LIFE my building is green

LIFE17 CCA/EN/000088

Application of Nature-Based Solutions for local adaptation of educational and social buildings to Climate Change

Action: C2

Deliverable: Technical manual for the installation of permeable surfaces, as an NBS prototype

Deliverable: Technical Manual for the installation of permeable soil prototype.

Date: 07/31/20

LIFE my building is green - LIFE17 CCA/ES/000088

Deliverable: Technical Manual for the installation of permeable soil prototype.

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1. SUMMARY EN ESPAÑOL

This document collects the premises established for the design of a prototype of draining pavement, the description of the materials used and its manufacturing process, at prototype level.

In addition, its mechanical and functional properties have been verified, in accordance with the test regulations applicable to this type of elements for the execution of pedestrian pavements, so that it has been verified that it meets the necessary requirements for its commercialisation and installation.

Finally, the manual for the installation of the draining pavement is presented, with the possible geometric configurations, the technical instructions for its installation and an example of a demonstration platform executed in the facilities of the Eduardo Torroja Institute of Construction Sciences with photocatalytic functionality.

2. SUMMARY

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3. OBJECTIVE OF THE PERMEABLE SOIL PROTOTYPE

During visits prior to the start of the project, a problem was detected on the perimeter of the C.P. Gabriela Mistral. It was observed that next to the facade of the building, water was accumulating from surface runoff from the playground area. This area of water accumulation generated a muddy area, with the disruption and inconvenience that this circumstance generates in a children's playground.

The possibility of solving this problem was considered by paving the perimeter of the building, using a draining pavement system that would evacuate the excess water provided by surface runoff, but at the same time would allow reusing this water flow for its use.

This approach was extended to the other two schools participating in the project, since the climate of their locations is even more rainy than that of the Badajoz school and, logically, they would have similar situations of water and mud accumulation during the rainy season.

Once the problem to be solved had been identified, the objective of the proposal was set, which had to respond to the following conditions:

- Pedestrian traffic pavement
- Permeable pavement for surface runoff drainage and use of this water flow.
- Incorporation of vegetation in the pavement, generating a green pavement, to minimize its visual impact on the environment.
- Reduce the pavement's contribution to the "heat island" effect by incorporating vegetation into the pavement, which favors moisture retention.
- Enhance the contribution of the pavement to the improvement of environmental quality. In addition to the vegetation on the pavement itself, tiles with photocatalytic activity will be designed.

The combination of tile pavements and creeping or meadow vegetation has traditionally been used to facilitate pedestrian traffic in landscaped areas and to take advantage of its aesthetic effect, minimizing the visual impact of the pavement (Figure 1). But this type of solution only responds to this need to facilitate pedestrian traffic.

Figure 1: Examples of green pavements.

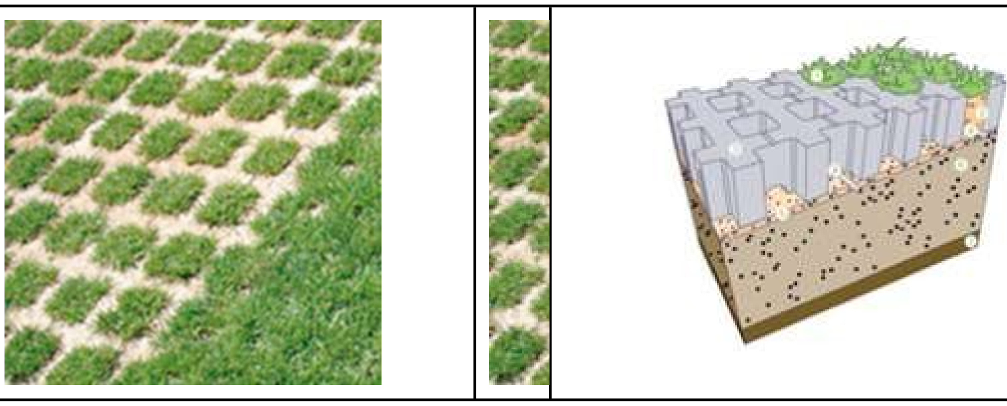

Figure 2: Examples of commercial green pavements.

In addition, there are several commercial solutions on the market for the implementation of green pavements (Figure 2). These types of industrialized solutions can be combined with permeable substrates that drain rainwater. The drained flow can be channeled subway to reservoirs for collection and subsequent reuse. The result of this combination is the Sustainable Urban Drainage Systems (S.U.D.S).

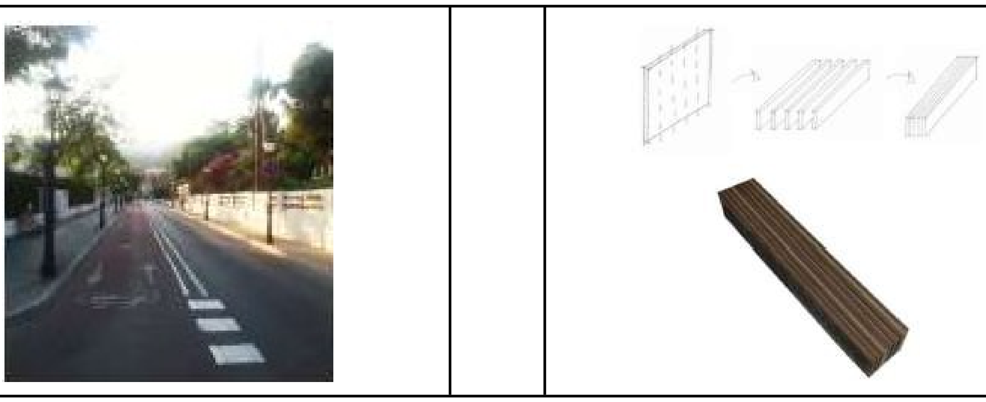

Figure 3: Proposed SUDS of the LIFE CERSUDS Project (LIFE15/CCA/ES/000091)

The advantages of SUDS systems can be summarized as follows:

- Reduce flooded pavement areas, especially in storm situations, by increasing the permeable surface of the pavement.
- It allows the filtering of runoff flows, retaining plant debris or dragged aggregates, improving water quality.
- Allow the reuse of stored rainwater for use in times of drought.
- Reducing peak runoff flows to the urban sanitation system and, therefore, to the wastewater treatment system. As well as the reduction of solid materials, since they have been retained at source by filtration.

The proposal of the prototype of the present project could be used in SUDS pavements, combined with channeling systems and storage tanks. But it can also be used in more traditional solutions, to provide an aesthetic and walkable solution in landscaped areas, with the prototype itself providing the drainage, channeling and storage capacity.

The proposal focuses on the design of a permeable tile for pedestrian traffic, with interior collection and evacuation of surface runoff water, incorporating creeping vegetation and with decontaminating characteristics thanks to its photocatalytic activity.

4. PROTOTYPE DESCRIPTION

The tiles are made of three materials: a layer of porous concrete, with photocatalytic activity, permeable to water that prevents the formation of puddles on its surface as a result of rainfall; a resistant mortar base and a layer of topsoil in which the plants can grow. The mortar layer forms a slight slope (~2°) that conducts rainwater to the fertile soil layer; thus, all the water captured by the total pavement area ends up being available for the plants.

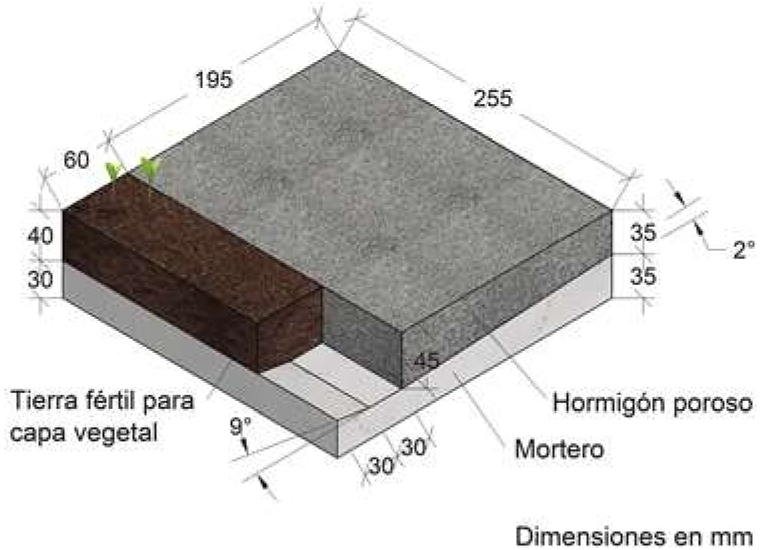

Figure 4: Schematic diagram of the tile.

5. MANUFACTURING OF TEST TUBES

5.1 Dosing of materials

5.1.1 Compact supporting concrete

For the mortar base, a pre-dosed Propamsa brand material called M7.5 was used. This material has been the same in all the pieces, combining it with each of the porous concretes shown in the following subsection.

5.1.2 Drainage porous concrete

Various dosages of porous concrete have been studied.

Initially, the tiles were manufactured with Paviland brand pre-dosed porous concrete. The amount of water indicated by the manufacturer was added to the mixture during mixing.

Subsequently, in order to reduce the weight of the pieces, the porous concrete was manufactured using different types of expanded clays of two maximum sizes: 2.5 mm, called "XS", and 5.0 mm, "S". This material was always saturated for several days before kneading to prevent it from absorbing water in the mixing and cement paste process. The mixtures, in addition to expanded clay, were made with CEM I 52.5 R cement, standardized sand from the Eduardo Torroja Institute and water. In some dosages, a plasticizing additive from BASF, MasterEase 3690, was added.

Finally, in order to add more strength to the mix, following the initial results of the wear tests, another dosage was developed in which the expanded clays were replaced by siliceous gravel with a grain size of 4-8. This dosage did not contain additives.

With this last mixture, chosen after passing the suitability for use evaluation tests, several series of test tubes were produced again to check the reproducibility of the mixture at laboratory level, before proceeding to its industrialized production.

All dosages studied are shown in Table 1 below (values are in kg). "A. E." is used as an abbreviation for "expanded clay":

Materials	A.E. S	A.E. S + A.E. XS	A.E. S + A.E. XS (without additive)	Gravel 4-8
CEM I 52.5 R Tudela Veguín	10,0	10,0	10,0	10,0
Standardized sand IETcc - CSIC	10,0	10,0	10,0	10,0
Water	3,0	3,0	2,4	5,8
S Weber expanded clay (saturated)	18,3	15,5	15,4	-

Weber XS Expanded Clay (saturated)	-	6,6	6,6	-
MasterEase 3690 MasterEase 3690 MasterEase 3690 MasterEase 3690 MasterEase 3690 MasterEase 3690 MasterEase 3690 BASF	0,026	0,026	-	-
Siliceous gravel 4-8	-	-	-	128,8
Ratio w/c	0,30	0,30	0,24	0,58
% additive	0,26%	0,26%	-	-

Table 1: Dosages studied

5.1.3. Photocatalyst

The photocatalyst used was a commercial TiO_2-based photocatalyst in aqueous emulsion, whose supplier is not provided for confidentiality reasons.

5.1.4 Vegetation layer

For the topsoil, a solution was sought to facilitate handling, transport and installation. For this purpose, compostable plastic bags were sealed by heat, in which "universal" commercial vegetable substrate had been previously introduced. The seeds can be introduced mixed with the substrate before sealing the bag or they can be sown later by making small holes in the bag. Once the substrate settles through the passage of time and, above all, by the roots of the plants, the plastic bag will no longer be needed to contain the soil and will self-compost serving as nutrients to the vegetables.

Figure 5: Compostable plastic bag filled with plant substrate.

5.2 Tile manufacturing process

All the tiles have been manufactured at IETcc-CSIC following the process described in this point. Perhaps, some of the following points may suffer slight changes if this process is carried out in an industrial way in the future.

1. The molds are filled with porous concrete. The upper side of the mold is placed facing upwards, with the same orientation as the piece will have when it is finished. The porous concrete is poured into the mold (Phase 1a). Once the molds are flush (Phase 1b), they are placed in a humid chamber for 24 hours (23°C ± 3°C temperature and relative humidity). ≥ 95%).

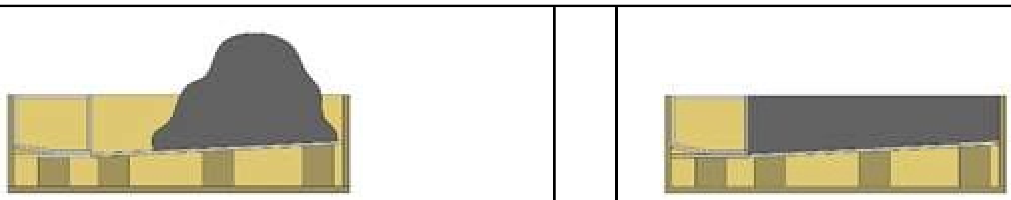

Figure 6: Tile manufacturing process. Phase 1a and 1b.

2. The molds with the cured and hardened porous concrete are removed from the wet chamber. Before filling the mold with the mortar that forms the base layer, the porous concrete parts are rotated horizontally so that they are face down.

3. Each mold is filled with mortar and, after screeding, the whole assembly is returned to the wet chamber.

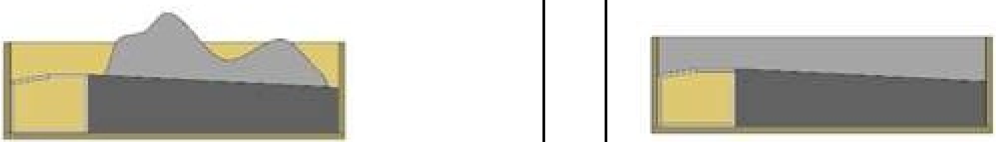

Figure 7: Tile manufacturing process. Phase 2 and 3.

4. After 24 hours, the molds are removed from the humid chamber and, once the parts have been demolded, the manufacturing process can be considered completed.

Figure 8: Tile manufacturing process. Phase 4.

6. TESTS PERFORMED AT AT MATERIAL CURED AND HARDENED

The higher the value of relative hydraulic conductivity, the better the drainage of the part. The mix made with gravel has the best drainability value without reaching the values of the predosed concrete. However, as can be seen in the mechanical properties table, the width and length of the footprint of the predosed concrete are not sufficient to comply with the minimum values of the UNE 127748-1:2012 and UNE-EN 13748- 2:2005 standards; only the last dosage reaches acceptable values in the mechanical tests. Due to this, the mix chosen to elaborate the final specimens has been the one elaborated with the last dosage, the one containing siliceous gravel.

The results of the tests mentioned in the previous paragraph are detailed below.

6.1 Drainability

These tests have been performed according to the standards "UNE-EN 12697-40:2013: Bituminous mixtures. Test methods for hot bituminous mixtures. Part 40: Drainability in situ." and "UNE-EN 1936:2007: Test methods for natural stone. Determination of the real and apparent density and of the open and total porosity".

The relative hydraulic conductivity, bulk density and open porosity of porous concretes have been obtained. The relative hydraulic conductivity represents the time required to drain water from the surface of the material. Bulk density gives an idea of the lightness of the specimen. The open porosity reflects the number of pores that are connected in the mass of the specimen, but does not consider the isolated pores inside the material, such as, for example, those inside each expanded clay sphere.

All these results are shown in the table below:

Name of the mixture	Relative hydraulic conductivity (HC) [1/s].	Bulk density [kg/m]³	Open porosity [%].
Paviland (predosed)	0,142	2446	12,1
Initials	0,023	-	-
A.E. S	0,030	-	-
A.E. S + A.E. XS	0,005	1105	20,8
A.E. S + A.E. XS (without additive)	0,009	1096	22,6
Gravel 4-8	0,042	2362	9,8

Table 2: Test results related to drainability.

Figure 9: Drainability test.

6.2 Total water absorption

This section presents the water absorption results of the specimens of the chosen mix.

Probe	Capillary absorption 24 hours [g/cm]^2	Total water absorption [%]
1	0,5	4,5
2	0,4	4,4
3	0,3	4,5
4	0,4	5,4
Media	0,4	4,7

Table 3. Water absorption of the specimens of the chosen mix.

According to Standard UNE 127748-2:2006, the tiles will have sufficient climatic resistance if the average water absorption on the fair face is not greater than 0.4 g/cm^2 in the sample composed of 3 test specimens. In this case, the results satisfy this requirement.

In addition, to ensure the durability of the element for the usual use for which it is marketed, the tiles must comply with the requirement of class 2 and marking B. This indicates that the average absorption in percent of water by mass must be less than or equal to 6 %. This requirement is also met by the tiles tested.

6.3 Mechanical properties

The tests in this section have been carried out to study the characteristics of the porous concrete, especially the resistance to abrasion. These tests are governed by the standards "UNE 127748-1:2012: Terrazzo tiles. Part 1: Terrazzo tiles for interior use.

National complement to UNE-EN 13748-1" and "UNE-EN 13748-2:2005: Terrazzo tiles. Part 2: Terrazzo tiles for exterior use".

The results are shown in the table below:

Name of the mixture	Footprint length [mm].	Footprint width [mm].	Maximum footprint width value obtained among all specimens of the same type [mm].
Paviland (predosed)	70,5	30,0	31,0
Initials	70,0	34,0	34,0
A.E. S	69,0	35,0	36,0
A.E. S + A.E. XS	70,0	31,0	31,0
E.I.F. S + E.I.F. XS (sin additive)	64,5	26,5	28,0
Gravel 4-8	64,0	23,0	24,5

Table 4: Test results for mechanical properties at the first dosages.

There are two tables in the standards cited in the first paragraph of this section that indicate the category to which the tile belongs according to the above results. It is necessary that no specimen of the group exceeds the required value, so that maximum rather than average values should be considered.

REESISTENCIA AL DESGASTE POR ABRASIÓN SEGÚN USO PREVISTO	
USO PREVISTO	DESGASTE POR ABRASIÓN (VALOR INDIVIDUAL)
Uso normal	≤ 25 mm
Uso intensivo	≤ 23 mm
Uso industrial	≤ 21 mm

Table 5: Requirements according to UNE 127748-1:2012.

REESISTENCIA AL DESGASTE POR ABRASIÓN SEGÚN USO PREVISTO		
CLASE	MARCADO	DESGASTE POR ABRASIÓN (VALOR INDIVIDUAL)
1	F	CARACTERISTICA NO MEDIDA
2	G	≤ 26 mm
3	H	≤ 23mm
4	I	≤ 20 mm

Table 6: Requirements according to UNE-EN 13748-2:2005.

Thus, the last dosage of porous concrete studied, the one made with siliceous gravel of grain size 4-8, belongs to the "normal use" category, class "2" and marked "G".

Once the most satisfactory mix has been chosen and prior to its industrial manufacture, test specimens have been prepared in the laboratory to study the uniformity that can be achieved by repeating mixes in which a maximum of 20 test specimens are made.

With these tiles, the USRV sliding resistance with friction pendulum and the flexural strength of the specimens of the chosen mix were determined. All the tested tiles have reached a minimum value of 2.9 N/m^2 ; the average value is 3.5 N/m^2 and the maximum value is 3.7 N/m^2 .

Probe	Thickness [cm]	Breaking load [kN]	Bending strength [kN]
1	6,60	16,4	3,7
2	6,80	17,4	3,7
3	6,80	17,1	3,7
4	6,80	13,2	2,9

Table 7: Flexural strength results of the selected mix specimens.

According to Standard UNE 127748-1:2012, for these specimens, whose size does not reach 1100 cm^2 , the tiles comply with the strength required to withstand normal use.

CARGA DE ROTURA SEGÚN USO PREVISTO Y TAMAÑO DE LA BALDOSA		
USO PREVISTO	TAMAÑO DE LA BALDOSA (cm²)	CARGA DE ROTURA (VALOR INDIVIDUAL) (kN)
Uso normal	≤ 1100 > 1100	≥ 2,5 ≥ 3,0
Uso intensivo	≤ 1100 > 1100	≥ 3,0 ≥ 3,9
Uso industrial	≤ 1100 > 1100	≥ 3,6 ≥ 4,7

Table 8: Requirements according to UNE 127748-1:2012.

According to the UNE-EN 13748-2:2005 Standard, the tiles have class 1 ST.

CLASES POR RESISTENCIA A FLEXIÓN PARA SU USO EXTERIOR			
CLASE	MARCADO	RESISTENCIA MEDIA A FLEXIÓN (MPa)	RESISTENCIA INDIVIDUAL
1	ST	3,5	2,8
2	TT	4,0	3,2
3	UT	5,0	4,0

Table 9: Requirements according to UNE-EN 13748-2:2005.

The following table, also from Standard UNE-EN 13748-2:2005, indicates that the tile belongs to class 30 and the 3T marking. This is obtained by considering that the average breaking load of four specimens should be greater than or equal to the values established in the table according to their corresponding bending class, and that no individual value of breaking load should be less than the values established in the table according to their corresponding bending class.

CLASES POR CARGA DE ROTURA			
CLASE	MARCADO	CARGA MEDIA DE ROTURA (kN)	CARGA INDIVIDUAL DE ROTURA (kN)
30	3 T	3,0	2,4
45	4 T	4,5	3,6
70	7 T	7,0	5,6
110	11 T	11,0	8,8
140	14 T	14,0	11,2
250	25 T	25,0	20,2
300	30 T	30,0	24,0
Nota: Por consideraciones de diseño, se deberá prestar una atención especial a las posibles condiciones de carga en el caso de baldosas de longitud superior a 600 mm y si se requiere clase 30, sólo están recomendadas para su uso sobre base rígida continua.			

Table 10: Requirements according to UNE-EN 13748-2:2005

Figure 10: One of the final specimens after breaking in flexure.

As for the slip resistance tests, for each tile tested, an area of its fair face was chosen. This area was tested using the 76.2 mm wide slider, a length of 25.4 mm, and a rubber thickness of 6.4 mm. The length tested was 126 mm, and the reading was made on the C scale of the apparatus.

The results are presented in the following table:

	Mean test value [USRV].	
Probe	0º	180º
1	57,0	57,0
2	57,0	57,0
3	57,0	57,0
4	58,0	57,0
5	57,0	57,0

Table 11: Sliding resistance test results.

According to the Technical Building Code, in section SU 1, Safety against the risk of falling, the slip resistance value obtained establishes that the tile has a class 3.

CLASIFICACIÓN DE LOS SUELOS SEGÚN SU RESBALADICIDAD	
RESISTENCIA AL DESLIZAMIENTO R_d	CLASE
$R_d \leq 15$	0
$15 < R_d \leq 35$	1
$35 < R_d \leq 45$	2
$R_d > 45$	3

Table 12: Classification of soils according to the CTE.

Figure 11: Tile subjected to the slip resistance test.

The following table shows the possible locations where the tile can be installed according to the CTE. These tiles could be used in any of the areas shown in the table.

SEGURIDAD DE UTILIZACIÓN Y ACCESIBILIDAD RESBALADICIDAD DE LOS SUELOS (Rd según UNE-ENV 12633:2003)		DB-SUA 1
LOCALIZACIÓN Y CARACTERÍSTICAS DEL SUELO. SUA 1-1.		CLASE
ZONAS INTERIORES SECAS	Pte. < 6 % Pte. ≥ 6 % Escaleras	1 2 2
ZONAS INTERIORES HÚMEDAS, TALES COMO LAS ENTRADAS A LOS EDIFICIOS DESDE EL ESPACIO EXTERIOR (EXCEPTO CUANDO SE TRATE DE ACCESOS DIRECTOS A ZONAS DE USO RESTRINGIDO), TERRAZAS CUBIERTAS, VESTUARIOS, BAÑOS, ASEOS, COCINAS, ETC)	Pte. < 6 % Pte. ≥ 6 % Escaleras	2 3 3
ZONAS EXTERIORES		3
PISCINAS	ZONAS PREVISTAS PARA USUARIOS DESCALZOS. FONDO DE VASOS DE PROFUNDIDAD ≤ 1,50 m.	3 3
DUCHAS		3

Table 13: Class required for floors depending on their location according to CTE.

On the other hand, the factor "k" of the porous concrete chosen is equal to 0.83. This number represents the ratio between the actual mass of aggregate contained in the porous concrete in a volume V and the mass of compacted aggregate in the same volume V.

Figure 12: Final surface appearance of the selected porous concrete.

6.4 Dimensional characteristics and visual appearance

There is no difference in color or tonality between the pieces that make up the sample, nor are there any superficial defects that can be seen with the naked eye.

The following tables show the dimensional characteristics of the parts:

	Sides						Thickness [mm]		
	Length [mm] Length [mm] Length [mm] Length [mm] Length [mm] Length [mm] Length [mm			Width [mm] Width [mm					
	1	2	3	1	2	3	1	2	3
1	253,5	253,5	253,4	254,5	254,5	254,5	65,8	64,9	69,6
2	256,5	256,5	256,5	252,5	252,5	252,5	65,5	64,8	68,5
3	255,5	255,0	255,5	257,0	257,0	257,0	65,3	67,4	66,7
4	256,5	256,5	256,5	254,5	254,5	254,5	68,2	68,7	65,5
5	256,5	256,0	256,0	253,0	253,0	253,5	67,0	67,8	65,2
6	255,5	255,5	255,5	255,0	255,5	255,0	65,2	66,5	65,5
7	256,5	256,5	256,5	254,5	254,0	254,0	65,8	65,2	65,6
8	257,5	257,5	257,5	250,0	255,0	250,0	67,1	69,0	67,9
Media		255,9			254,2			66,6	

Table 14. Sides and thicknesses of the specimens of the chosen mix.

	Edges (arrow) [mm].		Flatness (arrow) [mm] [mm	
	A	B	A	B
1	0,1	0,1	1,5	0,5
2	0,1	0,1	2,0	1,2
3	0,1	0,1	0,3	1,0
4	0,1	0,1	1,2	1,0
5	0,1	0,1	1,9	0,7
6	0,1	0,1	1,3	0,8
7	0,1	-	0,6	1,0
8	0,1	0,1	0,9	1,2
Media	0,1		1,1	

Table 15. Edges and flatness of the selected mix specimens

	Minimum footprint layer thickness [mm].			
	1	2	3	4
Media	31,5	30,5	32,0	31,0

Table 16. Minimum footprint layer thickness of the specimens of the chosen mix.

According to Standard UNE-EN 13748-1:2005, tiles must comply with the following table:

DIMENSIÓN	TOLERANCIA SOBRE EL VALOR MEDIO
LONGITUD DE LADO	± 0,3 %
ESPESOR	± 2 mm (para un espesor < 40 mm) ± 3 mm (para un espesor ≥ 40 mm)
La diferencia entre dos medidas cualesquiera del espesor de una baldosa individual debe ser ≤ 3 mm. Las baldosas especificadas como calibradas tendrán una tolerancia sobre el espesor de ± 1 mm	

Table 17. Requirements according to UNE-EN 13748-1:2005.

Although they do not strictly comply with what appears in the standard, due to their "handmade" manufacture, it is expected that they will comply when industrially manufactured

7. TECHNICAL MANUAL FOR INSTALLATION OF TEST TUBES

7.1 Arrangement of specimens

The geometric characteristics of the tiles make it possible to create combinations that provide formal diversity to avoid aesthetic monotony. The following image shows nine different configurations as an example.

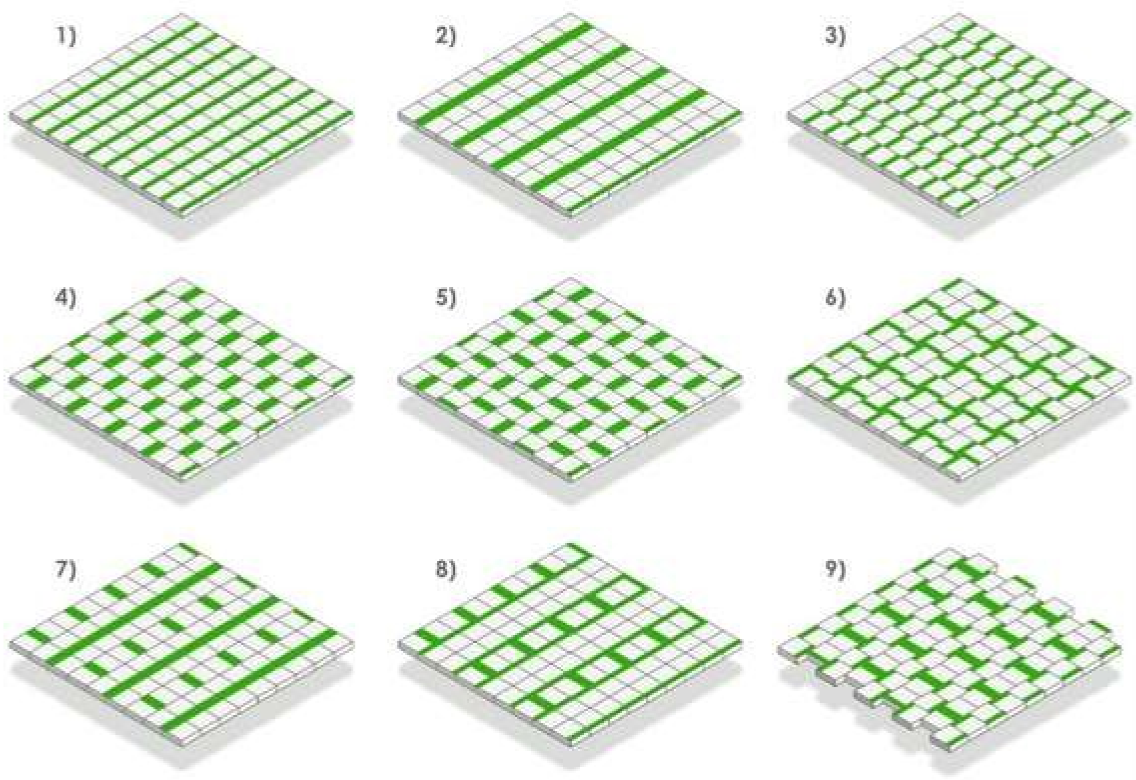

Figure 13: Different configurations thanks to the geometrical characteristics of the parts.

7.2 Demonstration platform for test tubes

A 4 m area[2] consisting of 64 pieces has been installed at the Instituto de Ciencias de la Construcción Eduardo Torroja (CSIC). Two different layouts have been used based on numbers 1 and 2 in the previous image. In addition, this installation has a system of slopes, pipes and manholes to collect the leachate water for analysis.

Figure 14: Tiles installed in the IETcc-CSIC facilities.

Figure 15: Tiles installed in the IETcc-CSIC facilities.

Figure 16: Pavement with vegetation installed on the IETcc-CSIC platform.

7.3 Prototype on-site installation manual

The drainage tile prototype is designed for outdoor paving solutions, executed on pavement for category C4 traffic (pedestrian areas).

The prototype can be installed on site in two ways, depending on whether it is planned to recover the excess runoff or without recovery of this excess, a more aesthetic solution but with partial recovery of the collected rainwater flow, up to the saturation of the substrate and the installed vegetation.

7.3.1 Installation without recovery of excess runoff.

The vegetated draining pedestrian pavement system will be composed of the following layers:

- Base grade, grade category E1 (5 <= CBR < 10) (California Bearing Ratio), composed of a flexible base of natural gravel, 20 cm thick, with paving and compacted to 100% of Modified Proctor. Executed with slopes according to project.

- Execution of the pavement for pedestrian use, of draining concrete tiles for exteriors according to prototype, on a layer of sand of granulometry between 0.5 and 5 mm, leaving between them a separation joint of between 2 and 3 mm, for subsequent grouting with natural sand, fine and dry, of a maximum size of 2 mm; placed in a pot footing.

- Filling and sowing of the vegetal substrate in the spaces provided in the tiles, by filling with preformed sowing cartridges, with a prepared mixture of topsoil, pre-seeding fertilizer and pre-selected seeds of creeping vegetation. Opening of the cartridges and first watering.

7.3.2 Installation with recovery of excess runoff.

For this solution with excess runoff recovery, the vegetated draining pedestrian pavement system will be composed of the following layers:

- Base course category E1 (5 <= CBR < 10) (California Bearing Ratio), composed of a 20 cm thick flexible base of natural sour gravel, paved and compacted to 100% of the Modified Proctor.

- Non-structural concrete slab in mass (HM-20/P/20/X0), 10 cm thick, with manual paving and vibrating with a 3 m vibrating screed, with a screeded finish. Executed with slopes in the direction of water evacuation, according to the project, towards the canalization of the recovery and storage system.

- Execution of pavement for pedestrian use, made of draining concrete tiles for outdoors according to prototype, placed on a 3 cm thick bed of M-5 cement mortar, leaving between them a separation joint of between 1.5 and 3 mm and with joint filling with siliceous sand of size 0/2 mm.

- Filling and sowing of the vegetal substrate in the spaces provided in the tiles, by filling with preformed sowing cartridges, with a prepared mixture of topsoil, pre-seeding fertilizer and pre-selected seeds of creeping vegetation. Opening of the cartridges and first watering.

8. INCORPORATION OF PHOTOCATALYTIC FUNCTIONALITY

Half of the permeable green pavement surface exposed at the IETcc was given photocatalytic properties by application of a commercial emulsion product on 10/20/2021.

The non-photocatalytic half was covered and sealed with plastic film and the photocatalyst was applied on the permeable pavement platform, as well as on cores of the same material (permeable part and structural part). Two passes of the product were applied with a spray gun, ensuring that the product was fixed on the substrate (see Figures 17-20).

Figure 17: Application of the photocatalytic emulsion.

Figure 18: Application of the photocatalytic emulsion.

Figure 19: Platform with photocatalytic emulsion applied on one half.

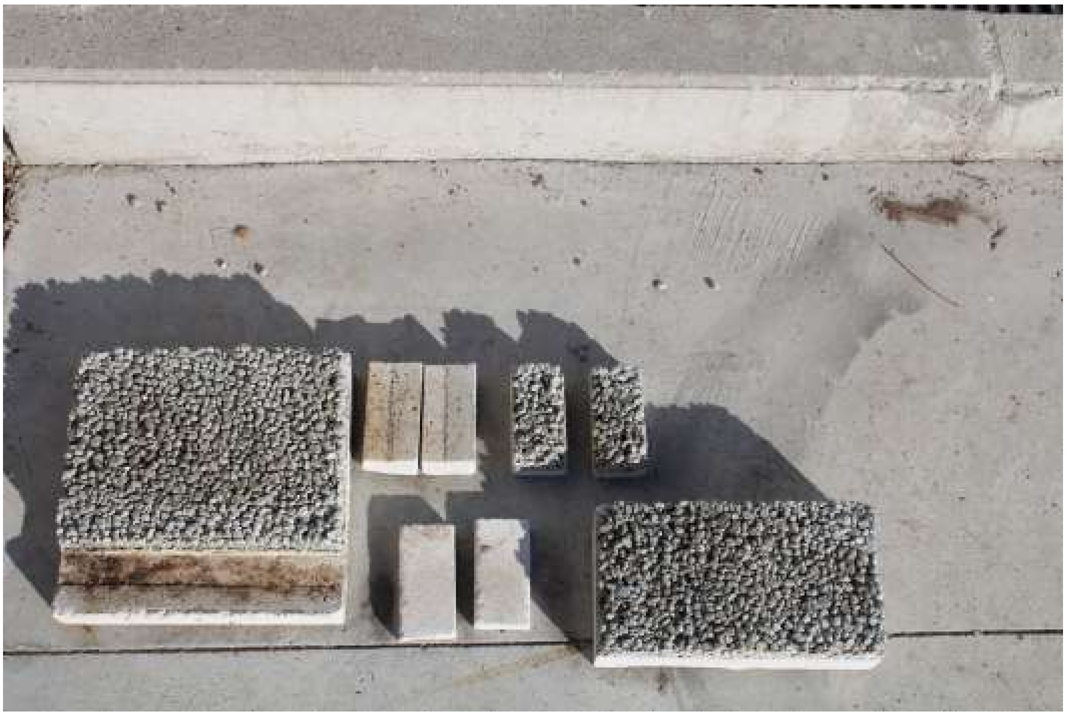

Figure 20: Witnesses with applied photocatalytic emulsion

Seven days after the application of the photocatalyst, a week during which no rainfall was recorded in Madrid, the determination of the efficiency for environmental NOx degradation was carried out according to ISO 22197-1 "Fine ceramics (advanced ceramics, advanced technical ceramics)-Test method for air-purification performance of semiconducting photocatalytic materials- Part 1: Removal of nitric oxide", modified for a shorter test time for the samples located next to the platform.

The principle of this method consists in the measurement of the air pollutant removal capacity of photocatalytic materials by exposing a test specimen to a stream of air contaminated with nitric oxide (NO) under ultraviolet light illumination conditions. The test specimen, placed in a continuous flow photoreactor, is activated by the ultraviolet light, absorbing and oxidizing NO to form nitric acid or nitrate on its surface. Part of the NO is oxidized to NO2, so the performance of the process is determined by measuring the net amount of nitrogen oxides removed, NOx, where: NOx = NO removed - NO2 formed.

The variation in NO and NO_2 concentrations for the specimens throughout the tests is plotted in Figure 21.

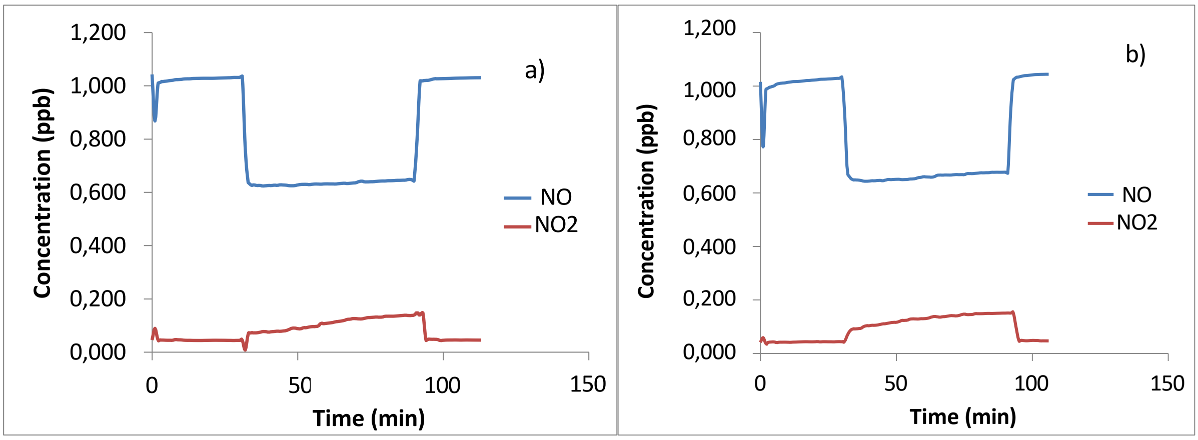

Figure 21: Variation in NO and NO_2 concentrations throughout the tests a) structural part of the pavement, b) permeable part of the pavement.

The test results according to ISO 22197-1 calculations are shown in the table below.

18. The final result of the test, according to the protocol of this standard is the net amount of NOx eliminated (μmol), considering the NO supplied as the initial value. This value, together with the intermediate values of which the latter is composed, is presented in Table 4 (values shaded in blue). It should be noted that these values correspond to an irradiation time of 60 min, shorter than that of the test under standard conditions. Additionally, the percentages of NOx removed have been calculated based on the supply concentrations and just before turning on the radiation source, considering only the illumination time and normalizing by the area and nominal radiant flux. For the latter case, the % of NOx removed has also been determined, being these the results obtained on the basis of the calculation protocol of the UNE standard

127197-1:2013 of air purification performances, for NO and NOx (values shaded in pink).

Probe	Structural part	Permeable part
Concentration NOT supplied	1015	1042
Stabilization time (min)	30	30
Amount of NOx adsorbed (µL/L)	0,02	0,09
NO concentration after adsorption period (just before illumination)	1028	1031
Fraction in volume with respect to delivered (%)	100	99
Lighting time (min)	60	60
Amount of NO removed - nNO (µmol)	2,79	3,19
Amount of NO_2 formed- n_{NO2} (µmol)*	0,67	0,47
% NOx removed: considering NO delivered	**24,27**	**30,13**
% NOx removed: considering NOx just before illumination= NO (%)-UNE 127197-1:2013	**25,38**	**29,33**
% NO removed: considering NO just before illumination= NOx (%)-UNE 127197-1:2013	**34,10**	**36,24**
*considering NO_2 supplied		

Table 18: Results obtained for the specimens tested according to ISO 22197-1 and UNE 127197-1:2013 standards

9. CONCLUSIONS

- A green, permeable and photocatalytic soil prototype has been designed and manufactured as a SBN solution and installed at the IETcc.
- It has been verified that it meets the necessary requirements, according to current regulations for this type of pedestrian pavement, for its commercialization and installation.
- It has been provided with photocatalytic functionality, as foreseen in the project work plan.
- The installation manual has been presented, with the possible geometric configurations and technical instructions for its installation, as well as an example of a demonstration platform executed in the facilities of the Eduardo Torroja Institute of Construction Sciences.