REPORT 1.2.2

BEST PRACTICE REPORT ON METHODS, SKILLS AND COMPETENCES IN RELATION TO STONE PRODUCTS

CONSTRUCTION PROCESS OF MARBLE OR GRANITE INCLINED ROOFS

Consortium members: Deutscher Naturwerkstein-Verband E.V (DNV), Asociatia Romania Green Building Council (RoGBC), Colegio Oficial de Arquitectos de la Región de Murcia (COAMU), Asociación Empresarial de Investigación Centro Tecnológico del Mármol, Piedra y Materiales (CTM), Klesarska Skola Pucisca (KLESARSKA)

Content

1. INTRODUCTION

The BIMstone project was born from the fusion of three lines of action whose convergence is a consolidate a didactic material base for the training in the stone sector. These three lines of actions are:

- BIM (Building Information Modeling).
- LCA (Life Cycle Assessment).
- Digitisation of stone products placement methodologies.

The European Commission is focused on the construction sector on the criteria of smart growth (knowledge and innovation-based development and economy) and inclusive growth (ensuring social and territorial cohesion through employment).

According to the above context, the general aim of BIMstone project is to increase the skills of workers in the field of placing the stone products particularly in placing different type of floors and walls in buildings and urban environments, in order to increase the quality of the final work, the permanence of the work and the environmental sustainability, by using methods without non-recyclable and/or eco-friendly materials. For that reason, it is necessary to define and compile the most suitable execution systems and placement methods for stone products.

The first task of the BIMstone project "O1. *Establishment of common learning outcomes on stone placing methods, Life Cycle Analysis (LCA) and regulations*" encompasses a number of specific tasks among which we find the elaboration of this report.

This best practice report addresses the establishment of skills and competencies, as well as the definition of the most sustainable and environmentally friendly implementation processes.

Of all the natural stone construction elements selected in this project, this report focuses on the construction of a marble or granite inclined roof, describing in detail some of their characteristics, both constructive and environmental, and the construction process to be followed to achieve an optimum result.

2. ENVIRONMENTAL CONSIDERATIONS

The Environmental Product Declarations (EPDs) are the clearest, most rigorous and internationally accepted way to provide the environmental profile of a product throughout its life cycle.

The EPD "***Jura Limestone façade panels and wall cladding (limestone slabs)***" include natural stone products which main function is for ornamental use to cover interior and exterior surfaces, such as floors, walls, facades, stairs, etc. and has been verified and published at https://ibu-epd.com.

The EPD of limestone slabs has been carried out according to the LCA methodology with quantified environmental information of its entire life cycle. That is to say, the EPD of these materials is of the "cradle to door" type, as can be seen in the following table, which includes the life cycle stages considered.

DESCRIPTION OF THE SYSTEM BOUNDARY (X = INCLUDED IN LCA; MND = MODULE NOT DECLARED)																
PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARIES
Raw material supply	Transport	Manufacturing	Transport from the gate to the site	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse- Recovery- Recycling-potential
A1	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**	**D**
X	X	X	X	MND	MND	X	MNR	MNR	MNR	MND	MND	MND	MND	MND	X	MND

Source: IBU - Institut Bauen und Umwelt e.V.

This EPD has been developed and verified according to the EN 15804 and EN ISO 14025 standards and the Product Category Rules (PCR) for marble and limestone slabs used in the building construction.

The EPD functional unit is defined as 1 tonne of mass of natural stone (corresponds to 12.82 m², 30 mm thick). The scope of the study has been defined from the cradle to the door, covering only the manufacturing module (extraction and preparation of the raw materials, processing of the natural stone slabs and transport between these stages).

The EPD details the formulation to be used (conversion factor) to transform the functional unit from a tonne of mass of natural stone to a square meter of facade.

Factors for calculating results for different thicknesses:

Parameter	1 t (corresponds to 19,23 m² of 20 mm thickness)	1 t (corresponds to 12,82 m² of 30 mm thickness)	1 t (corresponds to 9,62 m² of 40 mm thickness)
GWP	1,29	1,00	0,85
ODP	1,37	1,00	0,81
AP	1,18	1,00	0,90
EP	1,19	1,00	0,90
POCP	1,27	1,00	0,86
ADPE	1,41	1,00	0,78
ADPF	1,31	1,00	0,85
PERT	1,36	1,00	0,79
PENRT	1,31	1,00	0,84

Source: IBU - Institut Bauen und Umwelt e.V.

The results of the LCA – Environmental Impact are:

RESULTS OF THE LCA - ENVIRONMENTAL IMPACT: 1 t Jura Limestone façade panels and wall cladding (corresponds to 12.82 m², 30 mm thick)

Parameter	Unit	A1-A3	A4	B2	C4
Global warming potential	[kg CO_2-Eq.]	59.90	4.73	0.04	16.14
Depletion potential of the stratospheric ozone layer	[kg CFC11-Eq.]	6.33E-11	6.00E-13	2.21E-9	1.52E-11
Acidification potential of land and water	[kg SO_2-Eq.]	1.80E-1	1.96E-2	9.75E-5	9.54E-2
Eutrophication potential	[kg $(PO_4)^{3-}$-Eq.]	2.72E-2	4.84E-3	6.26E-5	1.30E-2
Formation potential of tropospheric ozone photochemical oxidants	[kg ethene-Eq.]	1.25E-2	-7.24E-3	2.47E-5	7.51E-3
Abiotic depletion potential for non-fossil resources	[kg Sb-Eq.]	8.61E-5	4.92E-7	-6.13E-9	5.79E-6
Abiotic depletion potential for fossil resources	[MJ]	842.44	64.26	0.59	208.74

RESULTS OF THE LCA - RESOURCE USE: 1 t Jura Limestone façade panels and wall cladding (corresponds to 12.82 m², 30 mm thick)

Parameter	Unit	A1-A3	A4	B2	C4
Renewable primary energy as energy carrier	[MJ]	1188.26	4.25	0.15	25.24
Renewable primary energy resources as material utilization	[MJ]	0.00	0.00	0.00	0.00
Total use of renewable primary energy resources	[MJ]	1188.26	4.25	0.15	25.24
Non-renewable primary energy as energy carrier	[MJ]	850.92	64.45	0.61	216.11
Non-renewable primary energy as material utilization	[MJ]	14.29	0.00	0.00	0.00
Total use of non-renewable primary energy resources	[MJ]	865.22	64.45	0.61	216.11
Use of secondary material	[kg]	0.00	0.00	0.00	0.00
Use of renewable secondary fuels	[MJ]	0.00	0.00	0.00	0.00
Use of non-renewable secondary fuels	[MJ]	0.00	0.00	0.00	0.00
Use of net fresh water	[m³]	2.02	0.00	0.01	0.04

RESULTS OF THE LCA – OUTPUT FLOWS AND WASTE CATEGORIES: 1 t Jura Limestone façade panels and wall cladding (corresponds to 12.82 m², 30 mm thick)

Parameter	Unit	A1-A3	A4	B2	C4
Hazardous waste disposed	[kg]	1.32E-5	4.06E-6	1.12E-5	3.42E-6
Non-hazardous waste disposed	[kg]	1.35E+3	4.70E-3	8.28E-3	1.00E+3
Radioactive waste disposed	[kg]	9.03E-3	7.40E-5	5.89E-6	2.92E-3
Components for re-use	[kg]	0.00	0.00	0.00	0.00
Materials for recycling	[kg]	0.00	0.00	0.00	0.00
Materials for energy recovery	[kg]	0.00	0.00	0.00	0.00
Exported electrical energy	[MJ]	0.00	0.00	0.00	0.00
Exported thermal energy	[MJ]	0.00	0.00	0.00	0.00

Source: IBU - Institut Bauen und Umwelt e.V.

3. CONSTRUCTIVE CONSIDERATIONS

The roof covering with slabs made of natural stone requires a water-impermeable substructure, as the natural stone slabs are not completely waterproofed, and rainwater can in particular pass through the joints of the natural stone slabs.

The roof covering with natural stone slabs is independent of the existing roof construction, but the net weight of the natural stone slabs and substructure must be taken into account for the structural analysis of the roof structure and the building.
As a rule, a waterproofing membrane with overlapping joints is applied to the roof structure made of reinforced concrete or wooden beams with board formwork.

On the hydroisolation layers, support profiles are attached to support the vertical rail profiles at the statically required distance. When drilling through the hydroisolation layers, it must be taken care to ensure a waterproofed fastening (e.g. with rubber side plates). On the vertical rail profiles, horizontal rail profiles are screwed at a distance of the width of the natural stone plates. On the horizontal rail profiles, the retaining angles for the natural stone slabs are fixed depending on the plate lengths.
The natural stone slabs are fixed on this substructure. In the case of very high wind loads, additional mechanical protection for the position of natural stone slabs may be required.
The required corrosion protection must be observed for all metallic fasteners

The auxiliary elements required in each particular case, as well as their dimensioning and arrangement, must be determined by means of structural analysis.

With the self-supporting roof construction system, exposed natural stones broaden their scope of application, being able to be used both residential or office buildings, with panels of modest geometric proportions, and industrial or commercial buildings, with panels of large proportions.

In addition to its good structural behaviour, from a functional point of view, this roof covering presents an excellent hygrothermal behaviour as it allows the passage of an air chamber and continuous thermal insulation in front of the structure, thus avoiding thermal bridges in the roof.
The elimination of the cold bridges reduces the energy demand of the building, as well as the risk of formation of surface condensations at these points, allowing the construction of buildings with a very high level of energy efficiency.

Likewise, if the impermeability requirements make it advisable, self-supporting roof coverings with natural stone allow the ventilation of the air chamber, achieving a roof with the advantages of ventilated roof (with a higher degree of impermeability and a lower risk of interstitial condensation forming on the enclosure) and other additional advantages associated with natural stone (such as durability, low maintenance, etc.).

For all the above reasons, this construction system is the optimum solution for ventilated natural stone facades in the construction of Nearly Zero Energy Consumption Buildings (EECN) and Passivhaus.

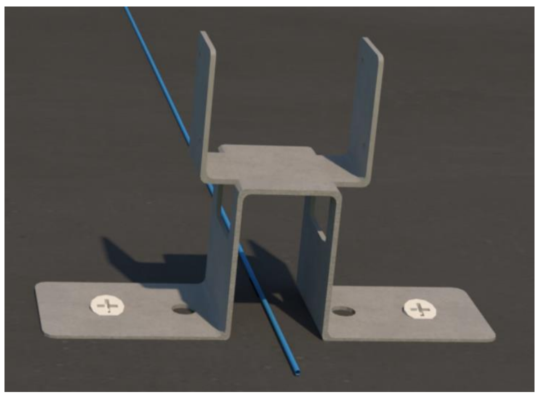
In addition, this construction system allows a perfect lead and flatness of the outer leaf of the façade to be achieved, regardless of the geometric deviations of the structure, as well as homogeneity in the tonality of the cloth of the façade.

3.1 Auxiliary elements

The stability and resistance of the self-supporting rove against horizontal and vertical actions is resolved with anchors and metal rails, which have a structural function in self-supporting roof coverings.

3.1.1. Metal brackets

The metal brackets are installed to support the of the vertical profile on two sides. It is required to use both fixed point metal brackets (on the upper end of each profile) and brackets with a sliding point to allow for the profile movement.

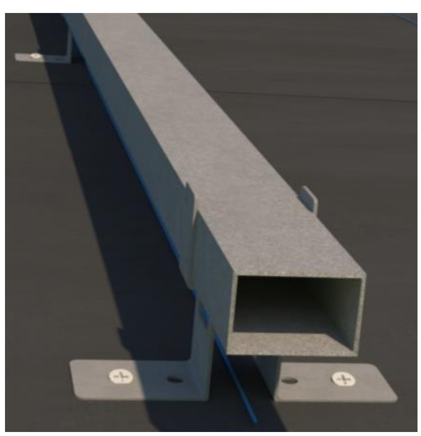


Source: BIMstone project website.

3.1.2. Profiles

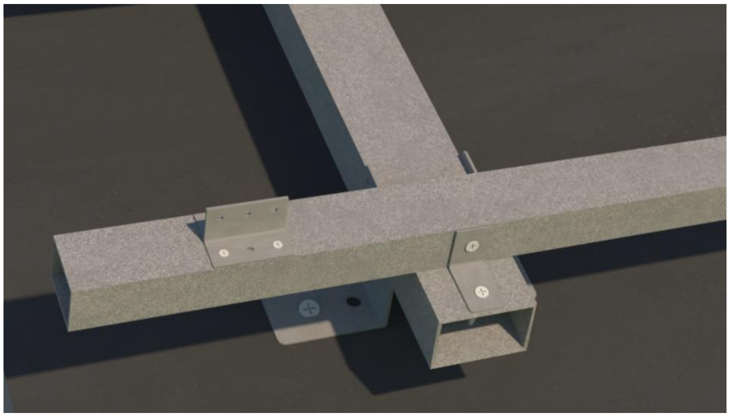
In this type of ventilated facade with self-supporting structure, two types of profiles are necessary:

- Vertical profiles: These profiles must allow for an air cavity between the insulation and the cladding material. For an optimal air circulation, the cavity must allow minimum of 2 cm width in the narrow areas.



Source: BIMstone project website.

- Horizontal profiles: These profiles will be fixed on the vertical profiles with a separation that depends on the dimensions of the natural stone slabs and the thickness of the fixing bracket and a movement gap of min. 2 mm. For example, if the slabs are 60 x 30 cm and the fixing bracket are 3 mm thick, the the axial dimension between the profiles must be 305 mm (= 300 + 3 + 2).



Source: BIMstone project website.

3.1.3. Insulation

Depending on the requirements of the project and the climatic conditions of the area in which it is to be installed, the most suitable insulation will be chosen. The thermal insulation is installed under the board formwork and the waterproofing membrane.

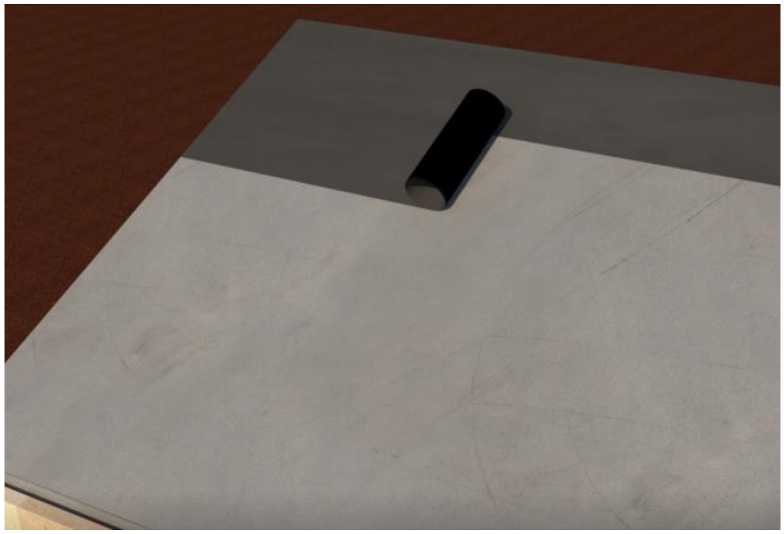
There are various types of insulation on the market suitable for ventilated claddings. The nature and thickness of the insulation must be carefully calculated on an individual project basis taking into account the varying factors (type of building, location and exposure…).

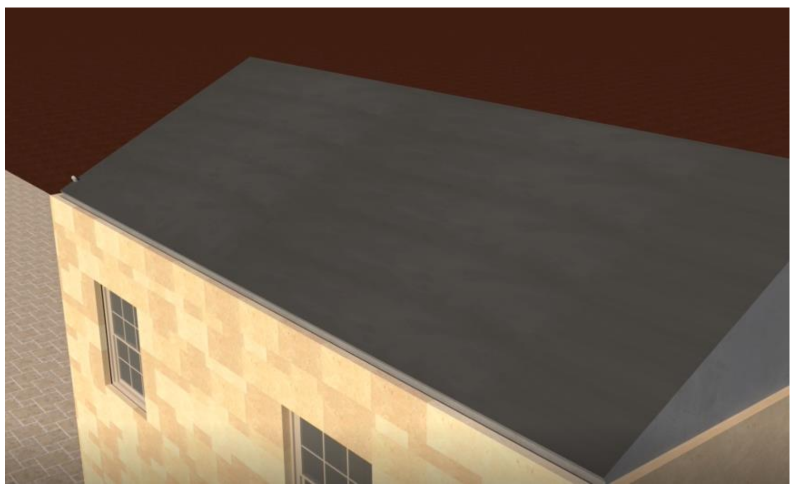
4. CONSTRUCTION PROCESS

4.1. Placing the waterproof layer

The first step in achieving a waterproofed roof is to lay the waterproofing layer, preventing water or moisture from entering the building (leaks).

In order to optimize the placement of this waterproofing, it will be done from top to bottom and from left to right and making some small overlaps between the adjacent layers to ensure that there are no gaps without waterproofing. This process will be repeated until the whole surface is completely covered.





Source: BIMstone project website.

4.2. Layout of the metal brackets

To begin with the construction process of ventilated roof, the metal brackets will be laid out on the waterproof blanket. To do this, a ruler or laser level will be used, and the line strip will be used to leave marks on the support on which the whole roof supporting structure will be placed. With this layout, the exact position of the profiles that will be necessary will be determined according to the plans.

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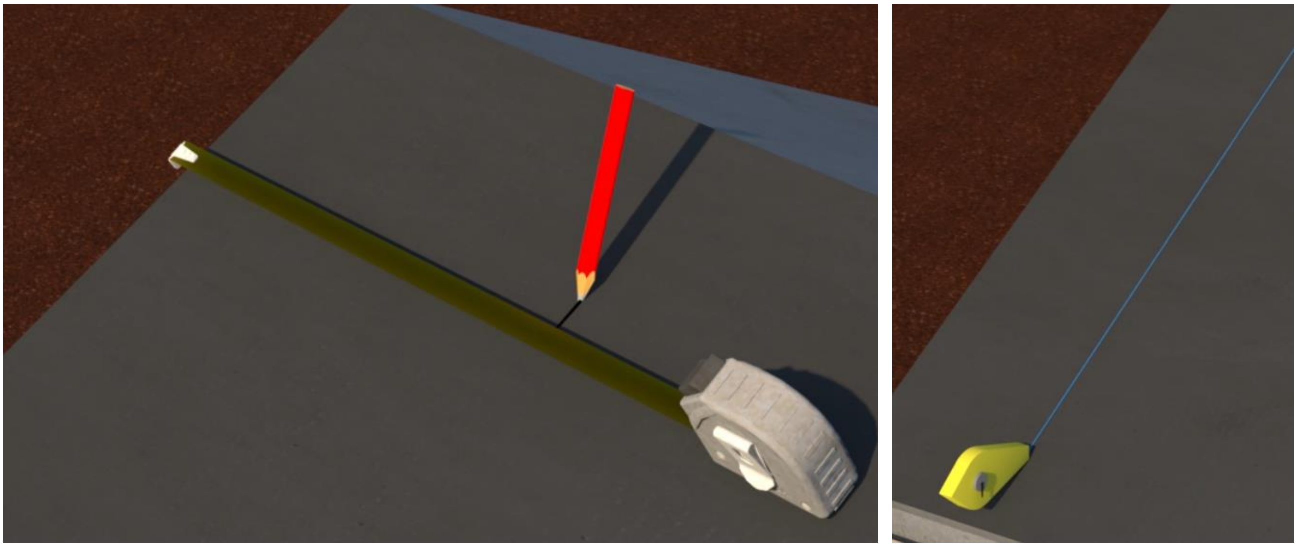
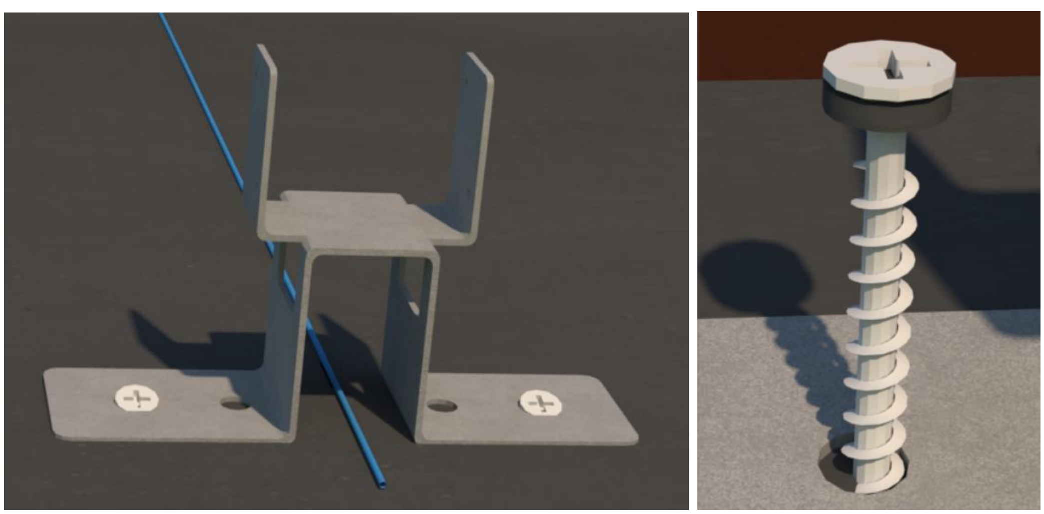


Source: BIMstone project website.

4.3. Fixing the metal brackets

The metal brackets will be installed in a staggered manner to support the vertical profile.

The dimensions of the metal brackets and the distance of the fixing must be taken from a structural analysis.
Screws with seals should be used to fix these metal brackets. The sealing of the screws will serve as a waterproofing in the area of the hole created by the screw.



Source: BIMstone project website.

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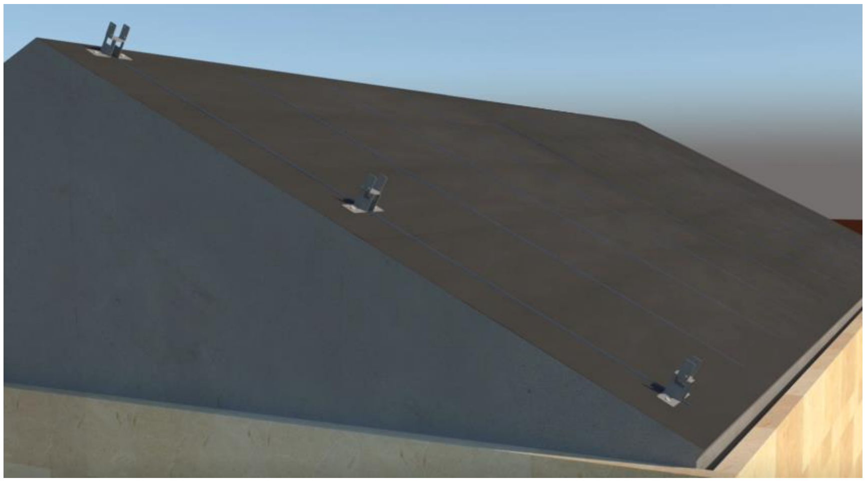
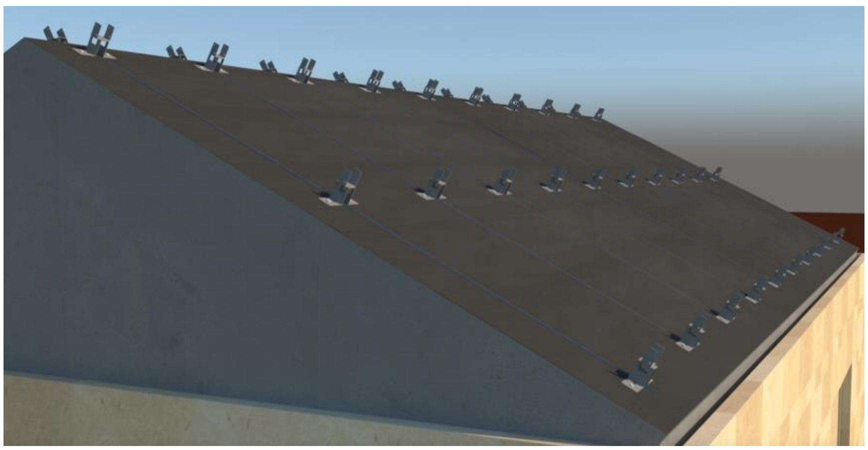


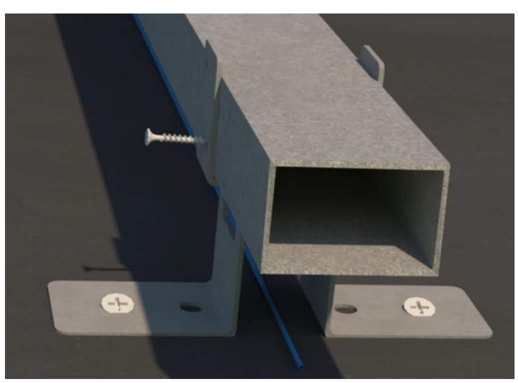


Source: BIMstone project website.

4.4. Fixing the vertical profiles

The vertical profiles will be fixed to the metal brackets in such a way as to ensure a ventilated air chamber with a minimum thickness of 2 cm. The possible thermal expansion of the profiles must be taken into account when fastening (fixed point and sliding point).

The vertical profiles must be perfectly levelled to receive the rest of the components of the ventilated roof covering construction system.



Source: BIMstone project website.

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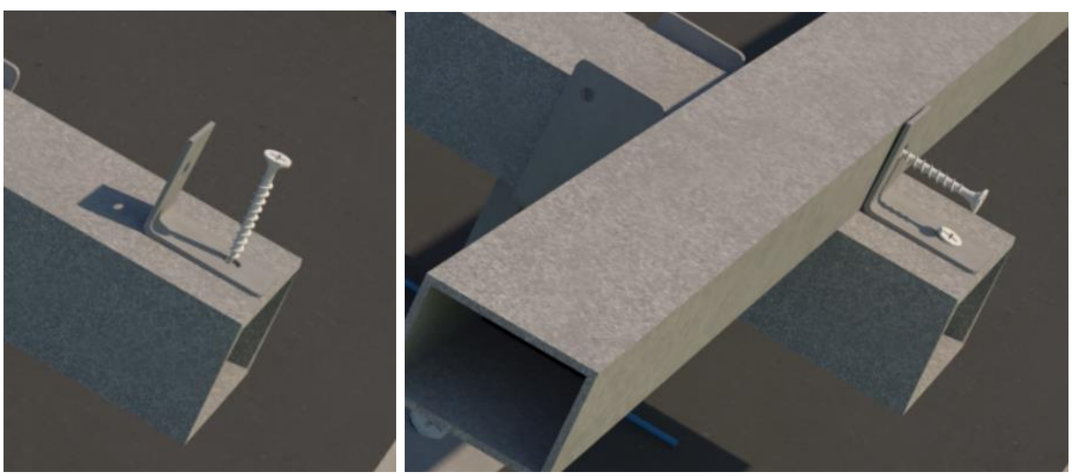
Source: BIMstone project website.

4.5. Fixing the horizontal profiles

Once the vertical profiles are in place, the horizontal profiles will be installed and fixed to the vertical ones at each intersection. The separation between horizontal profiles is 305 mm, for natural stone or pieces of 600 x 300 mm, with consideration of the thickness of the fixing bracket and a movement gap of min. 2 mm.
The horizontal profiles must be perfectly level as their position will dictate the final position of the natural stone slabs.



Source: BIMstone project website.

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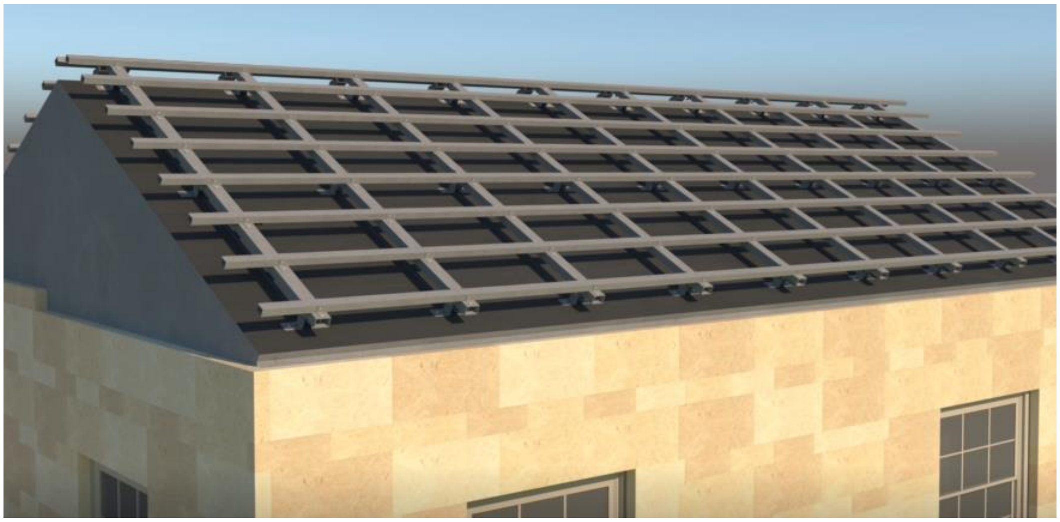
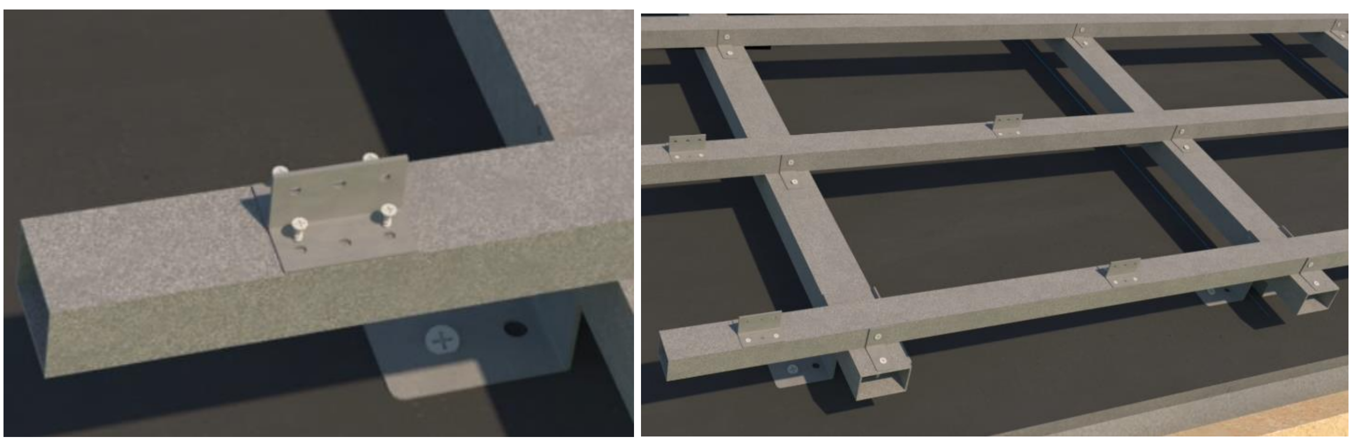


Source: BIMstone project website.

4.6. Fixing the brackets for natural stone slabs

Once the horizontal profiles are in place, the fixing brackets will be installed to hold the natural stone slabs. A minimum of two brackets per slab is requested. For very long slabs, three or more brackets are recommended.



Source: BIMstone project website.

4.7. Placing the natural stone slabs on the roof

After that, the finishing natural stone slabs will be installed on the roof. If necessary, the natural stone slabs must be secured against wind suction.

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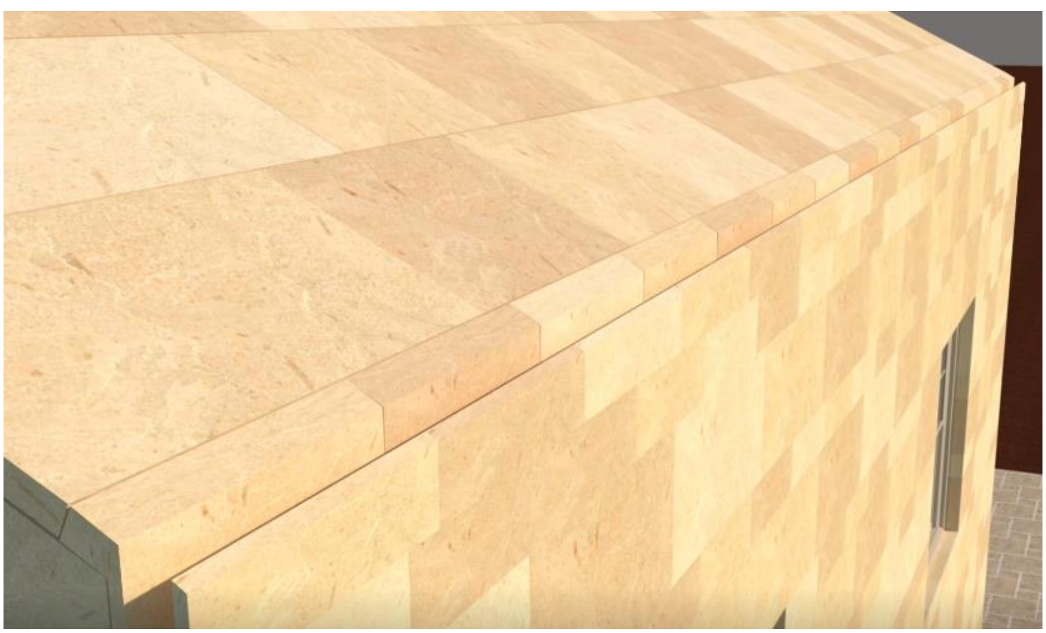
Source: BIMstone project website.

4.8. Placing the bottom stone

On the eaves of the roof a special natural stone piece will be installed to close the gap between the wall and the roof. It is recommended to use a natural stone with a gutter profile, to collect the rainwater and drain it to an internal downpipe.

Source: BIMstone project website.



Source: BIMstone project website.

4.9. Completion of the installation

Repeat the processes indicated in the previous steps until the total surface of the roof and its edges are completed with the special pieces. In this way, the process of laying the ventilated roof with natural stone slabs will be completed.

Source: BIMstone project website.

5. SUMMARY. STEPS TO FOLLOW IN THE CONSTRUCTIVE PROCESS

The construction processes of a self-supporting ventilated façade are summarised below:

1. Placing the waterproof layer.
2. Layout of the metal brackets.
3. Fixing the metal brackets.
4. Fixing the vertical profiles.
5. Fixing the horizontal profiles.
6. Fixing the brackets for natural stone slabs.
7. Placing the natural stone slabs on the roof.
8. Placing the bottom stone.
9. Completion of the installation.

6. REFERENCES

1. BIMstone project website. www.bimstoneproject.eu/bimstone-products

2. Jura Limestone façade panels and wall cladding. Franken-Schotter GmbH & Co. KG. Environmental Product Declaration. IBU – Institut Bauen und Umwelt e.V. https://epd-online.com/EmbeddedEpdList/Download/10098

3. Video “02. Marble or granite inclined roofs construction process” of BIMstone project. https://www.youtube.com/watch?v=pQHL5ak0uHw