PROSPECTIVE ANALYSIS AND DESIGN OF NEW PRODUCTS BASED ON REUSING AND RECYCLING CERAMIC BY-PRODUCTS

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ABSTRACT

This paper presents the main results, as well as the method used, of a project conducted in 2010. The main objectives of the project were as follows:

- To develop strategic product lines by studying and analysing the stock of discontinued ceramic goods and scrap products generated in the ceramic-manufacturing process that were eligible candidates to be recycled and re-used in urban environments, indoor habitats, industrial flooring, etc.
- To obtain the highest possible yield from the manufacturing process by recycling and reusing discontinued or worthless products.
- To open new lines geared towards sustainability.
- To reduce the excess storage space required for such surplus ceramic stock.

The project applies innovation to ceramic products that for various reasons are currently obsolete by affording them added value, basically through design. This same process was also applied to scrap materials generated in the ceramics manufacturing process. Thus, all these products have either been given a new architectural use or have had their original design altered even though they maintain their original function.

As a result, four new product lines for direct industrial use have been formulated by taking discontinued or scrap materials and applying design procedures and post-production techniques to generate products of significantly increased value. The four product lines in question are: lattice screens, new uses for ceramic tile backs, urban furniture and self-draining paving for public areas.

1. INTRODUCTION

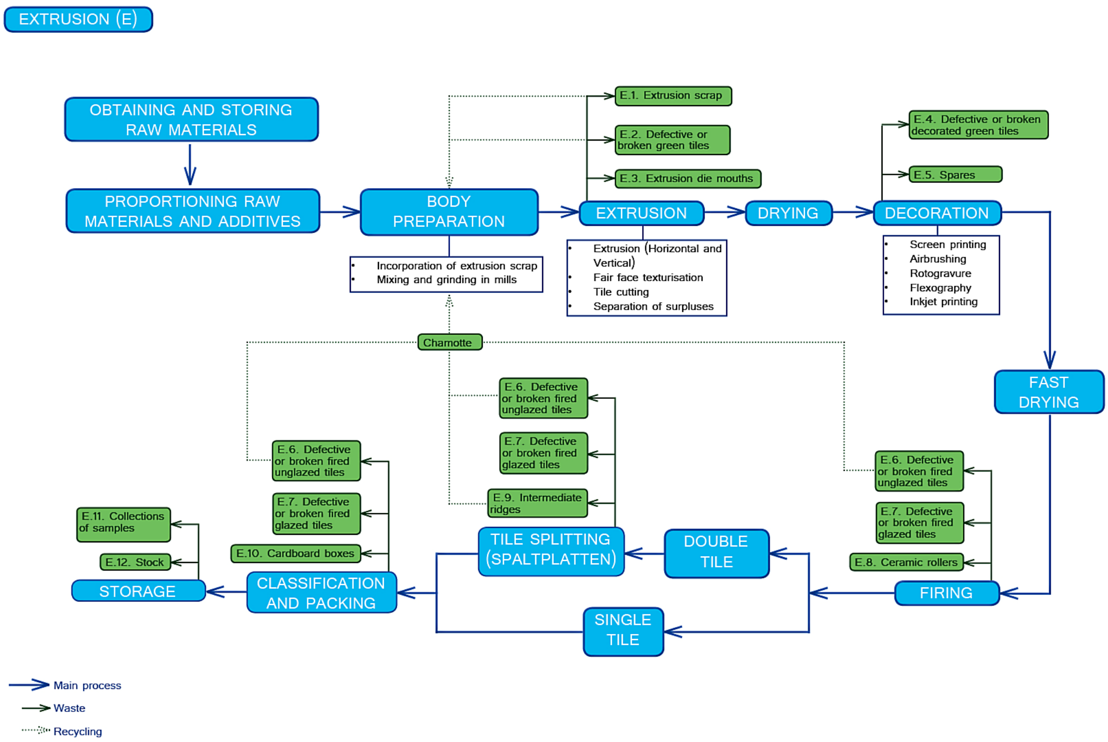
The world economic downturn, which started in late 2007 and is still running rife, has led to a significant drop in ceramic material consumption levels, which at the same time has led to a dramatic increase in the number of products that have been left unsold. The aim of the project outlined in this paper was to increase the value of these ceramic goods, which would otherwise have been sold at a price below their manufacturing cost. Furthermore, the call for environmentally sustainable and responsible manufacturing processes and products has led the authors to design new building systems using surplus materials from the ceramic manufacturing process. The project was conducted during 2010 and its main objectives were as follows:

- To develop strategic lines based on putting remnant ceramic stocks, unsold or scrap products generated in the ceramic manufacturing process that were eligible for reuse/recycling in urban environments, indoor habitats, industrial flooring etc. to use.
- To obtain the maximum yield from manufacturing processes by reusing and recycling discontinued or worthless products.
- To open new lines geared towards sustainability
- To reduce the excess storage space required for such surplus ceramic stock.

The project was split into two phases, the first of which principally analysed what type of materials would be suitable inputs for these new products, while the second stage consisted of designing and producing prototypes. These phases comprised the following tasks:

Compilation study of processes and solutions already existing in other sectors: This stage involved a general study of the status and actions plans currently being implemented in other sectors with regard to re-using and recycling in order to analyse the chances of them being transferred to our own sector. This task brought to light the large number of initiatives which are already being implemented in this field both privately and on a corporate level.

Identification of 'black spots' and scrap materials: This task involved compiling and analysing information about the production processes required in ceramic manufacturing in order to detect the 'black spots' in our current processing where physical scrap is produced. It covered all areas from raw materials preparation to final product packaging and looked at all post-manufacturing processes, such as water-jet cutting, PVD, etc. The chart below shows one of the diagrams used to illustrate the extrusion process and the by-products it generates.



Characterisation of the scrap material obtained: in this stage, a catalogue of materials was generated and their main characteristics listed, including product type, morphology, mechanical properties, production volumes and frequency, possible post-manufacturing processes applicable to the material, and its current value or cost.

Idea selection process

Generation, evaluation and selection of ideas. This stage consisted of analysing the data obtained from the previous tasks and generating action proposals for each of the various types of materials catalogued in the previous stage. At the same time, these new ideas were plotted into a matrix to be evaluated and sorted into new strategic product lines.

Definition of product lines. Finally the various products and systems were defined and prototypes made and tested. This task is described below in greater detail, where four of the new product lines are highlighted: latticework screens, new use for tile ribs, urban furniture, and outdoor paving.

2. LATTICE SCREENS

The aim of this product line was to develop a lattice screen system that used scrap from the 'Spaltplatten' (double-tile) extrusion process (ceramic ridges) and other obsolete stock pieces to form units that could be joined together to form a second skin, thereby regulating the effect of sunlight and acting as a visual screen between different areas (both internally and externally).

The first system proposes a self-supporting ceramic lattice system, which consists of placing the ridges in layers in opposite directions to create ceramic blocks with different degrees of opacity.

Basic latticework unit. First system

Although Spaltplatten tile ridges with convex surfaces were used for the prototype, the industrial product would require parallel-face ridges to ensure improved contact between each face. Adhesion testing between ceramic ridges using a transparent epoxy adhesive was performed and produced good adhesion results. Furthermore, the laborious process of setting up the block could be overcome by using robots when the process is implemented on an industrial scale.

Latticework. Second system

The second system consists of creating a bulky piece of latticework by joining various flat pieces together using items from the remnant ceramic stock. To do so, these ceramic stock items were water-jet cut to make the desired hole. The intention was to create a new visual effect from these discontinued ceramic pieces by juggling with the glazes, textures, geometries, etc. of the different layers. Moreover, because the end piece has several ceramic layers, a further proposal is to move the central layers or pieces in order to create a tongue-and-groove system between the various pieces comprising the latticework.

By using four tiles bonded together in each latticework piece, a stable and robust construction unit is achieved. The tongue and groove joint, which in the prototype was 14 mm deep, means that the parts can overlap although some kind of adhesive in the joint is still needed to ensure bonding strength.

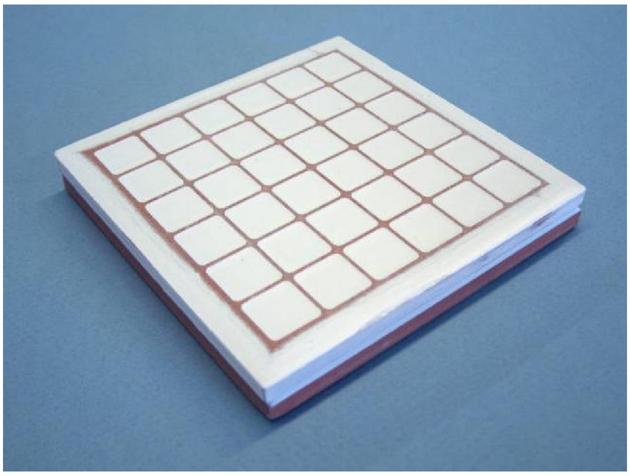
To use this kind of latticework in large extensions, some metal ribs or sections will have to be included in the design to strengthen the whole unit and to join individual pieces together.

The piece has been designed to sustainability criteria and attempts to reduce ceramic wastage as much as possible. For that reason, the holes in the latticework should be designed in such a way that the surplus material cut out of the centre of the hole can be reused for some other purpose.

3. NEW USES FOR TILE RIBS

A ceramic tile generally becomes obsolete because its surface design has gone out of fashion and no longer satisfies market trends. In order to give these tiles a second life, the idea of the project was to turn them 'upside down' and use the top face to adhere them to the substrate, while the under face with the ribbing becomes the decorative item. In this line, two product families were developed, one of which highlights the high relief pattern, while the second completely eliminates the ribbing to feature the ceramic nature of the substrate.

In the first product, a decorative effect was created by filling the spaces between the ribbings with glaze. Thus, the final effect produced a patterned tile with glazed squares and the natural-coloured ribbing.



Use of tile ribs as a decorative feature

Transforming tiles in this way calls for procedures which are quite standard in the industry and therefore manufacturing costs are considered to be reasonable.

Removing the ribs. Polished finish

The second product was made by polishing the back of the ceramic tile to eliminate the ribbing, either completely or partially, and thus to obtain a natural ceramic surface to be used as flooring. A second option was to polish the top face of the tile piece to remove the previous glaze and leave the biscuit bare. In either case, a new ceramic item can be made with an innovative finish that highlights the natural features of porcelain ceramics and which can be suitably used for flooring.

Depending on the format of the original piece, the type of ceramic tile and the kind of glaze, the cost of polishing either the rib face or the top glazed face will vary and no doubt depend on economic factors. Porosity in the new piece can be corrected by applying a waterproofing treatment similar to the one used with terracotta.

The colour of the finished product depends on the colour of the biscuit in the treated ceramic tile and, to a lesser extent, on the polishing and waterproofing processes used. Likewise, the finish can be altered to give it either a mirror gloss or matt finish.

4. URBAN FURNITURE

This line of research aims to develop items of ceramic urban furniture for outdoor use made from recycled material from the stock of ceramic scrap or material no longer on the market. This urban furniture can be used for various purposes, such as seating, rubbish bins, flowerpots, bollards, etc. depending on the end size and shape it is given.

To that end, post-processing treatments are added to alter the shape of the pieces, which in turn allows for a more versatile design of these pieces.

The actual item of furniture consists of a unit which is made of a series of horizontal layers stacked on top of each other to create a vertical structure. The layers are made of scrap or off-market ceramic materials. Each layer is individually made of one or several ceramic tiles cut into a pre-determined pattern depending on the size of the end unit and the position of the layer in it. Thus, the end unit is the result of the different shapes of each layer stacked one on top of the other to comprise the whole item of ceramic urban furniture.

At the same time, round holes are made at specific points in each layer except in the top and bottom layers, which do not have any holes and therefore seal the entire unit.

The reason for these holes is to strengthen the unit by placing the layers of ceramics over vertical pipes welded to the bottom layer.

Although on the first prototypes, the edge of the top layer was machined and rounded off, in the end it was decided that machining was not necessary given that the hydraulic cutter did not produce a rough or abrasive finish.

5. OUTDOOR PAVING

The aim of this line of research was to create a paving system using obsolete ceramic products. The pieces chosen were red stoneware tiles sized 410x410mm from existing obsolete stocks. The pieces were disc-cut into strips of various widths depending on the strength required of the end paving.

Paving module made up of several ceramic strips

Once the pieces had been cut, they were then grouped together in sets of 5 to 8 strips, as seen in the photograph, which allowed for both fast and simple laying of the paving given the much smaller number of pieces that have to be handled.

This paving features numerous benefits, including, among others:

- It can be installed using traditional methods for laying outdoor paving. In the prototype, the pieces were laid on a 2cm deep sand bed, but they could equally have been laid on semi-dry mortar.
- Given that the strips are not bonded together, the paving has good draining properties and thus the underlying base can be sloped while the top stepping surface remains perfectly horizontal.
- The various sets of strips can be laid in different directions to form decorative patterns as required: prisms of varying widths, herring-bone pattern, stretcher bond layout, etc.

On-edge paving. Mechanical strength

Detailed view of on-edge paving

To determine the mechanical strength of this type of paving system, its theoretical strength was first calculated by assuming a modulus of rupture of 40N/mm^2 (standard value for glazed stoneware) according to the formula:

$$F = \frac{2bh^2R}{3L}$$

Where:

F: breaking load (N)

R: modulus of rupture (N/mm^2)

L: span between supports (mm)

B: tile width (mm)

h: minimum tile thickness (mm).

The results obtained are shown in the following table:

Strip edge (mm)	Theoretical breaking load per unit strip (N)	Theoretical breaking load for a set of 15 strips (N)
30	600	9000
40	1000	15000
80	4000	60000

Subsequently, breaking tests were carried out according to UNE-EN ISO standard 10545-4, with a span between supports of L=390mm, using support rods and applying a 20 mm diameter load, with a 5 mm rubber ply under each rod to absorb irregularities in the strips. The results obtained are shown in the following table:

Test results						
Length of piece (mm)	Height of strip (mm) (mm)	No. of pieces	Width (mm)	Rough-ground?	**Experimental breaking load (N)**	Theoretical breaking load (N)
410	30	15	135	no	**2669**	9000
410	40	15	135	no	**5596**	15000
410	40	15	135	si	**8029**	15000
410	80	15	135*	no	**27576**	60000

* Merged width. Original value with 5 pieces of 410 mm each. Breaking load = 9192 N

Practically all the tests were carried out using sets of 15 strips, except in the case of the 80 mm wide strips, where sets of 5 strips were used. Furthermore, the strength of the 40 mm wide strips was also tested after the edges had been rough-ground to create a more uniform support surface.

The test values were clearly lower than the theoretical values, which may be due to the fact that the pieces had been cut with a disc-grinder and therefore varied slightly in height, which then caused certain strains.

Moreover, with regard to how this type of paving will foreseeably perform in reality, one should take into account that actual laying conditions will be more favourable than in our test environment:

- The hypothetical load exerted by a vehicle to assess outdoor paving involves using rubber tyres with no metal core, unlike in our test model.
- The surface area bearing the wheel is much larger than the area used in the test.
- In real-life conditions, the entire bottom edge of the pieces will rest on a soft sand bed.

The Guide for terrazzo was used as a reference to forecast the strength values that such paving might achieve. This guide assumes that the strength values obtained in experimental tests will increase thanks to the conditions in which real-life paving is laid and that such an improvement may vary between 200% and 300%, corresponding to an installation factor of between 2 and 3 respectively.

Thus, taking a conservative installation factor of 2, the following breaking load values would be obtained:

Hypothetical values with an installation factor = 2					
Length of piece (mm)	Strip height (mm)	No. pieces	Width (mm)	Experimental breaking load (N)	Assumed breaking load (N)
410	30	15	135	**2669**	5339
410	40	15	135	**5596**	11191
410	80	15	135	**25738**	51475

6. CONCLUSIONS

New strategies have been proposed to derive value from various scrap and obsolete products from the ceramics industry through innovative design processes.

Various products and systems have been designed and developed that enhance the value of the base materials that they are made from.

A paving system has been created from low-value ceramic materials, whose breaking load can be altered by adjusting the height of the ceramic strips.

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