LIFE CERSUDS. CERAMIC SUSTAINABLE URBAN DRAINAGE SYSTEM

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1. ABSTRACT

LIFE CERSUDS is a demonstration project that puts into practice, evaluates and publicises Sustainable Urban Drainage Systems (SuDS) in a context in which these systems are new or little known. In addition, it innovates by using ceramic material with a low commercial value in the development of permeable paving, being easily replicated in similar geo-economic areas.

The project's main aim is improving cities' abilities to adapt to climate change and promoting the use of green infrastructures in their urban planning through the development and implementation of a demonstrator consisting of a SuDS with low carbon emissions for the refurbishing of urban areas. The demonstrator's permeable skin will be made up of an innovative system, which has a low environmental impact, based on the use of ceramic tiles with a low commercial value. This demonstrator will be sufficiently large in order to validate its technical and economic viability.

The project was approved in October 2016 by the European Commission in the LIFE programme and is expected to end in 2019. Currently, work is being done on developing the system and the implementation project, so that this presentation will present the project plan and the laboratory results of the ceramic system.

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2. SUSTAINABLE URBAN DRAINAGE SYSTEMS (SUDS)

The continuous and rapid growth of our cities, which results in progressive soil sealing, is seriously altering the natural water cycle. Increasingly larger collectors are required, which results in the need to purify rainwater that was originally clean. The necessity of dealing with the management of rainwater from a non-conventional perspective, which combines hydrological, environmental and social aspects, is leading to a worldwide progressive increase in the use of Sustainable Urban Drainage Systems (SuDS), also known as BMPs (Best Management Practices). The main idea of SuDS is to reproduce the natural water cycle prior to urbanisation as accurately as possible. Its aim is minimising the impacts of urban development regarding the amount and quality of run-off (at source, during its transport and destination), as well as maximising landscape integration and the social and environmental value of intervention.

There are multiple types of these systems, which include green roofs, infiltration trenches, swales, detention basins or permeable surfaces, among others[i].

The LIFE CERSUDS project focuses on the last type, permeable surfaces, as the total surface of cities has increased in the EU by 78% since the mid-1950s, while the population has only grown by 33%[ii]. These figures make it necessary to rethink the treatment of the soil in cities due to the enormous environmental impact that the sealing of urban surfaces causes, increasing the consequences of climate change.

One of the methods for reducing soil sealing is the use of filtering pavements, the aim of which is to collect and pre-treat run-off and, if the quality characteristics of the water and the ground allow, to infiltrate it into the lower levels of the ground. All of this reduces run-off and its associated contaminating load such as the hydrocarbons or heavy metals that are common on roads and car parks and can seriously affect the final collectors if they do not biodegrade sufficiently or are retained in the filtration process[iii,iv].

3. THE LIFE CERSUDS PROJECT

Climate change in Spain will be evidenced by a general tendency towards temperature increases and reduction in precipitation, which will have the following effects[v]:

- Reduction in general water availability. Previous estimations for the whole of Spain (with a 2030 horizon, considering temperature increases of 1ºC and 5% reductions in precipitation) calculate reductions in water intakes of between 5 and 14%, which may increase to 20-22% by the end of the century.
- Arid and semi-arid regions (approximately 30% of Spain) are predicted to be especially impacted; inputs in these regions may reduce by up to 50%.
- The variability of water will increase in the Atlantic basins, while in the Mediterranean and inland basins the increased irregularity of the precipitation regime will cause an increase in changes to the regime of flash or torrential flooding and subsidence of floodwaters.

The consequences are therefore an increase in the risk of drought (fewer resources) at the same time as provoking an increased risk of torrential episodes and floods. In order to better manage the problem resulting from scarcity (drought) or excess (flooding) of water in urban environments, systems that allow the storage of water for its later reuse must be put into practice to alleviate the former and improve the hydrological response in the event of torrential rain in order to make systems that are more resilient to flooding.

In this respect, SuDS, especially permeable pavements, help to achieve these aims. During periods of rain, they allow a decreased production of surface run-off and therefore, they encourage the infiltration of the adjacent land at the same time as temporarily storing the excess in the porous structure of its base and sub-bases. This translates into a lower volume of run-off that will eventually reach the final point in the system and a lower response time, therefore with lower peak flood discharges. Alternatively, the stored water surplus that does not end up overflowing to the network of collectors or the receptor medium can be stored in small buried tanks for later reuse in watering gardens or cleaning the streets, which reduces the use of networked water.

The project is being developed by a consortium where ITC-AICE is responsible for leading and contributing its knowledge of ceramic tiles; the Research Institute of Water and Environmental Engineering of the UPV (Universitat Politècnica de València) contributes with its substantial knowledge of Sustainable Urban Drainage Systems; the Benicàssim City Council provides its land for implementation as well as bringing its experience of the city itself; CHM Infaestructuras construction firm will implement the pilot; and Trencadís de Sempre, with a long history in the design and development of pre-assembled ceramic pieces and lastly the Centro Cerámico Bologna and Centro Tecnológico da Cerâmica e do Vidro de Coimbra make it possible to replicate the proposed system in areas of Italy and Portugal with industrial characteristics similar to those of Spain. All members participate in managing, monitoring and publicising the project.

The aims pursued in this project are essentially as follows:

- On the one hand, to publicise sustainable urban drainage systems in geographical environments where they are little known.
- On the other, to design and validate a ceramic system for permeable paving based on ceramic tiles with low commercial value.

The aim of this presentation is to show the key characteristics of the ceramic system. The evaluation of this new system will be performed in an urban environment in the city of Benicàssim, specifically in Calle de la Torre San Vicente near to the city's sports centre. The project, with an intervention area of approximately 3000 m^2, was written by Enrique Fernández-Vivancos and Eduardo de Miguel (Illustration 1).

Illustration 1

4. DEFINITION OF THE CERAMIC SYSTEM

The most frequently used materials in permeable pavings for SuDS are: turf, gravel, grills (plastic and concrete) embedded in turf, porous concrete or asphalt pavements. This project proposes an innovative permeable ceramic pavement that originated in an R&D project[vi]. One of the results, presented at Qualicer 2012[vii] was a permeable urban pavement made up of ceramic pieces with a low commercial value that were already in stock. These ceramic pieces were cut into strips of various widths, therefore increasing their bending strength (Illustration 2).

Within the framework of this project, the complete design of this system was undertaken, as well as its evaluation using laboratory testing. It should be mentioned that there is no testing method that allows the evaluation of the behaviour of urban pavement that undergoes dynamic loads similar to those produced by vehicle traffic. It is for this reason that, given the nature of the research project, the use of the designed system was limited to contained areas of the roads so that, in case of inappropriate performance, its substitution would not be a problem or inconvenience for the public.

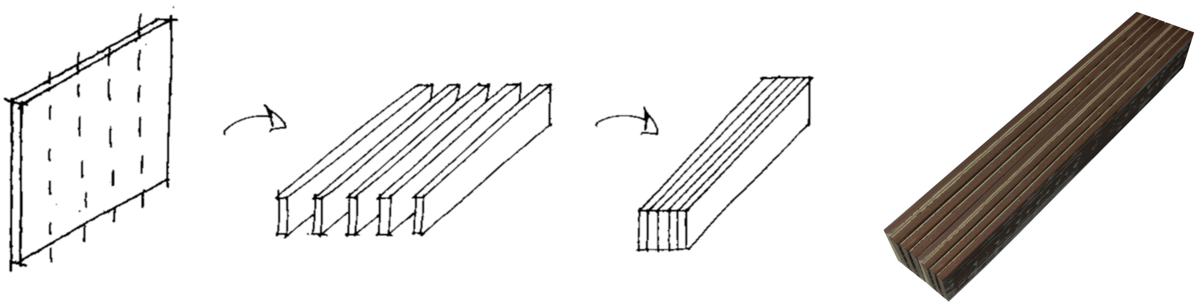


Illustration 2

Although the values obtained in the 2010 project were promising, it was considered necessary to carry out a rigorous design and testing period on the pieces in order to ensure that the paving would meet its requirements throughout its useful life (40 years) without issues. Therefore, a cyclic testing period was followed with the aim of completely defining the characteristics of the ceramic modules that would make up the paving system. This presentation describes the most relevant tests that defined the final characteristics of the ceramic SuDS.

4.1. FASTENING BETWEEN STRIPS

Given that the strips, if they broke, could lift, creating dangerous edges, it was considered necessary to integrate them safely using an appropriate adhesive. This same adhesive would increase resistance as the strip system, or module, would work as a single paving unit. Alternatively, the packaging would allow easy handling and improved installation efficiency.

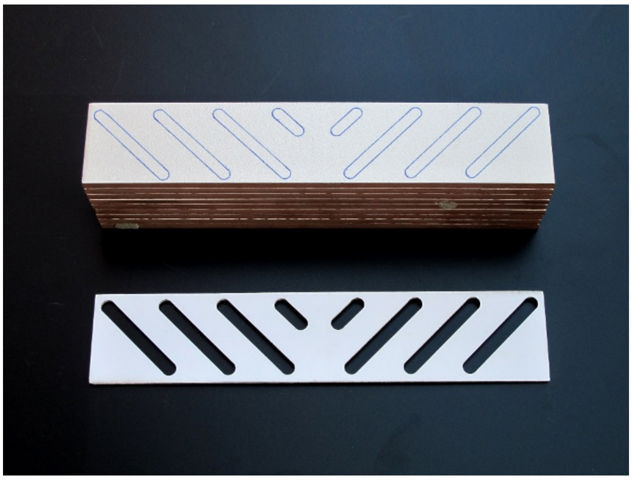
4.1.1 MATERIAL

The proposed adhesive was a C2 adhesive according to UNE-EN 12004, whose adhesive strength must be greater than 1 N/mm^2 once set and after ageing with heat and freeze/thaw cycles according to UNE-EN 1348.

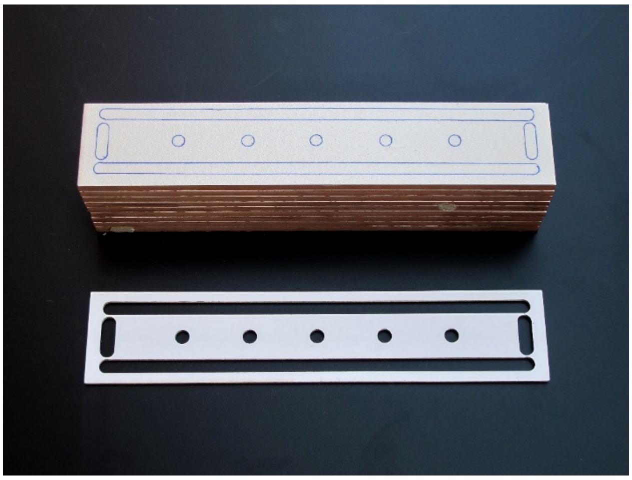
4.1.2 ARRANGEMENT OF THE MATERIAL

Four arrangements were proposed for the bonding material between the pieces (F1 to F4). The manufacturing process consisted of applying the adhesive using 1.5-mm-thick templates cut with a laser (**Illustration 3**).

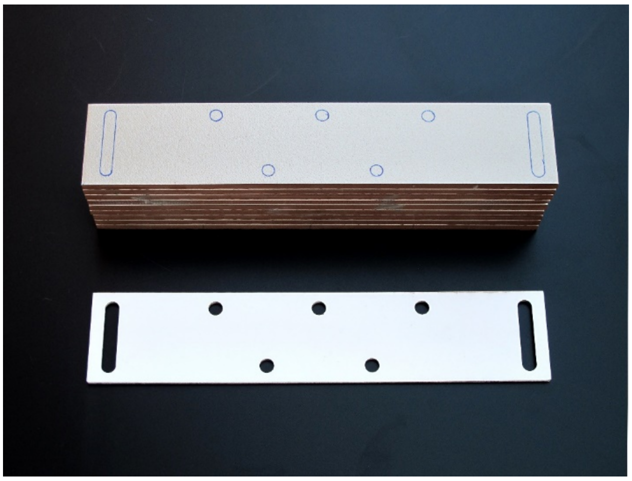
FAMILY 1



FAMILY 2



FAMILY 3



FAMILY 4

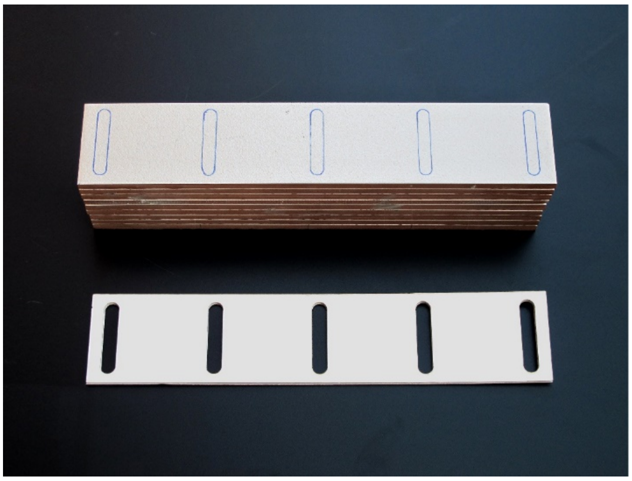


Illustration 3

4.2. PERMEABILITY

According to various authors[viii], the minimum permeability of this type of pavement should be 2,500 mm/h to be able to cope with the rainwater that falls on it. This high requirement takes into account the clogging of the pavement throughout its useful life and therefore a safety factor of 10 was applied. This means that by reducing the permeability of the paving by ten, it would be capable of absorbing at least 250 litres/hour per square metre.

On the other hand, in addition to the permeable surface itself, this permeability must be designed such that it can cope with the impermeable areas of the SuDS. It was assumed that the impermeable area had a surface area A and that the impermeable areas could reach up to 2A. Therefore, the permeable pavement needed to be capable of handling 3A. Given that the maximum intensity of precipitation in Benicàssim for the return period of 15 years was estimated at 154 mm/h, the recommended permeability would be 154*3*10 = 4620 mm/h. This was rounded up to 5,000 mm/h.

4.3. PERMEABILITY OF THE CERAMIC MODULES

Firstly, a test was carried out on the four proposed families and later, the selected family was tested on the paving system, including the sub-layers and joint-filling materials.

4.3.1 TESTS CARRIED OUT ON THE 4 FAMILIES

Permeability was evaluated using the NLT 327/00 test from CEDEX, obtaining the following results (**Table 1**)

	piece F1	piece F2	piece F3	piece F4
Evacuation time (s)	71.8	-	8.8	9.6
Permeability coefficient K (cm/s x 10^{-2})	6.4	-	109.1	97.0
Permeability coefficient K (cm/s)	0.064	-	1.091	0.97
Permeability (mm/hour)	2,304		39,276	34,920
	Does not comply	-	>recommended value	>recommended value

Table 1

Therefore, families 1 and 2 were discarded for the purposes of permeability. However, the project does consider impermeable modules for certain areas of the demonstrator. In parallel with these permeability tests, bending tests were carried out, as set out further below. Family 4 was ultimately selected as the most optimal.

4.3.2 PERMEABILITY OF THE SYSTEM (MODULES, JOINT FILLING AND SUB-BASES)

The paving system is composed of a series of layers standing on the earth, and the project provides for various areas in the intervention surface area where each of these fulfils a different function. Therefore, there are areas for water lamination, others for filtration and conduction, and some for filtration and storage, among others.

The aim of this trial was to verify how the paving's joint filling affected its drainage capacity. The function of the joint filing was to keep the pieces in place to minimise their movement, which could adversely affect the system's operation.

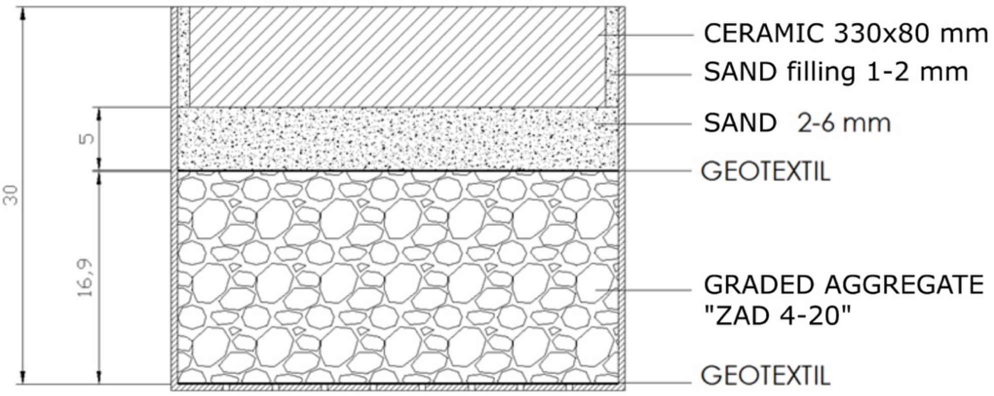


Illustration 4

In order to carry out permeability tests on the system, a metallic box was used (**Illustration 5**) where this layered structure could be reproduced. In addition to permeability testing, the box allowed for the validation on a laboratory scale of the performance of the paving system as a whole.

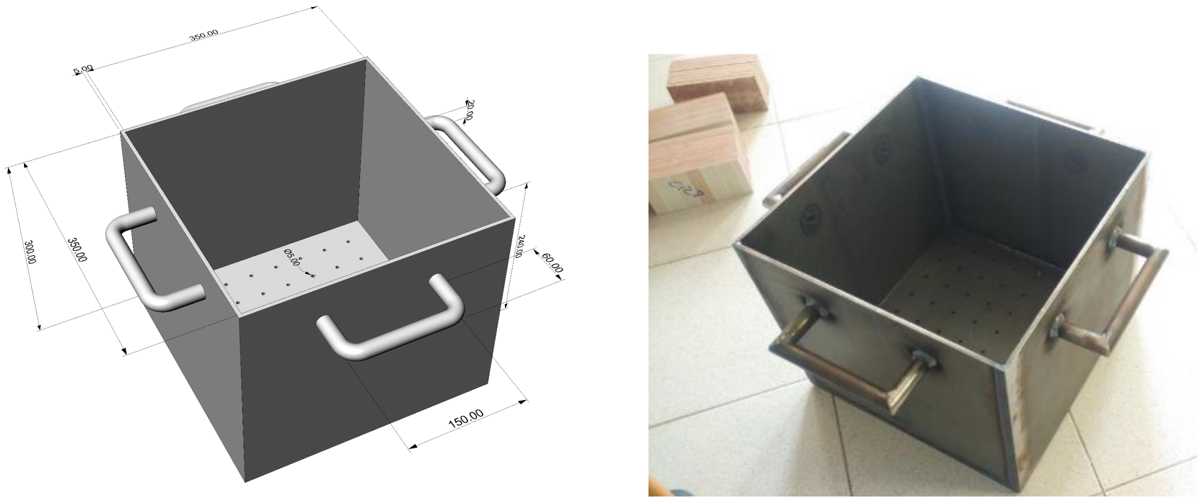


Illustration 5

After various tests with different sands and semi-dry mortars for joint filling between the paving units, it was concluded that a sand with the finest grading possible, but without the capacity to penetrate the gaps between the strips, which were all smaller than 1 mm, offered the best results, which meant ensuring system stability by maintaining an acceptable permeability. Using washed sand of 1-2 mm, the test offered the following permeability (*Table 2*):

Evacuation time (s)	
Time (s)	38
Permeability coefficient K (cm/s x 10^{-2})	15.5
Permeability coefficient K (cm/s)	0.155
Permeability (mm/hour)	5,580
	>recommended value

Table 2

4.4. BENDING STRENGTH

The minimum breaking strength for travelled area T40 needed to be greater than 80 N/mm[ix]. Therefore, the four families were subjected to bending tests with the following results (**Table 3**). For analysing bending strength, tests were carried out on the 4 families and later a battery of tests with different thickness and materials were performed on the selected family.

Adhesive distribution	Length (mm)	Thickness (mm)	No. of strips	Width (mm)	Breaking load (kg)	Breaking load (N)	Breaking load (N/mm)
Family 1	330	65	10	88	1639	16077	182
Family 2					1774	17399	197
Family 3					1117	10961	124
Family 4					1597	15671	178

Table 3

As noted above, families 1 and 2 were discarded for their low or non-existent permeability. Family 3 had the lowest resistance, so that family 4 was eventually selected.

4.4.1 THICKNESS TESTS

Once the optimum adhesive distribution on the strips had been selected, a series of tests on different strip thicknesses were carried out.

The test was conducted based on standard UNE-EN 1344: 2015, consisting of exercising a progressive force at a constant velocity on the paving units, using a roller resting on their central area until they broke. Meanwhile, the paving unit was held on another two rollers, each located at a distance of 1.5 cm from the edges. The resulting breaking load enabled the transverse breaking load to be determined (N/mm^2). **Illustration 6** shows the values obtained. It may be observed that from 40 mm thickness on, the values obtained were greater than the required 80 N/mm^2 in all tested lengths and materials (165 and 330 mm in length for red-body stoneware tile and porcelain stoneware tile)

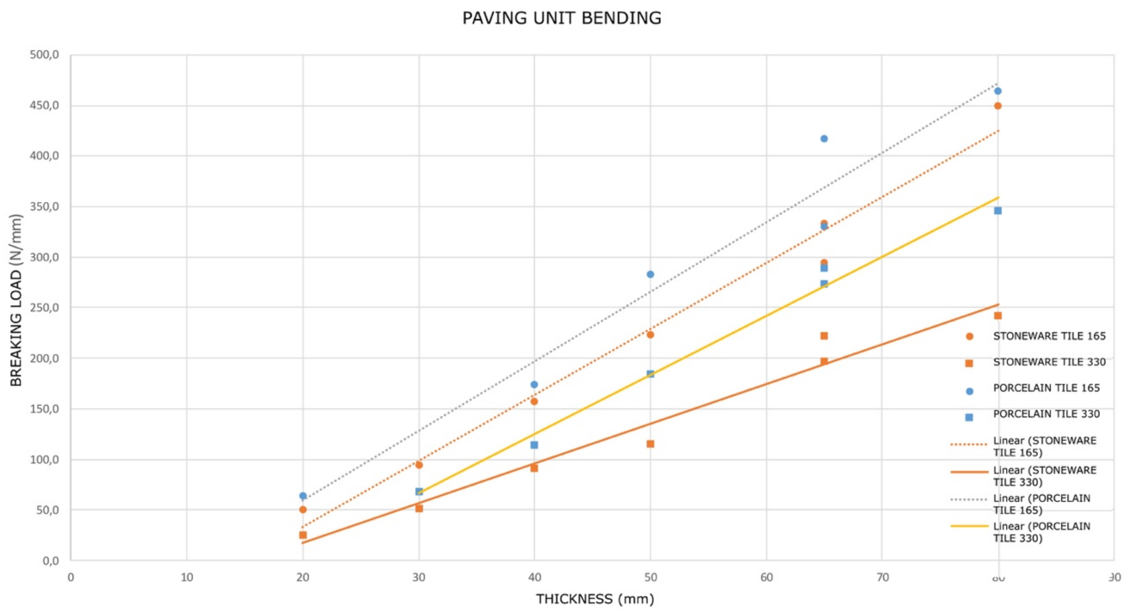


Illustration 6

4.5. SHEAR

The test was carried out using the steel rod described in ASTM C 648-04 (2014) "Standard test method for breaking strength of ceramic tile". The test, which is not standardised, consists of applying a progressive force at a constant velocity on the centre point of the tile in the middle, using a steel rod with a semi-sphere tip, until it separates from the rest of the tiles making up the paving unit. The paving unit was only supported by the tile at each end of the paving unit on a smooth and continuous surface so that the rest of the paving unit was in the air (**Illustration 7**). The results are shown in Table 4.

Illustration 7

A cyclical testing process was carried out to evaluate the ideal distribution and thickness of the adhesive to be applied to the strips. The results obtained indicated that the optimum distribution corresponded to family 4, with an adhesive thickness of 1.5 mm.

Tests were conducted on modules made up of 7 strips, with a module length of 330 mm and with the following variants:

- Strips of porcelain stoneware tile and glazed stoneware tile,
- Variable thickness of the strips: 65 mm and 80 mm

Table 4 shows the average value of the tests carried out on 5 modules with several variations:

MODULE LENGTH (mm)	BODY	THICKNESS (mm)	MODULE WIDTH (mm)	STRIPS PER MODULE	Separating load (kg)	Separating load (N)
330	RED STONEWARE	65	60	7	424.6	4164.25
	RED STONEWARE	80	60	7	528.7	5184.96
	PORCELAIN	65	60	7	511.1	5012.16
	PORCELAIN	80	60	7	675.7	6626.98

Table 4

Therefore, both the porcelain stoneware tile and red stoneware tile were capable of withstanding concentrated loads greater than 400 kg in very unfavourable conditions.

4.6. IMPACT

The study was carried out based on the method described in annex 6 of Cahier 3778:2017 from the Centre Scientifique et Technique du Bâtiment, "Détermination de la tenue au choc lourd des carreaux céramiques non émaillés-choc à la bille de 510 g", which consists of dropping a steel ball with a mass of 510 g in weight from a height of 80 cm. The paving units were then examined for defects.

With the aim of simplifying and grouping the defects, it was decided to classify them as follows (**Illustration 8**):

- Type 1: Small chip
- Type 2: Breakage of the piece
- Type 3: Fragment detached from the piece

TYPE 1 Defect

TYPE 2 Defect

TYPE 3 Defect

Illustration 8

The test was carried out with paving units of various thickness and types of bodies to see how these variables influenced the study. 30 impacts were made on a paved surface of 33x33 cm for each type of paving unit, with the aim of obtaining representative results.

The results of the tests carried out on permeable modules of porcelain stoneware and glazed stoneware tile with thickness of 80 mm are detailed in Table 5.

	No. of defects		
BODY	**type 1**	**type 2**	**type 3**
RED STONEWARE	24	4	2
PORCELAIN	19	5	6

Table 5

The tests revealed the following:

- The porcelain stoneware tile modules behaved worse in the event of impact, due to sharp fragments being produced when the piece was broken or detached, as can be seen in **Illustration 9**.

Illustration 9

- With strip thicknesses greater than 70 mm, strip defects under impact were minimised.

The results indicate that with a strip height greater than 70 mm, defects were minimised and barely visible. Nevertheless, given the characteristics of the paving, this was the weakest point of the system. For this reason, to be able to offer better guarantees, strip height was set at 75 mm.

4.7. FROST

The test was carried out based on the method described in standard UNE-EN ISO 10545-12: 1997 "Ceramic tiles - part 12: Determination of frost resistance".

Firstly, the paving units were impregnated under vacuum, with a depression of 400 mbar below atmospheric pressure. The vacuum at this pressure was maintained for 30 min. After this time, the paving units were completely covered with water for a period of about 45 minutes.

The paving units were then subjected to 100 freeze-thaw cycles based on the following scheme:

- The temperature of the paving units was lowered to -5°C at a rate no greater than 20°C/h. The paving units were maintained at a temperature lower than -5°C for 15 min. The paving units were immersed in water so that they reached a temperature above +5°C and kept there for 15 minutes. After 100 cycles the paving units were examined for defects.

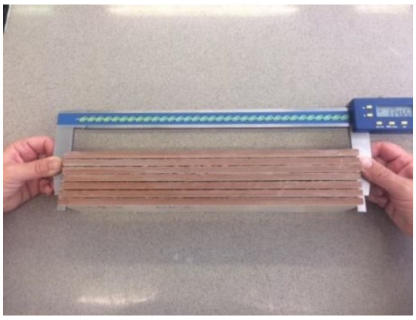
As was to be expected, the ceramic material resisted the test. However, separations resulted between some strips, this defect being more pronounced in the porcelain tiles due to their low porosity and therefore lower adhesive bonding. Nevertheless, these results were considered satisfactory given that the strips were not individually separated and that, due to the installation system, they remained in place and would not be expected to lift.

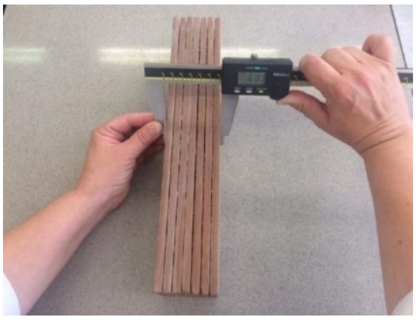
The Tile Guide does not recommend the use of glazed stoneware tile in areas with frost risk. However, as the installation of the ceramic tile was different in this case, this recommendation was not considered applicable.

4.8. DIMENSIONAL STABILITY

The test was carried out based on the method described in standard UNE-EN 1344: 2015 "Clay pavers - Annex B: Determination of dimensions", which consists of measuring the length, width and thickness of pavers. The standard requires measurement of 10 pavers.

In our case, 10 samples of the 6.5-cm-thick permeable paving units were measured. In addition, 5 samples of other lengths and thickness were measured to detect possible deviations in the production process (**Illustration 10**)





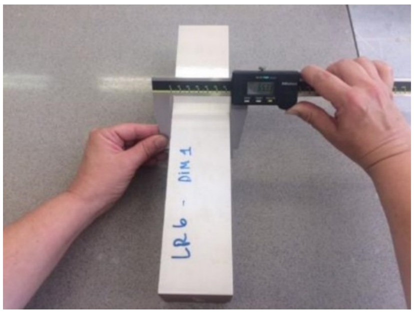


Illustration 10

The paving units measuring 330x60x65 mm passed the test, obtaining deviations below the maximum values set in the standard.

Nevertheless, it was decided to be more restrictive regarding the deviations and therefore, in the quality control for the paving units the requirement would be as follows: The maximum deviation regarding the manufacturing dimensions must be length (±2 mm); width (±3 mm) and thickness (±2 mm). In addition, compliance with this test would guarantee the orthogonality of the paving units and the absence of "lipping" greater than 2 mm between strips.

4.9. SLIPPERINESS

This test was carried out following the method described in standard UNE-ENV 12633:2003 "Method of determination of unpolished and polished slip/skid resistance value". The assembly consists of a pendulum with an arm length of 510 mm, which supports a rubber slider of hardness IRHD 59±4 of about 76 x 25 mm. The height of the device was adjusted so that the slider, which supported a constant load of 22.2±0.5N, maintained contact with the surface for a travel of 126±1mm. The sample was submerged in water for at least 30 minutes prior to the test. Each of the tiles was tested in two opposing directions (0° and 180°), their surfaces being saturated with distilled water.

All results were satisfactory, obtaining values greater than 60º, so that the paving belongs to Class 3 according to CTE.

4.10. POINT LOAD

The test was carried out based on the method described in standard UNE-EN 12825: 2002 Section 5.2.1 "Raised access floors. Load test on element".

The test consists of uniformly applying an increasing load on an element until it breaks. The result is plotted on a graph showing element deflection versus the load.

In order to carry out the test, the paving units were placed in the box and a progressive force was applied at a constant rate on the centre point of a tile in the paving unit by a steel rod with a semi-sphere tip. Next, in the same way a progressive force was applied using a steel cube with 50 mm sides.

The test with the semi-sphere-tipped steel rod was carried out in the centre of the tile and on the joint between two tiles of the same paving unit to compare the results. The cube test was carried out in the centre of the paving unit.

The test was carried out on modules of red-body stoneware tile, 330 mm in length, with two thicknesses: 50 mm and 80 mm.

Illustration 11 shows the breakage produced using the application of the point load and the 50x50 mm load.

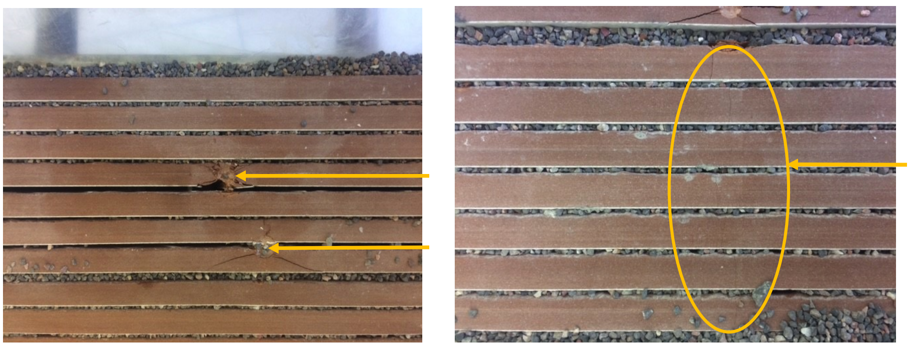


Illustration 11.

On the 80-mm-thick modules, in the point load test carried out in the centre of the strip, breakage values were obtained greater than 4600N, while in the test carried out on the joint between strips, values greater than 9000N were obtained. In the 50x50 mm load test on the centre of the 80-mm-thick strips, the values obtained were greater than 27000N.

4.11 ABRASION

This test was carried out following the method described in standard UNE-ENV 1344:2015 "Clay pavers - Annex E: Determination of abrasion resistance", which consists of scoring, on the visible surface of the pavers, a track using a steel disc rotating at 150 revolutions perpendicular to the test surface.

A constant stream of corundum of FEPA grit size 80 is allowed to fall as abrasive between the steel disc and the tile surface.

On ending the test, the resulting track is measured and the mass-loss volume is calculated. The value obtained (252 mm^3) indicated excellent performance under abrasion: Class A3 (<450 mm^3)

5. CONCLUSIONS

A ceramic system is proposed, involving permeable modules measuring 330x65x75 mm and weighing about xx kg. Each module is made up of seven ceramic strips obtained from tiles with a low commercial value.

The proposed system has permeability coefficients greater than the recommended values.

All of the tests to which the ceramic modules and paving system were subjected produced satisfactory results. However, the impact tests indicated that this was the system's weak point. The results indicate that the paving system proposed in the project can perform appropriately as a sustainable urban drainage system.

On the other hand, and given that there is no type of laboratory test to validate the performance of the complete paving system, it will be necessary to await the results of the project demonstrator. During the monitoring stage, the system's hydraulic performance as well as its performance under vehicle and pedestrian traffic will be analysed.

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