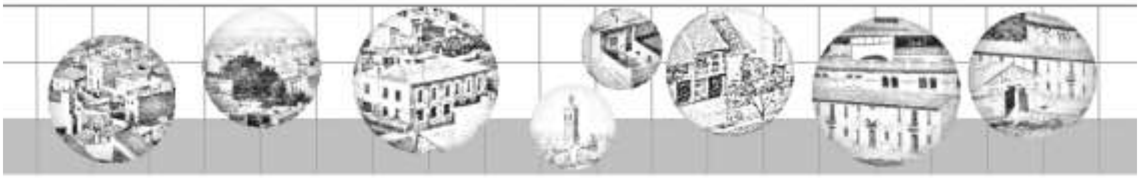

GUIDE OF CERAMIC APPLICATIONS IN URBAN SPACE

cerurbis
Ceramic Observatory for Urban Space

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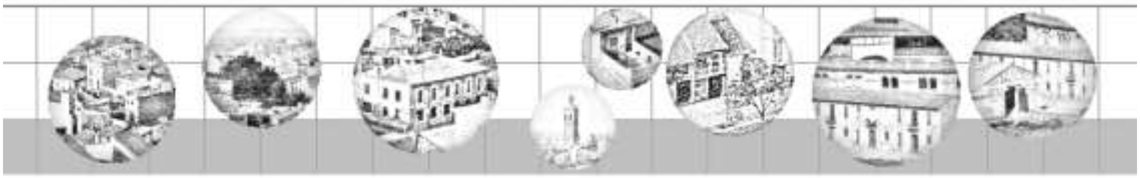

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1. Introduction

This guide forms part of the CERURBIS project "*Acción 2.4*, *Diseño y desarrollo de la guía de aplicaciones de la cerámica urbanas*" (Guide for the design and development of ceramic tiling in cities), a project financed by SUDOE, Programa de Cooperación Territorial del Espacio Sudoeste Europeo (Regional Cooperation Programme, South West Europe), with the support of the European Regional Development Fund for financing transnational projects

The aim of this guide is to provide specifiers with a tool to facilitate decision making in respect of different ceramic materials for specific construction projects. Specifiers are those persons who make decisions regarding cladding materials for a given project, and who may be municipal architects, public works construction companies or even citizens themselves.

Ceramic products are highly durable and adaptable to all functions, thus making them a clear choice for urban paving systems. As well as mechanical performance, they offer advantages over other materials for improving productivity during construction (reduced weight and volume, ease of transport and storage etc.) and the availability of special features: non-slip surfaces, low maintenance, geometric surface designs for tactile paving, prefabrication and/or accessibility, etc.

Nevertheless, although for some years ceramic paving and cladding have been used in urban areas with excellent results, there are factors which limit the development of this market, including:

- Heavy reliance on available paving systems, designed for traditional materials which, in some cases, are incompatible.
- Lack of knowledge regarding compliance with basic functional specifications.
- Regulations and accessibility aspects.
- Economic feasibility and technology for using ceramic materials.
- Concerns regarding inadequate specifications which give rise to safety problems, additional costs or poor finishes and which may damage the global image of ceramics.

Therefore this document is intended to act as a guide in order that specifiers are fully aware of the undoubted advantages that ceramic systems can offer public spaces and to reduce the risk of misuse.

2 Aesthetic appearance and range of colours

Ceramic materials, due to their manufacturing, decoration and post-production processes, offer complete freedom for adapting formal and technical aspects to the particular project requirements. Some of these options are due to the ceramic supports or die cutting which produces reliefs and textures. Decorative patterns and laser engraving can be produced with new printing technologies, such as inkjet printers.

2.1 Colouring

The wide colour palette can respond to the requirements of specifiers of public paving which are predominantly in neutral colours. Furthermore, if there is a need for colours which contrast with the base colour, ceramics have a wide variety with exceptional durability.

Figure 1. Neutral colour palette. TAU Cerámica

Figure 2. Contrasting colour palette. TAU Cerámica

2.2 Textures and reliefs

The ceramic tile industry has specialised machinery to produce and mill reliefs. These machines normally work with laser scanners so there is no contact between the surface and the device. This feature allows reliefs and textures from a wide number of sources to be produced including non-cohesive organic and mineral sources.

Once the surface is obtained or generated on the computer, a multitude of materials can be obtained via numerically controlled milling machines. It is therefore possible to easily generate textures or reliefs. This three-dimensionality opens up a huge range of possibilities, especially in paving, for the **restoration of historic town centres** where the appearance of stone is required together with negligible porosity, in accordance with the *Código Técnico de la Edificación* (Technical Building Code) **slip resistance standards**.

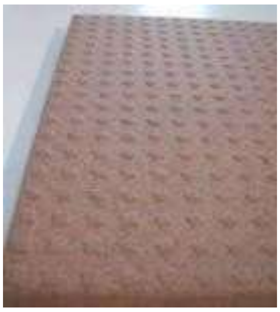


Figure 3. Porcelain tiles with relief. TAU Cerámica

2.3 Laser

This equipment offers the best prospects for customising ceramic tiles. Currently engraving machines are available with sufficient power and speed to easily customise ceramic tiles.

The laser works via **abrasion of the ceramic surface**. It is normally used for the surface machining unglazed tiles such as porcelain to obtain an effect similar to sandblasting, although with a much better resolution and quality.

Figure 4. Laser engraving Invesplasma

2.4 Inkjet printing

Another technology that enables customisation is inkjet printing. This system for printing ceramic tiles is based on using four basic colours (cyan, magenta, yellow and black), which together with an electronic image transfer process allows the piece to be decorated with the chosen patterns and colours. Printing is carried out without halting or contact with the piece, given that the colour is deposited on the piece by injectors. This allows decoration of the ceramic tile's entire visible surface, including tiles with reliefs and rounded edges.

The advantages of this decorative system are printing without contact, high speed and control over the production process. Furthermore all production stages including printing the piece are done electronically; therefore the colour can be quickly adjusted without the need to create new colours or screens.

Figure 5. Customised paving with inkjet printing. Ceracasa

3 Advantages of porcelain tiles for use in urban areas

Although the use of ceramic tiles externally is backed up by a long architectural tradition, it was necessary to analyse its performance over other materials habitually used for façades. For this an independent laboratory was commissioned to study and evaluate the characteristics of porcelain tiles in comparison with the performance of traditional products. Table 1 shows a summary of the results of this study.

The columns show the results obtained for the materials in each of the tests indicated in the rows. (High values indicate better performance.) The marbles chosen were White Macael and Red Alicante. With regard to the limestones Crema Marfil and Black Marquina were used. Granites used for testing were White Crystal and Rosa Porriño. The wood effect material corresponds to exterior grade wood cladding on plastic laminate. The last three columns correspond to laminated plastic, lacquered aluminium with polyethylene core and concrete slab, all for external use.

The rows show the criteria under which the different materials have been tested, as well as the relevant regulations for each test. For moisture expansion testing, samples were immersed for seven days at room temperature. The stain resistance test had to be defined as there are no regulations for this. Two staining agents were chosen: the first for impregnation (rhodamine solution 0.1 g/L) and the second for filming action (black permanent marker pen). The cleaners chosen were commercial bleach (35 gr CL2/L) for the impregnated stain and Trichloroethylene (99%) for the filming action stain. A mechanical cleaning device capable of applying the same pressure for all tests was used and Lab colour coordinates were compared before and after cleaning.

			Materials								
			Porcelain		Marble	Limestone	Granite	Wood	Plastic	Lacquered	Concrete
			Natural	Polishe							
Criteria	Sizes	UNE-EN ISO 10545-2	High	High	High	High	High	High	High	-	-
	Flexion Resistance	UNE-EN ISO 10545-4	High	High	High	High	High	High	High	Low	High
	Frost Resistance	UNE-EN ISO 10545-12	High	High	High	High	High	High	High	High	Low
	Permeability	BS 4131	High	High	Medium	Medium	Medium	Medium	Medium	High	Low
	Mass/surface ratio		Medium	Medium	Low	Low	Low	Medium	Medium	High	Low
	Moisture expansion		High	High	High	High	High	Low	Low	-	Medium
	Linear thermal	UNE-EN ISO 10545-8	High	High	High	High	High	Low	Low	Low	Medium
	Stain resistance		High	High	Low	High	Low	High	High	Medium	Low
	Salt spray corrosion	UNE 112017 ISO 9227	High	High	Low	Low	High	High	High	High	Low
	SO2 Atmosphere	UNE-EN ISO 6988	High	High	Low	Low	Medium	Medium	High	High	Low
	Solar ageing resistance	UNE-EN ISO 11341 (M2, C-A)	High	High	Low	Low	Medium	Low	Medium	Medium	-

Table 1 Comparison of different materials for use in urban areas

From this table we can conclude that porcelain tiles offer a level of performance equal or superior to the other materials habitually used for cladding façades.

4 Maintenance and replacement

4.1 Replacement

One of the main problems with the products normally used in urban areas (terrazzo tiles, concrete slabs, natural stone tiles or other materials) is the availability of pieces with the same appearance as those already installed when replacement is required.

It is difficult to reproduce the appearance of earlier batches manufactured from a mix of various materials, especially products coloured with pigments, or natural products whose appearance depends on the place where they were extracted. Usually there are changes of colour and/or appearance between different batches of the same product and, therefore, areas of replaced paving are noticeable.

Generally ceramic tiles do not usually present this type of problem as the manufacturing process is much more automated and therefore better controlled. Furthermore, it is common practice for manufacturers of ceramic tiles to colour classify all the tiles produced, separating the production run into uniform batches. The excellent quality control used in the production process allows reproduction of the same colour tiles in other production batches thereby guaranteeing the continued supply of uniform materials.

4.2 Stability and availability

Some of the materials used, especially for paving in urban areas, have high surface porosity leading to dirt being retained which cannot be removed by normal cleaning products. Furthermore, dirt retention is worsened with wear.

Normally, during wear there is a generalised darkening of the surface and therefore a distinct change in appearance between a recently laid piece and a replacement, even when it is possible to use replacements which are the same as the originals.

Generally ceramic tiles are one of the materials which require less maintenance due to low dirt retention and ease of cleaning.

Glazed ceramic materials are completely impermeable and therefore do not tend to retain dirt. Moreover, very low porosity unglazed tiles, such as porcelain barely retain any dirt due to the small pore size.

Another aspect to consider from an aesthetic point of view is surfaces fouled with chewing gum. These marks are very difficult to remove and usually require chemical and high pressure water treatment which may sometimes damage traditional materials (terrazzo tiles, concrete slabs or natural stone).

In contrast, with ceramic tiles the change of appearance because of dirt retention is minimal and, due to high chemical resistance, vigorous cleaning apparatus can be used to maintain the tiles' original appearance, which in turn means that replacements are not immediately obvious.

4.3 Maintenance and replacement costs assessment

Maintenance requirements include the following:

- Maintenance due to replacement or repair
- Maintenance for cleaning reasons

With regard to **maintenance due to replacement or repair**, the most frequent problems are poorly laid, loose or broken tiles, and cavities under paving.

As previously stated, ceramic tiles are not only **easy to clean** but their durability allows more aggressive cleaning methods to be used, reducing the time and effort required and therefore maintenance costs.

5 Signage

Special tiles are those that, due to colour or texture, can signpost or provide information useful for the safe movement of people with disabilities.

As part of the focus on accessibility, a wide range of options has been developed for ceramics, making it an ideal material to convert an urban area into a space suitable for everyone. Urban ceramics can take advantage of several post-forming processes (waterjet cutting, reliefs, laser engraving, combination of materials) to create signposting aimed at:

- Marking directions on the paving.
- Marking out bicycle lanes.
- Reflecting the city image (shields, emblematic wording, etc.)
- Marking out tourist routes.

In addition urban ceramics has essential properties in respect of signage from the point of view of customising individual projects, variation in format and installation, as well as being highly durable.

Although previously stated regarding post-formed systems, it is worth emphasizing the wide range of options for designing and implementing signage, by referring to existing examples:

5.1 Combination of materials

For this project the company has taken advantage of the versatility of waterjet cutting coupled with the wide range of materials available, combining these features in ceramic texts inserted in the paving which encourages the little ones to enjoy the urban space and interact with the area.

Figure 6. Plaza del Maestrazgo, Castellón de la Plana. TAU Cerámica

In this project these options are reflected in combining different materials with waterjet cutting to create signs which in some instances must be located on building façades.

Figure 7. Project carried out for TRANSHITOS 2009, ITC

5.2 Haptic reliefs

Tactile or haptic paving provide advice and directions through the use of texture, which is of great assistance to visually impaired people.

There are various types of haptic paving: blister paving, grooves, corduroy surfacing, etc. All types are included in the European reference document CEN/TS 15209, 2008, which includes technical specifications in respect of this type of paving in concrete, ceramic tiles or stone.

The ceramic industry focuses on accessibility and the technical feasibility of developing reliefs complying with prescribed optimal design standards which has led to the development of product groups which span the entire range of haptic pieces required for indicating directions, changes in level, danger zones and all other areas on urban paving that need to be conspicuous. It should be noted that current production methods enable manufacturing of haptic ceramic tiles with reliefs and required profiles.

Figure 8. Haptic pieces designed with optimal reliefs for pedestrians.

5.3 Surface treatments

Contrast should be borne in mind when designing a visually accessible product since visual impairment and ageing cause changes in perception which reduce visual acuity in respect of certain combinations of colours. Laser technology, used for marking urban facilities, also offers numerous options for signage particularly for identifying different utilities - electricity, water, network cabling, etc.

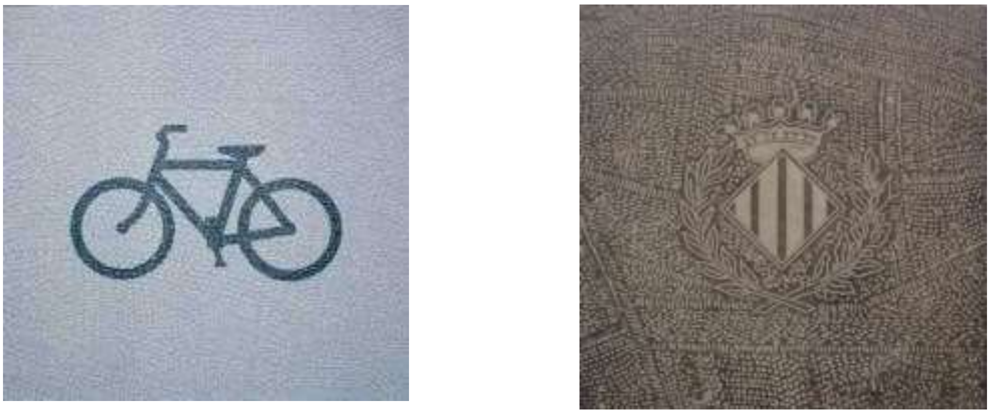


Figure 9. Laser signage on urban ceramic paving Rocersa

This technology offers the possibility of integrating or imitating images with the surroundings giving an aesthetic coherence to the entire urban paving network.

In addition, different systems, based on inkjet printing, can provide ideal solutions for urban spaces benefiting the external area and opening up a wide range of possibilities for signage, localisation and identifying different zones in the city, for example information points, tourist information points, services (hospitals, chemists etc.).

Figure 10. Emotile. Ceracasa.

6 Using ceramics for urban paving

6.1 Mechanical performance

Although traditionally there are other materials that have occupied centre stage for public spaces, in recent years we have seen a gradual increase in ceramic paving for pavements, housing developments, public spaces such as town squares, promenades, etc. For this type of paving, given external use, there are special requirements in respect of mechanical properties far superior to those for internal paving, and specific constraints regarding installation methods.

While the gradual improvement in ceramic paving performance (due to development of tiles with negligible porosity such as porcelain) has assisted with projects with higher mechanical requirements such as urban paving, the development of installation methods and the professionalism of fitters has also had a noticeable contribution.

Installation techniques for ceramic tiles have altered radically in recent years, changing from traditional installation with cement mortar and sand in a thick layer used for ceramic paving with medium porosity, to current installation systems of a thin layer over a levelling base used for installing porcelain tiles. This change in installation techniques has been necessary not only because of the drastic reduction in absorption capacity of porcelain, but also because of the gradual increase in instability or low construction specification, and ceramic tile size, as well as to prevent problems resulting from inadequate preparation or bonding materials.

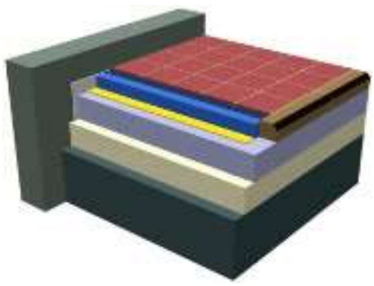


Figure 11. Paving system with thin layer over levelling base

All of this has contributed to greatly reducing breakages and sliding which occur when using traditional materials for urban paving, due largely to the problems of installing paving on a thick layer of cement mortar.

In order to develop ceramic tile urban paving systems and guarantee that breakages such as those occurring with encaustic and natural stone paving do not arise, a detailed study of mechanical performance under these conditions was carried out to determine the minimum requirements of both the ceramic materials and the installation system. For this purpose, loading limits in respect of urban paving with occasional access for goods delivery vehicles were considered. A study devised combined experimental mechanical trials on models of the installation system with finite simulation of the effect of the different construction system variables. The effects of ceramic tile design variables (size and thickness) and the effects of installation conditions when laying the tiles using cement adhesive were analysed by experimental performance under dynamic loading and impact tests.

Figure 12. Concentrated load tests on poorly installed ceramic tile models

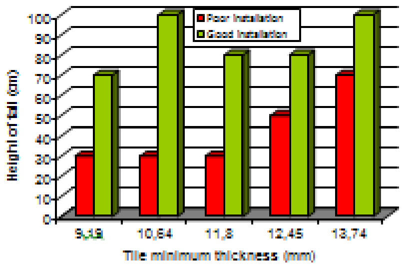


Figure 13. Impact resistance tests with 0.5 Kg steel ball under different installation criteria.

From the experimental test results for paving it was found that using porcelain tiles with a format equal to or less than 40 x 40 cm and 12 mm minimum thickness ensures a performance level with adequate safety margin, even when poorly installed.

The effects of variables in respect of the other layers that make up the paving system were also studied via simulation. Mortar layer deformation and possible settlement of the underlying substrate are the variables which contribute most to reducing the mechanical performance of the system. However, when correctly installed, with double bonding of cement adhesive on an average 6cm thickness levelling screed, it is estimated that porcelain tiles as above can withstand loading with no deterioration, even under the worst installation criteria - simulated load on minimum screed thickness (4cm), with low-stiffness compressible mortar and base with likelihood of settlement.

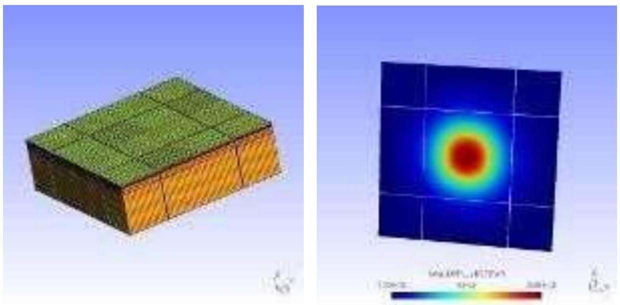


Figure 14. Urban paving system simulation and estimate of deformation under 1000 Kg loading

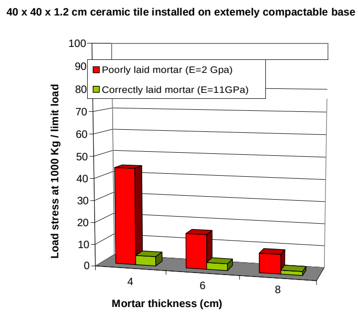


Figure 15. Estimate of loading stress reached under unfavourable conditions in respect of base settlement.

6.2 Tile format and spacing

The current manufacturing processes mean it is possible to obtain a wide variety of formats up to 90 x 90cm, with **excellent tile compaction**, resulting in high durability. However, formats for urban paving must be smaller as the bending strength of the tile is reduced when the format is increased.

40 x 40 cm size is considered suitable and provides **good strength/installation rate**.

These porcelain tiles may be tailored to specific projects by disc or water jet cutting. Similarly, it is possible to round or chamfer the edges by grinding.

Tiles used for urban paving, especially those in natural stone or encaustic tiles, have gradually increased in size from the traditional 20 cm format to tiles of 40 cm and even rectangular formats up to 60 cm in length. Whilst this change has brought improvements both in terms of aesthetics and productivity during installation, it has also caused a substantial increase in breakage in larger formats, in particular for rectangular tiles, stemming, in the majority of cases, from poor laying and lack of continuity in the paving system layers.

These large format tiles with several centimetres thickness are not capable of flexing to adapt to slight subsidence in the substrate and are too unwieldy to ensure correct installation.

Figure 16. 40 x 40cm tiles for paving garage entrances TAU

There are no such problems with ceramic tiles due to the installation techniques used. Installation on a thin layer over a levelling screed ensures adequate load transfer averting localised settlement, which is one of the main causes of broken paving. Likewise, the low weight facilitates easier handling and allows double bonding techniques which ensure correct installation of the tiles on the substrate, averting breakage caused by voids under the tiled surface.

Mechanical performance studies carried out to ensure the suitability of ceramic tiles for urban paving confirm that installation over a levelling screed avoids stress concentration on the tiled surface. The tile format and thickness can be adapted, depending on maximum anticipated loading levels, in order to limit the possibility of broken tiles.

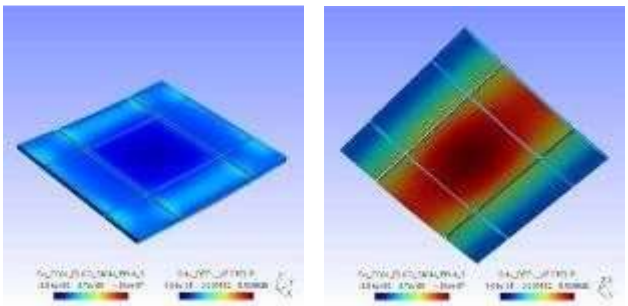


Figure 17. Modelling mechanical performance under wheel load (1000Kg)

For pedestrian pavements with occasional access by goods delivery vehicles, using porcelain tiles of 40 x 40cm or smaller with minimum 12mm thickness ensures the required mechanical performance, if installed in accordance with the proposed paving system.

Although feasible, if larger formats are used, consideration should be given to slightly reducing the load limit. It will be more difficult to ensure even distribution of the adhesive under the tile, therefore using a slightly thicker tile, or limiting use to areas exempt from heavy loads is recommended. For example, to adapt the paving by using smaller format tiles compatible with garage entrances and/or other surfaces with high mechanical stress.

6.3 Slipping

Slip resistance is one of the most important considerations when selecting ceramic paving depending on anticipated use. Despite its importance, this aspect only began to be considered for product criteria just a few years ago.

The increased use of ceramic paving in public areas and outdoor environments and consequent civil liability requirements, as well as the specifiers' and/or users' growing knowledge in respect of the product's technical qualities, have generated a growing market demand for these benefits, similarly for their durability.

After publication of the *Código Técnico de la Edificación* (Building Code of Practice), which determined basic slip resistance principles for different conditions, there has been a growing demand for non-slip surfaces, especially for exterior paving.

In meeting these demands by improving friction, many materials used for paving have tended toward an increased roughness and/or size of surface reliefs, at the expense of other properties such as no dirt retention and safe, comfortable walking textures.

6.3.1 Non-slip surfaces which do not retain dirt

Current ceramic paving manufacturing technology can produce made to measure surfaces, by adapting both roughness and the type and height of surface reliefs. These materials, traditionally used for hygienic applications, have been adapted to the new regulatory requirements reasonably easily, due to the wide range of geometric surface designs whilst the benefits of easy cleaning are maintained.

For surfaces without reliefs, adapting the micro texture means that adequate friction levels can be achieved without needing to excessively increase surface roughness, and therefore dirt retention, thus providing an ideal solution which conforms to slip resistance requirements for all applications in public spaces.

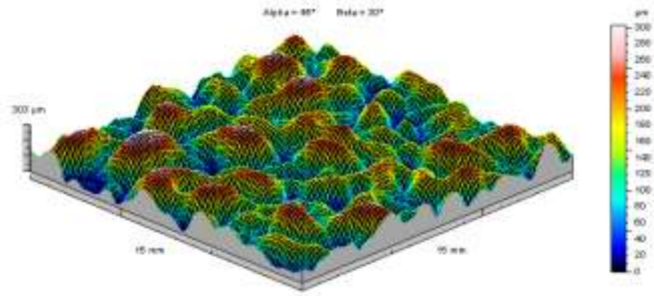


Figure 18. Stain resistant, non-slip ceramic paving surface texture.

In particular, any type of small-sized, reduced depth reliefs can be obtained using current dry-pressed manufacturing technology for use in urban paving. With this, both friction levels and availability of tiles with haptic reliefs can be obtained for demarcation of different urban paving areas, whilst at the same time maintaining both hygienic and ergonomic benefits for pedestrians.

Figure 19. Types of reliefs on 20 x 20 cm ceramic tiles. TAU Cerámica

6.3.2 Durability and performance

Ceramic materials are noted for their exceptional mechanical performance, and therefore difficult to compare with other, traditional materials. In respect of ceramic tiles, porcelain provides the best technical performance due to its negligible porosity and vitrocrystalline properties, making it especially suitable for paving subjected to intense wear or high mechanical stress.

Its high durability against wear not only maintains the same surface appearance, minimising the effects of sun, marking, etc., but also maintains slip resistance properties. On surfaces where friction is only provided by geometric reliefs, gradual wear and rounding of the edges causes a drastic reduction in slip resistance, as some materials with low resistance to wear rapidly lose their original properties.

Porcelain tiles designed for exterior paving have a large number of small reliefs which not only act as anchor points but also ensure slip resistance is maintained over time due to high abrasion resistance.

6.3.3 Biomechanical advantages of low friction reliefs

Friction or frictional force is defined as the resistance that one surface encounters when moving over another. It is produced due to imperfections, primarily microscopic, between the surfaces in contact.

Friction is one of the most important properties in relation to people and paving, not only for safety reasons but also for perceived comfort when walking. As the ground or paving in urban spaces is the part of the construction which interacts with the users for the greatest period of time, it is of prime importance in terms of safety.

Paving designs must increase user safety and facilitate easy walking. Appropriate paving design can prevent numerous falls, caused by slippery or low friction paving or uneven tiles. In addition, a design which prevents glare and reflections should be used to increase feelings of safety for the user. The aim is not only to increase user safety but also to make the user feel safe.

The paving must guarantee minimum slip resistance for safe walking, to ensure that the risk of slipping and falling is minimal. Paving within appropriate friction ranges, but always better than average, provides safety and comfort while walking.

The microtexture level in the paving must take comfort into account both for standing and waiting, which in the case of people with reduced mobility includes the interaction of mobility aids with the paving, as well as other forms of human movement: non-motorised vehicles, bicycles, buggies, wheelchairs, etc. In addition to considering new elements through which the user interacts with the paving, special attention should be paid to preventing vibration. In respect of this, friction coefficient evaluation methods have been adapted for these requirements (Juan V. Durá et al. 20051[1]).

The design of ceramic tiles can adapted to provide suitable surface roughness for friction greater than the minimum required without the need for large reliefs. An even surface can be obtained without excessive irregularities which may cause tripping, overbalancing, twisting, discomfort etc.

In addition, textured paving may help to prevent "aquaplaning" on the surface.

7 Using ceramics on façades

Ceramic façades have been used in architecture throughout history. Currently the two factors which give ceramics in today's architecture increased prominence are: greater concern for environmental issues and technical advances in respect of materials and the systems which make up ceramic façades, minimising the impact of low skilled labour.

[1] Juan V. Durá, Tomás Zamora, Esther Balaguer, David Rosa. Identification of floor friction safety level for public buildings considering mobility disabled people needs. Safety Science 43 (2005) 407-423.

Fundamentally there are three distinct types of façade systems.

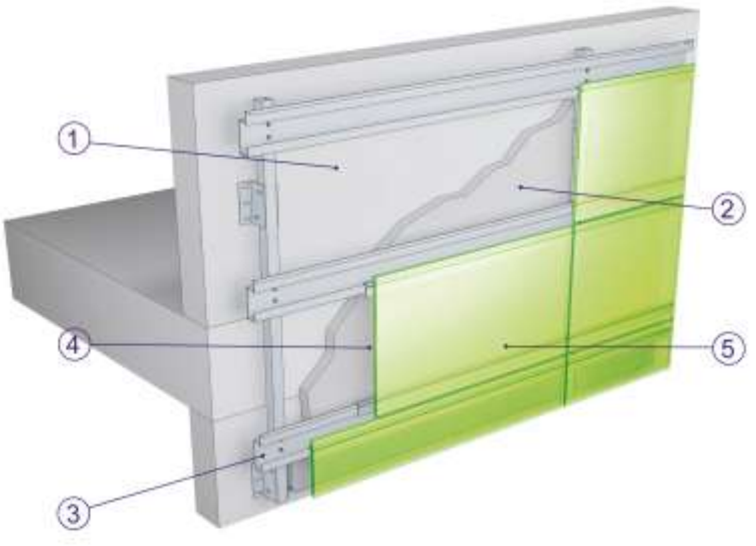
a) Direct bonding: The new direct bonding systems are based on cement adhesives with a high proportion of mixed bonding agents which guarantee a high level of chemical bonding as opposed to traditional sand and cement mortar with mechanical bonding. These adhesives provide exceptional bonding to ensure proper fixing, if applied correctly.

b) Mechanical bonding: This is based on anchoring systems of various complexity, which fix the ceramic piece to the façade without the need for wet joints. This type of system is known as ventilated façades and will be analysed in detail in the following section.

c) Mixed bonding: As the name indicates, mixed systems consist of combining the two previously mentioned systems. Although both can be used individually as stand-alone systems, when exceeding the conventional size or weight of ceramic tiles, combining the two systems offers greater security.

7.1 Description of ventilated façade systems.

Ventilated façades basically have an enclosed space with a ventilated cavity, separated by two leaves, the interior responsible for thermal insulation and watertightness, and the external leaf, whose main function is to enclose said air cavity, ensuring continuous ventilation throughout the surface of the façade.



1. Support element
2. Thermal insulation
3. Metallic substructure
4. Air cavity
5. Exterior face (ceramic)

Figure 20. Parts of the façade

7.1.1 Support components.

This is responsible for providing stability to the structure, providing sound insulation properties to the system and serving to support the internal finish of the structure and the thermal insulation.

If on a load bearing wall, the substructure is anchored directly with point fixings, whilst if the structure is a framework of pillars and girders, then the substructure is fixed to these via "support" fixings.

7.1.2 Thermal insulating layer.

The fundamental characteristic of the insulation is its exceptional thermal resistance. To function properly the entire face should be clad continuously, to avoid any thermal bridging.

There are many types of thermal insulation on the market such as extruded polystyrene, polyurethane, glass fibre, etc. These are supplied in rigid sections that are fixed to the supporting structure in accordance with the manufacturer's technical specification or in liquid form that is sprayed onto the supporting wall, structure and other elements that make up the external face.

7.1.3 *Metal substructure.*
The substructure is a framework of metal profiles which support the external layer to sufficiently separate the layers and create the air cavity required for the ventilated façade to function correctly.

The structural framework will depend on the system used, and may have point elements, vertical linear elements or vertical and horizontal elements.

Generally extruded aluminium profiles are used, due to their lightness and wide range of design options, However, they are low strength and easily deformed.

Steel is the other material used for substructures, normally cold pressed galvanised plate. However, due to high costs it is rarely used.

At all times, incompatibilities should be taken into account between materials generating galvanic pairs from contact between different materials, such as aluminium and stainless steel alloys in corrosive atmospheres (near the sea or industrial environments).

The substructure is responsible for receiving and transmitting to the support element vertical loading, the weight of the external leaf and its own weight and horizontal wind load.

7.1.4 *Air cavity.*
The air cavity is a fundamental part of the entire ventilated façade which differs from other conventional cladding. This cavity allows ventilation and considerably increases the energy efficiency of these façades by improving thermal insulation performance, eliminating condensation, eliminating thermal bridges and providing waterproofing.

7.1.5 *External face.*
The main functions of the external surface are:

- To provide the air cavity and allow appropriate ventilation. It is therefore essential to study the joint size and distance of the surface from the thermal insulation layer, which is usually around five centimetres.

- To receive directly applied horizontal loading and transmit it to the ventilated façade substructure. As the pieces flex in one or two directions, depending on the type of fixing to the substructure, resistance to these conditions must be checked.

- Finally, due to the demands of contemporary culture, aesthetic function is an essential requirement for external surfaces, based on image, brand, individuality or identity.

7.2 Ventilated façades function.

The ventilated interior cavity provides excellent energy efficiency, in contrast to other types of cladding. The fundamental advantages are analysed as follows:

7.2.1 *Thermal insulation.*
The ventilated façade as a whole provides effective insulation from extreme heat, due to the different strata. The first section involved in insulation is the external skin that protects the rest of the system from direct sun rays.

The heat generated in the lower surface due to the sun warms the air in the cavity reducing its density and causing it to rise. Thus, an air flow is produced inside the cavity which extracts the warm air.

Finally the third element is the thermal insulation which must cover all the wall cladding continuously to prevent possible thermal bridges.

During colder months, the ventilated façade works in a different way, since the warmer temperature is inside the building. Therefore the first barrier to prevent heat loss is the wall followed by the bonded thermal insulation. Lastly, rising warm air keeps the thermal insulation dry.

7.2.2 *Prevention of Condensation.*
All façades, separating two spaces with different temperatures, generate a flow of heat that may lead to condensation due to moisture in the air.

To prevent condensation it is essential that the temperature in any zone does not fall below the dew point or that the moisture is sufficiently low.

In ventilated façades these requirements are met since the difference in temperature between the interior and external surfaces of the thermal insulation are controlled due to the first barrier represented by the skin and the air cavity. Additionally, the continuous air flow in the cavity prevents any condensation on the thermal insulation surface.

7.2.3 Elimination of thermal bridges.

The determining factor for insulation in buildings is the elimination of any thermal bridges. By thermal bridges we mean those elements of high thermal conductivity in direct contact with the exterior which form a bridge to allow high or low temperatures to pass to the interior.

Ventilated façades eliminate any thermal bridges due to the continuous thermal insulation over the entire wall, covering pillars and forms.

7.2.4 Waterproofing

The external skin and air cavity provide effective waterproofing. The little water that penetrates the ventilated façades joints is eliminated by the air cavity ventilation.

7.3 Prerequisites and requirements for ventilated façade systems

After analysing the requirements and main functions of ventilated façade systems, the main prerequisites and requirements desirable in ventilated façade systems are listed below:

1. Wide range of formats (modular): The system can have pieces of different materials and sizes installed, to give the designer as much creative freedom as possible.
2. Option of adjusting the line and level of the structure and pieces: so that the distance from the cladding to the wall can be altered to correct inevitable irregularities, which exist on every project, and ensure that the façade is completely flush.
3. Adjustable joints: to vary the distance between cladding pieces, both horizontally and vertically.
4. Easy replacement or removal of pieces for possible repair or replacement and which allows the façade to be inspected.
5. Distance between the support structure and external layer must be sufficient to fix the thermal insulation, currently 4 - 5cm plus similar for the ventilated air cavity (4 - 5cm).
6. Solutions available for all junctions on the façade: provision must be made for all non-robust detailaing such as façade corners and angles, window flashing, expansion joints etc.
7. Guaranteed stability: safety of the whole installation involves the stability of every component to withstand internal and external stresses which it will be subjected to throughout its working life.
8. High level of safety if pieces break: It is essential that the system is able to prevent fragments falling if any cladding pieces break.
9. Good response to deformation. It is essential that any stresses from contraction of the façade, wind load or other factors which may alter the structure of the system are provided for.
10. Competitive cost: if the same function with fewer materials can be obtained, costs will be greatly reduced.
11. Good thermal insulation. Thermal insulation depends on the type and thickness of the thermal insulation rather than the type of ventilated façade system. Therefore, as previously mentioned, the façade system must allow for this thickness along with the thickness of the air cavity.
12. Soundproofing is not reliant on the chosen ventilated façade system. Basically this depends on the supporting structure.
13. Ease of cleaning and maintenance. Ease of cleaning mainly depends on the type of covering, finish, etc.
14. Quick installation, which will depend on the simplicity of the system and the size of the tiles, since larger pieces require greater handling time. As much as possible specialist manpower should not be necessary.

15. Option of installation directly on the wall without cavity, since the ventilated façade is effective on the southern elevation. In this way, the remaining façades may be covered with the same cladding to reduce costs.
16. Stability over time (Durability), of the entire system, especially for the parts that will not be seen, such as substructure adhesives, etc.

7.4 Types of fixings

There are different fixing systems for ventilated façades. The system chosen affects the installation's final appearance, since external pieces, materiality, sizes, etc. will depend on the choice of these fixings, as well as the possibility of combining pieces.

The fixing system can use concealed fastenings connected to the substructure by adhesives, clamps or railed or adhesive profiles or you can opt for visible clamps, profile or drilled fixings.

The following features vary depending on the system chosen:

- The need to machine the piece, with consequent internal stresses
- On site or factory assembled, improving efficiency
- Use only extrusion manufactured parts
- Greater or lesser freedom when fixing pieces and their composition
- Adaptable to different thickness tiles
- Complexity of installation

8 Using ceramics on street furniture structures

The potential for using ceramic tiles on street furniture structures is far reaching and represents an interesting fusion between architecture and sculpture.

The technical properties of ceramic materials have already been discussed and their aesthetic versatility means their use is unlimited. Perhaps the distinctive feature of these applications is the option of different formats. Therefore, to expand on some of the many options, the following show the most commonly used post-processing techniques to obtain particular formats for use in urban areas.

8.1 Disc cutter

Tiles are cut to the required format by machines which use 300 to 350mm diameter sintered diamond discs with 1.2 to 2.4mm thickness generally with several discs and different axes centred on the same line, for **precision cutting** the piece. This technique is only for straight cutting although not right angles.

Figure 21. Islas de Platón. University Jaume I. ITC

Figure 22. Transhitos 2006. ITC.

8.2 Hydraulic cutter

This technique comprises water at high pressure (3000 to 4000 atm) via a hydraulic circuit and pressure intensifier. Then the water is fed through a diamond aperture of approximately 0.2mm diameter to a mixing chamber in order to add abrasive which will boost cutting.

Cutting speed depends on the material, from 1 to 2m/min for ceramic and less than 1m/min for porcelain materials.

Complete freedom in respect of the waterjet trajectory, which is ideal for formats with curved edges.

Figure 23. "Feet on the ground" paving, ITC

8.3 Grinding machine

This technique uses machines that modify the dimensions, to obtain required measurements, by means of sintered discs or grinding wheels, depending on the material. Different diamond crystals and binders are used in order to obtain a good cut without reducing productivity. These machines generally remove the edges and square off in order to get a specific size piece.

Figure 24. Fuentes de Boole and Islas de platón. University Jaume I. Castellón ITC.
Pieces obtained via radial and bezel cutting, used to clad sculptures.

8.4 Die cutting

This shaping technique, which provides a wide range of formats, comprises of passing a column of paste through a die, by means of a propulsion system. Once extruded, the material obtained is cut or cast to obtain the piece size required.

By modifying the die a wide variety of sections with difference thicknesses can be obtained and the shape of the die provides freedom to obtain varied shapes, including curves.

Figure 25. Porcelain shaped by extrusion and die cutting. Maritime walkway, Benidorm
Architect :Carlos Ferrater. Keramia

9 Specialised urban projects

For urban projects we have found precision technology offers the option of developing products tailored to specific technical characteristics and offers wide aesthetic and colour ranges appropriate for urban spaces.

In these projects urban ceramics forms the visible part of a whole paving system comprising multiple layers; each one having a crucial role in the correct functioning of the entire system. Therefore, in addition to a ceramic tile with appropriate properties, there should be good bonding materials, good base layer composition and the whole must be installed following timing, quantities and curing procedures appropriate for the specification of the chosen material.

A series of projects with made to measure ceramic products is shown below, for different urban spaces:

9.1 Main Square, University Jaume I, Castellón

This mosaic, in the shape of a glove, by the artist Manuel Sáez is located in the main square on the Jaume I University campus. The artist has chosen a white glove on blue background to represent the philosophy and identity of the university campus. Using the metaphor of a hand gesture, the artist has sought to capture the spirit of purity, the academic symbol for a graduate who has obtained his doctorate: the image of white hands raised to the sky as a clear symbol of peace.

Two different colours of non-slip, matt porcelain tiles have been used in 33 x 33 and 16.25 x 16.25cm formats.

Since this paving is for exterior use it was installed using a special exterior grade deformable adhesive, using impermeable mortar for installation joints and with expansion joints every 5 linear metres.


Figure 26. Main square. University Jaume I. Castellón, Manuel Sáez, ITC, Porcelanosa, Coarce

9.2 Calle San Vicente, Burriana.

The gradual environmental deterioration of calle San Vicente, its undoubted historic value and importance as the main thoroughfare in the centre of Burriana were the main reasons the designers decided on stunning paving and illumination, enhancing the pedestrian nature of the area. The proposal adopted is a complete visual and atmospheric regeneration of the route. Due to its undoubted historical roots and multiple colour options, ceramics were chosen as the basis for the paving following an in depth study of the inherent characteristics of the materials and new application.

A new developed tile of extruded stoneware has been devised with a profile suitable for exterior paving featuring low relief glazed protection, new size (10 x 10cm format) and new pattern for ceramic paving stones. In contrast to a city that, by default, is grey, the project provides an almost modernist colourful thoroughfare from Burriana's main square (El Pla) towards the *Iglesia de los Carmelitas* (Carmelite Church). The layout of the street is broken down into six sections, or six experiences, that by way of colour bubbles could be extrapolated throughout the entire city.

Installation is by double bonding with special C2EF adhesive bonding material installed on a concrete base.

Figure 27.Paving Calle San Vicente, Burriana. José Durán. ITC, Cerámica Cumella

9.3 Paving Paseo de Poniente, Benidorm

The seafront promenade in the west of Benidorm has been converted into a new transitional area between the built up city and the beach and sea area, making an intermediate space that facilitates this transition. The area has a rich topography as a dynamic area for walking and looking around which includes longitudinal and transversal movement flow, channelling this in such a way as to provide convenient access and at the same time removing architectural barriers to the beach and parking.

The walkway is structured in different levels. The first structural level is the boundary, finished in white concrete. The second level, by means of different coloured textured paving and shapes, defines the different areas which are reminiscent of the fractal structure of cliffs and the movement of waves and tides. The last layer is the urban street furniture in keeping with natural elements.

Materials used are pieces of glazed porcelain in a palette of 22 colours. Circular pieces with a diameter of 25cm have been obtained via die cutting an extruded ceramic sheet. Plus a triangular piece with curved sides that fits into the gaps in between the three circular pieces. Installed with high performance mortar joints (min. 10mm of Sikalatex or similar), the final finish of the joint is white cement with granule size 0 - 0.3mm e= 3mm and RAL colour chart (SIKA MONOTOP® 620 or similar).

Figure 28. Ceramic paving, seafront promenade, west beach, Benidorm. Photograph Alejo Bagué Carlos Ferrater-Xavier Martí. ITC, Keramia.

9.4 Project in the Plaza Mayor, Vila-real

The project in the Plaza Mayor, Vila-real shows how the urban area can be simply transformed to make it more functional.

The configuration of this space separately from the Town Hall corresponds to a wish to reinforce its character. The plaza does not relate solely to the Town Hall but forms part of a larger urban area with the subterranean parking becoming an important factor in its vitality.

In contrast to the pale gold granite cladding on the upper part of surfaces in the plaza, the interior of the canopies is black porcelain, whose colour, shape, size and installation has been closely controlled, resulting in more defined and restrained surfaces.

The installation was made up of 120 x 14cm pieces of porcelain with the edge cut and ground forming an angle of 68º with the lower side of the piece, mechanically and chemically fixed to aluminium T profiles screwed to battens on the structure of the canopies.

Figure 29. Project in the Plaza Mayor, Vila-real. Enrique Fernandez-Vivancos. Porcelanosa

9.5 Intelligent pedestrian crossing

A sensor system integrated into other elements can provide new solutions that make life easier for people today. The ceramic system can equip pedestrian crossings with this intelligence. Pedestrians waiting at traffic lights are detected by sensors under the special ceramic pieces (with blisters - a great help to people with visual impairment), and a signal using non-invasive technology is sent to activate the lights. Currently, more than 10 pedestrian crossings with these features have been installed in Castellón.

On the one hand, this system empowers people with reduced mobility, older people etc. since they simply have to wait for the light to be able to cross. On the other, the system is safe from urban street furniture vandalism as it is hidden under the tiles.

Figure 30. Images of pedestrian walkway Castellón (Source: http://www.inhedit.com/)

9.6 Heated surfaces in urban areas

Incorporating radiant systems under ceramic paving is finally a reality. The system allows ceramic pieces to be heated and used for urban street furniture (benches), for paving, for waiting areas in winter, such as in public transport shelters.

These ceramic systems provide comfort and increase safety in public areas in spite of weather conditions. An example of this type of installation is located in the public transport stop opposite the train station, in Castellón. Another recommended use is for thermal pavements in areas where there is the risk of ice.

Figure 31. TRAM stop in Avd. Morella. Castellón (Source: Ayuntamiento Castellón)

9.7 Ceramic tiled zebra crossing in Onda, Castellón (Spain)

Another ground-breaking use for ceramics is for zebra crossings. In 2011 this option was tested, an experimental one was installed in the "*Puerta del Sol*", Onda[2]. It uses a porcelain material installed on edge with high mechanical strength, slip resistance and which does not require maintenance.

Figure 32. Ceramic tiled zebra crossing. Onda. (Source: ITC)

The main advantages of using porcelain in zebra crossings are that they do not need painting and can be customised with colours and/or can be heated. According to the distributor of this product (Amaco Group), the ceramic zebra crossing can also include, if required, an LED lighting system.

9.8 Ceramic façade, "Oceanário", Lisbon (Portugal)

The avant-garde design of the "Oceanário de Lisboa", (Oceanarium) is by the architect Pedro Campos Costa. The building façade is clad with glazed pieces in a complex pattern, inspired by fish scales (Cerámica Cumella). The façade is made up of 7000 ceramic pieces simulating scales and repeated along the entire façade. It is actually based on a combination of two different sections: opaque flat pieces and arched pieces for views and ventilation, which offer sun protection and protection from falls.

[2] http://www.socialistesonda.org/2011/02/el-ayuntamiento-de-onda-instala-un-novedoso-paso-de-cebra-con-ceramica.html

Figure 33. Lisbon Oceanário (Images: http://www.designboom.com)

9.9 Central Saint Giles (London)

This building in the City of London was finished in May 2012. It was designed by the Italian architect Renzo Piano. The entire external façade is clad with 134,000 pieces of extruded ceramic material. 12 extruded profiles and 6 different colours were used in its construction.

Figure 34. Photograph of the building and detail of the 12 profiles used Source: http://archinect.com/news/gallery/67467606/9/editor-s-picks-302)

9.10 Banque Tarneaud. Limoges (France)

The project consists of cladding formed by numerous white ceramic profiles, supported by a metallic structure, forming a type of ceramic mesh and following the curve of the internal façade. In addition, at dusk the play of lighting on the external ceramic structure creates an allegory of multicoloured lights.

Figure 35. Banque Tarneaud 2005-2006. Architects Atelier 4. Photographic credits: © Ville de Limoges

9.11 St. Stephan's Cathedral, Vienna (Austria)

The use of ceramic materials for cladding façades and walkways has been discussed; however one must not forget its role as roof cladding. Leaving aside the usual ceramic roof tiles, the colour, strength and numerous patterns allow spectacular roofs to be created with ceramics.

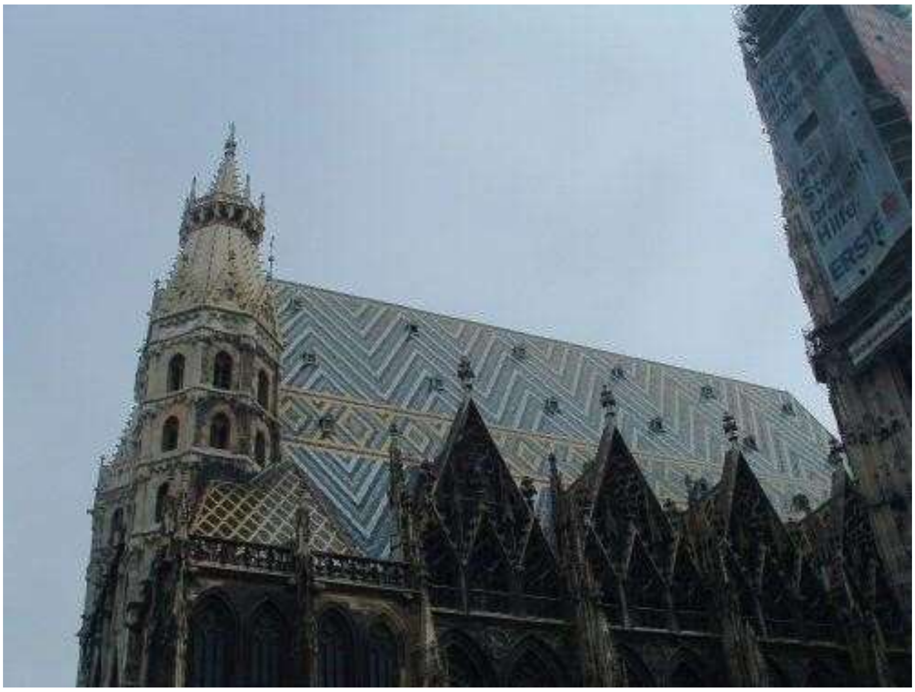


Figure 36. St. Stephan Cathedral (Vienna)
http://cruises.about.com/od/europeanrivercruises/ig/Vienna-Austria/vienna033.htm

9.12 Santa Caterina Market in Barcelona (Spain)

Another example of roof cladding is the project to refurbish the Santa Caterina municipal market, located in Barcelona's old Gothic Quarter, whose ceramic mosaic roof, designed by the artist Toni Cumella, is the most important façade in the market. The combination of hexagonal pieces, 10 x 30 plaques, and different colour mosaics results in this stunning urban ceramic design, visible only from above, as shown in the following photographs 3[3].

Figure 37. Santa Caterina Market (http://es.wikiarquitectura.com/index.php/Mercado_Santa_Catarina)

[3] [3] http://www.premiosceramica.com/premiados.aspx?lang=es-ES&tipo=arquitectura-interiorismo&edicion=anteriores&categoria=premiados&anyo=2004&id=151

9.13 Contumil Station (Porto)

In Contumil station, Porto decorative ceramic panels have motifs relating to the railway industry. This is a composition of 19th century locomotives cut into vertical strips with the logical order changed, as can be seen in the following photographs 4[4].

Figure 38. *Painéis figurativos em azulejo na Estação de Contumil*

9.14 Manuel Gea González hospital façade (Mexico)

The façade of the Manuel Gea González hospital *Torre de Especialidades* in Mexico City also has a noteworthy facade. The structure of some 2500 m2, similar to a beehive, allows better quality air to circulate in and around the building due to its cleansing properties.

The project was completed in April, 2013. Prosolve, a ceramic material based on TiO_2, was used in its construction, which allows contaminants to be removed from the air, via photocatalysis, in order to have a clean space conducive to health. Complex patterns were created for the façade, in this case "quasi crystals".

Figure 39. Decontaminating ceramic façade. Mexico (Fotos de Alejandro Cartegena http://prosolve.elegantembellishments.net/pr_torre1.htm)

The creators also suggested other applications for these structures in the city; cladding surfaces such as bridges, tunnels and even decorative sculptures.

[4] HTTP://POLYEDROS.BLOGSPOT.PT/2012/05/HISTORIA-DE-UM-AZULEJO-DE-EDUARDO- NERY_25.HTML

Figure 40. Depollution city (http://prosolve.elegantembellishments.net/intro_description.htm)

9.15 De Batavier (De Boekenkast) , Amsterdam

A curious example, poorly documented, is the following façade in Lootstraat (Amsterdam), in the district where the streets are named after 18th or 19th century Dutch poets or writers (for example, C. Loots, J.van Lennep, JP Heije, J. Kinker, etc.).

The De Batavier (De Boekenkast) façade takes the form of bookshop 10 metres high, which holds more than 250 ceramic books with titles by the Dutch writers and poets who give their names to the streets in this district. This project was carried out by a close collaboration between the ceramicist P.Kemink (Koloriet, Amsterdam) amd graphic designers Melle Hammer and Leyes Susanne[5].

Figure 41. De Boekenkast. Ámsterdam.
(Source: http://theblogonthebookshelf.blogspot.com.es/2009/10/de-batavier.html and andrevanb's photostream on Flickr)

9.16 Urban street furniture structures

Due to its durability and strength, ceramics are often used in the design and manufacture of urban street furniture, i.e. benches and tables in leisure spaces in cities (gardens, square, walkways, etc.). These elements can be manufactured completely from ceramics or merely clad in this material, for example with tile panels representing some feature of local art.

[5] http://www.mbagency.nl/page19/page173/page187/page187.html

Figure 42. Example of ceramic cladding for garden and park benches.

Throughout Europe there are many projects with different approaches. For example in Limoges (France)[6], the URBACER project, aimed at creating ceramic urban street furniture.

It is impossible to show all examples in this guide, therefore a selection of illustrative projects are featured:

- **Bench, stool and pouf "Onda"**

  White glazed porcelain pieces. Collage and link assembly fitted to metal structures to form small seats

  Manufacturer: Raynaud and CRAFT porcelain Design:

  Marc Aurel

- **Seat with porcelain mesh**

  Seat comprising small pieces of porcelain and metal structure.

  Manufacturer: Porcelaines Mérigous

  Design: Jérôme Pouey -Paradigme Design

- **Seats "Seat City"**

  Seat in white, glazed porcelain, in this case, made up of three modules.

  Manufacturer: Porcelaine Pierre Arquié.

  Design: Régis Courtoux - Formare Design

- **"Slide" Bench**

  Modular seat in white, glazed porcelain. Manufacturer:

  Porcelaine Pierre Arquié.

  Design: Jérôme Pouey -Paradigme Design

As can be seen, the materials and techniques for this type of design vary greatly, from conventional flat tiles through mosaic techniques, to pieces of porcelain machined by waterjet or laser engraving.

6 http://urbact.eu/fileadmin/Projects/UNIC/documents_media/Urban_integration.pdf and http://urbacer.com/

9.17 Ceramic bollards in Limoges

Recently (November, 2013) bollards with ceramic details were installed in several places in the city of Limoges. Made of cast aluminium with the upper part in white ceramic and designed by Marc Aurel, they have been installed in the Plaza Aimé Césaire, opposite the tourist office (12 boulevard de Fleurus) and in the Plaza Winston Churchill.

Figure 43. Ceramic bollards Photographic credit: © Ville de Limoges

9.18 Les lucioles de Patrick Corillon, (Limoges, France).

A sort of chimney is located in the entrance of the Hôtel de Police (rue Emile Labussière) clad with porcelain tiles on which are screen printed pictures of hands making different gestures. Each one is accompanied by a sentence, in some cases related to manual work and on others law enforcement. This simple description establishes a subtle connection between the history of the place, the old Haviland porcelain and its current use.

As is common in his work, the contemporary artist Patrick Corillon has introduced reading in public spaces and has invented a unique genre, with memories, connections which fires the imagination.

Figure 44. Les lucioles, Patrick Corillon, 2002. Photographic credits: © Ville de Limoges

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