEMBLY TASK STEPS AT WS#5

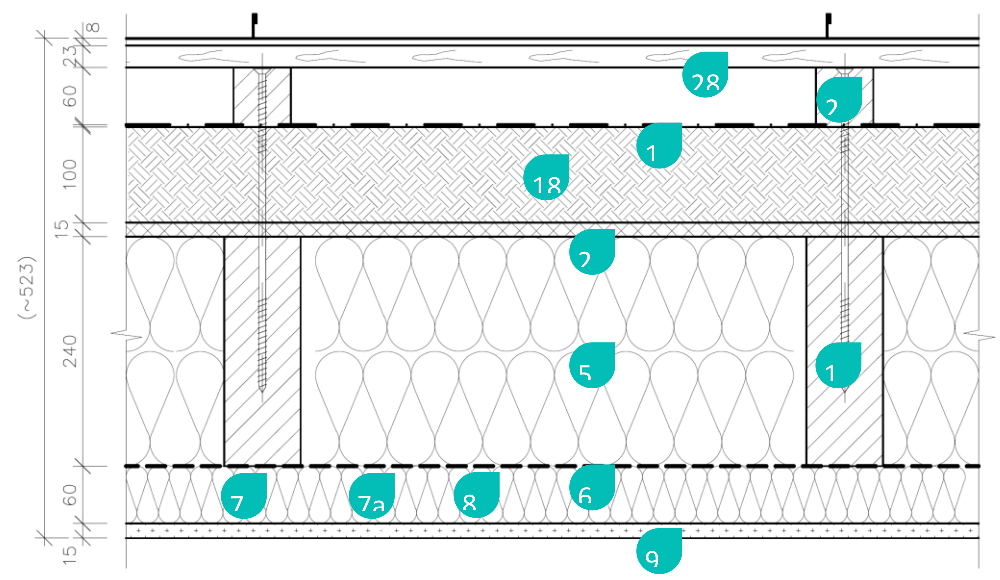

FIGURE 6: ROOF PANEL – COMPOSITION LAYER'S ASSEMBLY TASKS REFERRED TO IN TABLE 33

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5.1.6 *Working station #6: Façade cladding*

There are three options for the façade cladding prefabrication:

- First, the whole façade cladding will be preassembled at the production plant in a form of separate compact sections based on the detailed installation plan, while respecting the assembly and transportation size limits. For the detailed installation plan preparation, the use of cloud of points (coming from 3D scanning), imported to Cadwork software, is recommended to ensure that the façade cladding will fit the demo building perfectly after the panels' installation. The advantage of this option is the high degree of prefabrication and thus the reduced amount of works on-site. The disadvantage is the highest risk that the façade sections will not perfectly fit the demo building equipped with the installed panels due to installation tolerances.
- The second option is to pre-assemble only a part of the façade cladding, in a form attached to the wall panels, while the rest of the cladding will be completed on-site. This option has the advantage of possible adjustments to installation tolerances, yet still with the reduced amount of work on-site.
- The third option is to complete the ConExWall panels installation with façade cladding only at the construction site (the façade cladding will not be part of assembly process at all). This bears the highest possibility of final installation adjustments and the most solid look of the façade. The disadvantage is the increased amount of work on-site.

Final decision about way of façade assembly and installation will be made together with the installer, once selected.

In case the second option is chosen, semi-completed panels are transported from WS#4 to WS#6 where completed with the façade cladding parts.

In case the first option is chosen, the façade sections will be assembled at WS#4 as individual components.

Regardless of which façade cladding prefabrication option will be chosen, the exterior windowsill will be installed and sealed at WS#6. Then, window's head and jamb exterior cladding will be assembled.

Step description	Façade cladding assembly processes (façade cladding, WS#6)
Main equipment	Façade vertical workplace, bridge crane
Auxiliary equipment	Drills, screwdrivers, cutters and cutting tools, miter saws, hammers, and other hand tools, staple gun, compressor
Cut off point	None
Main materials	Coloured wooden planks, laths, exterior window sill
Consumables	Screws, slitting wheels, staples, nails, diffusion tape, seal
Workmanship units	8 workers at WS (they work in parallel on multiple panels)
Total duration	2.5 hours / 1 typical panel (in case of full façade cladding)
Task description	Attaching the façade cladding onto the wall panels (the parts where designed), exterior window sill installation and sealing, and window head and jamb cladding completion
Final result	ConExWall panel with completed parts of façade cladding (if part of assembly process), window head and jamb exterior cladding note: façade cladding cannot be fully completed since access to anchors, installation channels and panel joints must be ensured during installation on-site

TABLE 34: FAÇADE CLADDING ASSEMBLY RESOURCES (WS#6)

5.1.7 *Working station #7: Expedition area*

The completed panels are moved from WS#4/WS#5/WS#6 with the aid of portable crane or forklift to the expedition area. They are stored there on wooden pallets, stacked by floors and in sequence according to the installation plan on-site, with the precaution of placing a foam-type protection materials or woods among them to avoid contact between materials of different hardness reducing the possibility of damages by friction. Once all the panels are completed, they are loaded and transported to the construction site.

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5.1.8 *Quality Control Station (Q.C.S.)*

To complete the assembly process, a series of inspection actions/tests to all of its components should be performed, as presented in the *Deliverable D4.5 – PnU kit prototype property and performance characterization*. Quality control processes will be presented in detail in *D6.3 – Quality Assurance Plan – manufacturing / assembly*.

As a first level of quality control process, self-quality control is done at every working station after every assembly step. Further, at the end of the whole assembly process, overall inspection actions are done on the panels as part of a single operational result process.

Briefly, the inspection actions/tests to be performed at a designated area of the plant (Q.C.S.) are as follows:

Visual tests

- Measurements confirmation;
- ConExWall panel aesthetics;
- Surface observation – defects on paint, cracks, flakes etc.;
- Sealant check defects on windows, sealant, sills, edges, plastic protecting tubes for wiring.

Mechanical tests

- Slings for crane manipulation;
- Heating layer and pipes secured to the board;
- Window frame firmly attached to the frame;
- Window's hinges;
- Pressure test of the heating layer pipes.

Electrical tests

- Cable Continuity/impedance test;
- HVAC – operational test;
- HVAC – external control test;
- IAQ – functionality and communication test.

Operational tests

- Window's hinges functionality (open/close/tilt);
- Blinds operation;
- Plastic protecting tubes for wiring passable.

5.2 Assembly Process – Additional Data

5.2.1 *Assembly Process Duration*

Based on the detailed drawings, the assembly processes have been analyzed in more detail and the initial estimation on the assembly process duration has been refined since that presented in *Deliverable D6.1 – Manufacturing methodology of PLURAL kits*. The final assembly process duration will be calculated based on the production documentation and will be presented in *D6.3 – Quality Assurance Plan*.

Average panel production durations per panel types and in total are presented in Table 35.

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Panel type	Total number of panels	Average production time per 1 panel [h]	Total production time [h]
Wall panel type 1	14	9:00	126:00
Wall panel type 2	8	8:20	66:40
Roof panel	8	3:30	28:00
Total	–	–	**220:40**

TABLE 35: PRODUCTION DURATION ESTIMATION OF CONEXWALL PANELS TO BE INSTALLED ON KASAVA DEMO BUILDING

5.2.2 *Assembly Process Efforts (workmanship)*

The overall effort for the assembly process involves:

- direct assembly effort and,
- non-assembly effort, related to the plant operation and production in general.

Those two parts of total assembly process effort are presented in Table 36 and Table 37.

Panel type	Production time per panel type [h]					Number of workers at WS					Total effort [mh]	
	WS#1	WS#2 / WS#3	WS#4 / WS#5	WS#6	WS#7	WS#1	WS#2	WS#4 / WS#5	WS#6	WS#7	per panel type	per m²
wall panel type 1		0:20	6:10	2:30			2	4	2		30:20	1:57
wall panel type 2		0:20	5:30	2:30			2	4	2		27:40	3:53
Roof panel		0:20	3:10				2	4			13:20	0:38
ConExWall panels altogether	2:00				12:00	4				7	92:00	0:12
											all panels	**aver./m²**
Total	–								–		844:40	1:55

TABLE 36: ASSEMBLY EFFORTS PER WORKING STATION AND PANEL TYPES

Job position	Total effort	
	[mh]	[mh/m²]
Production documentation	100	0:13
Plant manager, safety engineer, administrative personnel, general duties workers*	254	0:34
Total	**344**	**0:47**

**typypically calculated as 30 % of total assembly time*

TABLE 37: NON-ASSEMBLY EFFORTS – ACTIVITIES NOT DIRECTLY PART OF ASSEMBLY PROCESS

Based on Table 36 and Table 37, total effort for the whole assembly phase presented in Table 38.

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Total efforts	Total effort	
	[mh]	[mh/m^2]
Whole assembly phase – assembly efforts + non-assembly efforts	**1199**	**2:43**

TABLE 38: TOTAL EFFORTS

The individual processes durations estimation will be refined based on production documentation. In the end, those estimations will be confronted with real durations during assembly process phase and the differences analyzed.

Note: Time needed for components production delivered to RDR plant (windows etc.) is not included in the presented efforts. Only processes taking place at RDR plant are considered.

5.2.3 *Assembly's Process Energy Demand*

In the RDR plant, natural gas and electricity are used as energy sources. Natural gas is used for heating, while electricity serves for machinery and appliances operation, lighting, and additional heating during periods of extremely low external temperatures. Energy consumption is not measured or analyzed in detail per individual processes/working stations/machines. Therefore, for a rough estimation of overall assembly process energy demand, the total annual energy consumption is taken as a basis and converted to average manufactured house through the number of manufactured houses per year (approx. 400), based on an assumption that houses produced in the RDR plant are approximately similar in their average size to Kasava demo building. Estimation of ConExWall panels assembly energy demand is presented in Table 39. It will be refined later based on the production documentation and further during assembly phase.

Energy carrier	Estimated demand [MWh]
Natural gas	8.517
Electricity	3.036

TABLE 39: ESTIMATED ENERGY DEMAND OF THE OVERALL ASSEMBLY'S PROCESS

5.2.4 *Assembly Process Drawings*

Extracts of the all the manufacturing drawings for all the types of the ConExWall panels for the Kasava demo building are presented at EMDESK *(EMDESK/Documents/ WP6/D6.2)* and due to their "Confidential" status will be included in *Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly*.

5.3 Assembly Cost Analysis

Similarly to paragraph 5.2.4 Assembly Process Drawings, all relevant Assembly Cost Analyses will be thoroughly presented in *Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly*.

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6 Conclusions

Assembly methodology is a process in manufacturing for production of goods where smaller products are assembled at different steps, in a sequence, to produce the final product. In assembly line production, the main product moves from stage one to the end stage in a defined sequence. In most cases, an assembly line is a partial automated process, and at each stage there might be a human intervention.

Manufacturing of PLURAL PnU kits might be a lengthy process (depending on the design of each PnU kit) and might require several smaller parts or components to be assembled together. While the proposed assembly line production ensures that the multiple stages defined in the current report are functional and sustainable, is important to highlight the role of *Design for Manufacturing and Assembly (DFMA)* [15] which was the real outcome of *D6.1 - Manufacturing methodology of PLURAL kits*.

DFMA can be determined as an engineering methodology that focuses on reducing total manufacturing time and total production costs by prioritizing both the ease of manufacture for the product's parts and the simplified assembly of those parts into the final product. In this sense, the outcome of the PnU kit design as presented in the Deliverables of *WP2 - Selection of technologies – Integration – Design of PnU kits*, identified the basic requirements for the key elements of DFMA:

- *Assembly Drawings* – the graphical view of the PnU kits with reference designators that tie back to numbers on the Bill of Materials (BOM) so that the component indicated can be identified. The Assembly Drawings also include notes which indicate the order of assembly, when to apply thread locking material, fastener torque and/or other special instructions that are not obvious to the assembler, while some of them have a table of material as part of the drawings.

- *Assembly Procedure* – which is typically used for complex assemblies such as SmartWall PnU kit, and is required in order everything to be put together, step by step. Many times, this document is used in conjunction with an Assembly Drawing. The procedure have sections identifying:

    a. Tools, equipment, jigs, and fixtures required;
    b. Assembly Steps;
    c. Any tests or measurements that need to be made during the assembly, they would have a step and may have a reference to a test report where information can be recorded.

NOTE: Some of the aforementioned information were identified by the manufacturers as "Sensitive information" and will be presented in the Deliverable D6.3 - Quality Assurance Plan – manufacturing / assembly which its Dissemination Status is declared in the Grant Agreement as "Sensitive".

Due to the nature of PnU kits, as well as the limited quantities needed to be manufactured, all three manufactures chose to use the Teams Assembly type[16], where workers work at one or two persons Working Stations and perform repetitive tasks. All involved teams participate at different stages (manufacturing steps), imposing quality checks (per stage) to ensure that the finished product is of high quality. In this method the different teams are responsible and accountable for their own set of steps within a stage and then handover to the next team ending to the final Quality Station where the Quality Assurance Protocols are applied. The "Teams production type" is considered as the one that creates greater worker involvement in the manufacturing process and knowledge of the system.

Though, the complexity of some PnU kits enforce manufactures to merge Teams Assembly type with the Sub-assembly type[17]. As sub-assembly type considers a group of components that are part of a larger assembly, but which can be installed or removed separately. It is a unit of a larger assembly that is made up of smaller components. Sub-assemblies are used to simplify the development and maintenance of complex systems by breaking them down into smaller and more manageable parts. Sub-assembly manufacturing is a critical part of the proposed manufacturing process. It reduces the complexity of PLURAL PnU kits assembly process by breaking it down into smaller tasks that can be completed more efficiently.

The benefits of using such an assembly line production type (Teams Sub-assembly type), are:

a. Time to manufacture of PnU kits have reduced.

[15] Nieble, Benjamin, and Andris Freivalds. *Methods, Standards, and Work Design*. July 2002
[16] Umble, Michael, Van Gray, and Elisabeth Umble. "Improving Production Line Performance." *IIE Solutions*. November 2000.
[17] https://www.researchgate.net/publication/306024521_Design_for_Manufacturing_and_Assembly_vs_Design_to_Cost_Toward_a_Multi-objective_Approach_for_Decision-making_Strategies_During_Conceptual_Design_of_Complex_Products

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b. Higher efficiency of output as each stage is driven by an expert worker.
c. Minimization of waste due to the expertise of the workers of each Working Station.
d. Assembly line enhanced by ensuring a constant streamlined, smooth & continuous flow of production.
e. People management is easier as each worker has their role clearly defined and is unique from other workers working at different stages of production.
f. Increased scalability.
g. Ensure better communication among Working Stations.

The implementation of the data occurred by the actions of *WP5 - IT renovation tools-BIM based LYSIS platform and Multi-objective Decision Support Tool (MODEST) for fast and low-cost deep renovation processes*, upgraded the Teams Assembly type to the *Joint Application Development* (JAD)[18] Assembly methodology. The BIM drawings of PnU kits brought together those working in the plant and those working in the information technology area into a single workshop, resulting in a dramatic shortening of the time it takes to complete the assembly of the PnU kits units.

Finally. it must be noted that all the mentioned conclusions were based on the results obtained by the manufacturers on a "Pilot Plant Scale" and can only be considered as the framework where the future industrialization of the PnU kits will be based on.

[18] https://en.wikipedia.org/wiki/Joint_application_design

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