

# Fabricating Ceramic Covers

## Rethinking Roof Tiles in a Contemporary Context

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**Abstract.** *This paper describes a studio experiment developed with the aim of exploring the design and fabrication of innovative roof systems based on ceramic tiles using digital technologies. History is rich in examples of the use of ceramic roof tiles since the ancient world. Today's systems derive from such ancient systems and fall into several basic categories depending on the form of the tiles and how they interlock. These systems present acceptable functional performances due to centuries of refinement, but as they have suffered little formal evolution in recent centuries, to respond to modern needs they require complex layering and assemblies. Recent technological evolution has emphasized the optimization of the tile production process in terms of time saving and cost reduction, and the improvement of product quality in terms of material homogeneity and durability. Little attention has been paid to the tile form and the roof system as a whole, including the assembly process. As a result, despite the variety and performance of existing designs, they are often perceived as outdated by architects who refuse to use them following a stylistic trend in architectural design towards primary forms and flat roofs. The challenge of the experiment was to take advantage of digital design and fabrication technology to conceive systems with improved performance and contemporary designs. The hope was that this could lead architects to consider integrating roof tiles systems in their architectural proposals. Results yielded five different roof systems. These systems are innovative from a formal viewpoint both at the tile and roof level. In addition, they are easy to assemble and possess better thermal and water-proofing performance. Digital technologies were determinant to enable students to design the complex shape of the tiles, to manipulate them into assemblies, and to assess the shape of the roofs, as well as their thermal and structural performance in some cases.*

**Keywords.** *design education; rapid prototyping; collaboration; ceramics; innovation; tiles.*

## Introduction

The paper describes work developed within an architectural design course at the undergraduate degree in Architecture at Instituto Superior Técnico (IST). The topic of the studio was the exploration of innovative systems of discontinuous roof covers using ceramic tiles, using advanced computer aided design and production techniques, within a University-Industry collaborative context. The objectives were twofold: first, to rethink the concept of the traditional roof tile within a contemporary context, and second, to explore the impact of new technologies on traditional production processes.

Following a renewed interest in ceramics as a building material, both for its technical and aesthetic characteristics, a challenge has emerged for architects to use advanced digital modeling and rapid prototyping technologies to develop new building systems and components that take the most advantage from the plasticity of this ancient material. The structural ceramics industry in Portugal is a traditional sector where robustness, quality and reliability of materials is often combined with lack of innovation and the repetitive production of elements with a design that does often not appeal to users and is similar to many other competitors. Following an acknowledgment from the industry that innovation and quality design were in need by the industry, the idea emerged to launch a competition sponsored by the Portuguese Association of Ceramics Producers, the Technological Center for Ceramics and Glass (CTCV), and the Portuguese Design Center, in which the professors at IST were asked to encourage students to participate. The competition eventually ended up not taking place, but the results produced by the students largely achieved the proposed results, to the extent that all systems have been subsequently patented.

## Collaborative Process

One of the aims of the project was to develop a

novel learning environment where students would be in close contact with the Technological Centre for Ceramics and Glass, with industry partners, and with factories, in order to develop technically feasible products that could also be easily fabricated using the existing industrial projects. The collaborative process involved physical visits to factories, review panels including industry partners, and participation of the Laboratory of Advanced Production Techniques for prototype production.

## Problem setting

Students were encouraged to rethink the concept of using ceramic covers in buildings, and to embed in their system design new architectural conceptions, which should remain coherent from the macro-scale of the building to the micro-scale of the tile. Solutions should be able to combine a reduced number of basic elements towards the creation of a wide variety of shapes, both curved and rectilinear. Apart from the basic tile elements, students also had to design all the special pieces that would make the system feasible, such as pieces for negative and positive corners and ridges.

## Design process

In a first stage, students studied existing discontinuous ceramic tile systems, both in Portugal and internationally, to get acquainted with both traditional systems and state of the art in innovative approaches. Research was targeted not only at reviewing existing systems and their application potential, but also at understanding how different problems were solved by the systems, from water tightness, structural, weather and wind load resistance, to durability and many others.

After this initial research stage, students were asked to elaborate both a list of systems requirements they needed to fulfill, and a conceptual description and initial sketches for their proposal. Following the initial presentations of their con-

cepts, the first visits to the factories and CTCV took place. It was considered that students would benefit more from these visits after having already been confronted with some of the challenges involved in the design process, than at a very initial stage when they had not yet been faced with concrete questions.

Presentations and theoretical discussions with CTCV and industry partners raised the awareness of students in relation to issues as problem solving in relation to functional requirements, molds and pressing difficulties, feasibility and efficiency at all production stages, client needs and market demands, and the difficulty of introducing novel products into the market.

Visits to the factory were essential for students to get acquainted with the issues involved in industrial production of elements, and to understand that despite the fact that some designs could provide adequate answers to the problems under study, they were not feasible to the difficulties that they would pose at fabrication stage, given the existing methods applied by the factories.

After having settled on their main concept, students developed the main tile to a detailed level, subsequently proceeding to developing several special pieces, namely for top ridges, crossing of different ridges, positive and negative corners, walk-over, and others. Progressive problem solving and detailing regarding the special pieces also lead to some modifications in the design of the main tile. Manual large scale models were developed to help the design process at this stage, until a stabilized design was met for all the elements of the system.

The final presentation included elements from the factories, CTCV, and invited architects and designers. In general, all designs were considered to be feasible and suitable for production, despite the fact that some minor changes might still be necessary for improving the functional requirements of some of them.

## Modeling and prototyping tools

Students used advanced CAD modeling tools, and Rapid Prototyping methods such as stereolithography and CNC machining in order to explore the formal solutions and the detailing of elements. The combined use of CAD/CAM and Rapid Prototyping was aimed at both the production of original parts and moulds for producing several copies using resins. Apart from the modeling techniques used, visualization techniques were also applied to simulate the impact of the products developed in existing and new buildings. The final rapid-prototyping mock-ups were built in 1:1 or 1:2 scales, and presented to industrial partners.

## Results

Five projects were generated by this experiment. A brief explanation of each design is provided in following.

Hexagon (Figure 1): The hexagonal ceramic tile was first conceived as a process for covering geodesic dome-like shapes with a minimum radius of 8 m. The system later revealed a large degree of flexibility that enabled it to be used in planar systems both in roofs, terraces, and walls. It is based on three different tiles, called “a” “b” and “c”. The third one is used only as key-stone to close the dome. The tiles possess a system of water channels that can be hidden when the tiles are superimposed and placed into position, or remain visible. The tiles are produced by press-molding and are fixed to the support structure using metallic spiders. The size of the tiles and the original placement and assembly process mean that the distance between the purlins of the support structure can be further apart than in traditional systems. The great advantages are the lightness of the support structure and the low number of tiles per square meter that compensate for the heaviness of each individual tile when compared with traditional systems as shown in Table 1.

| Type        | Hexagon | Move   | Face | Niu             | Unda             | Portuguese tiles | Marseille tiles |
|-------------|---------|--------|------|-----------------|------------------|------------------|-----------------|
| Weight (kg) | 5.3     | 4.0    | 3.7  | 5.6             | 6.4<br>(4.2)**   | 2.9-4.5          | 3.0-3.5         |
| Units/m2    | 5       | 9      | 11   | 7 (9)*          | n/a              | 10-15            | 11-12           |
| Weight/m2   | 26.5    | 36.0   | 40.7 | 39.2<br>(43.4)* | 32.7<br>(30.1)** | 43.5-45          | 36.0-38.5       |
| Length (cm) | 56.7    | Ø 45.0 | 38.5 | 45.0            | 60.0             | 40.0-48.0        | 40.0-45.0       |
| Width (cm)  | 65.5    | Ø 45.0 | 38.0 | 40.0            | 34.0             | 23.0-30.0        | 26.0            |

\*with hidden water-channels, \*\*lower tile

*Table 1 Comparison of the features of the proposed roof systems with those of traditional ones*

Move (Figure 2): This system is based on round, concave tiles that allow the covering of all types of surfaces, including free-form ones, by 'pixelating' the requested surface. The system is inspired in the scales of fishes. The tiles are positioned in a concave and in convex manner alternately as in the simplest traditional roof system. However, unlike in the traditional system, depressions in the tiles permit to superimpose them in such a manner that they remain continuous. The size and weight of these tiles are only slightly above the heaviest traditional tiles (45cm and 4 kg vs. 40 and 3.5 kg) but the number of tiles per square meter is considerable lower (9 vs. 15). The system requires a support structure composed of purlins with different heights due to the concave and convex positioning of alternate tiles. This tile is fixed to the support using a nail which is hidden by the upper tile. A prototype of the tile was fabricated using a milling machine.

tiles that can form continuous planar surfaces, planar surfaces with visible water-channels, or even single-curved surfaces. If used for flat roofs, this system can be supported on traditional structures, but if used for curved roofs it requires a special support structure that depends on the particular shape of the roof. It covers a wide range of roof slopes from 4° up to a maximum of 90°. This means that the system can be used on façades. The shape of the main tile includes a flat surface, a deep water channel, and interlocking parts that permit two interlocking positions. In one, adjacent tiles are superimposed in such a way that they hide the water-channel causing them to seem coplanar. In the other, the superimposed interlocking parts, located on the extremes of the tiles, can move around each other so that the tiles can adjust to curved surfaces. In the latter position, the water-channel remains visible. The depth of the water channel ensures that the roof remains water-proof in both cases, even in the event of unusual rain

Niu (Figure 3): This system is based on flat

levels and almost flat roofs. Special tiles permit to complete the roof. The tiles are produced through a two-step process that uses extrusion and then press-molding. The weight of the tile is above the heaviest traditional system (5.6 kg vs. 4.5 kg in the Portuguese tile system). The additional weight is compensated by the lower number of tiles per square meter it enables (10 vs. 15).

Face (Figure 4): A system that can cover walls and roofs with a seemingly uniform skin, as well as embedded printed images. The system can be used in planar and curved roof and wall surfaces. A special tile ensures complete continuity between roof and wall. The shape of the tiles with three, parallel water-channels diminishes the probability of leaking. Despite the additional superimposed surface that this triple channel requires, the weight of the tile is only slightly above traditional tiles (3.7 kg vs. 3.5 kg). A prototype of the tile was produced in a milling machine, which was then used to produce copies as in the Unda system. This system can be viewed as a logical evolution of the Marseille tile system.

Unda (Figure 5): It is a double-tile system that can encapsulate insulation materials, forming simultaneously the exterior and interior skin of the building and bringing the ceramics to the interior space, in complex geometrical shapes. The upper tile is produced by press-molding and the lower

tile is produced by extrusion. The goal is to generate flat, as well as single-curved roof surfaces by superimposing curved elements. The shapes of the upper and lower tiles terminate with a semi-cylindrical shape that lets them be hanged from a tubular structure, which makes assembly easy and permits the tile to rotate around the support to adjust to the curvilinear shape of the roof. Thermal and acoustic insulation is guaranteed by a layer of foam attached to the upper tile. Prototypes of both tiles were produced using a milling machine. The prototype of the upper tile was used to produce a silicon mould, which in turn was used to produce four copies of the tile using a resin casting process. The prototyping process constrained the shape of the tile to ensure that the machining was possible. The system incorporated special tiles to complete the roof form.

## Conclusions

This paper reports a collaborative teaching experiment by one university, a professional research center and a factory with the goal of designing and producing innovative ceramic roof tile systems using digital technology. The main motivation behind the experiment was to produce systems with contemporary designs thereby prompting their use by architects in their proposals. Another motivation

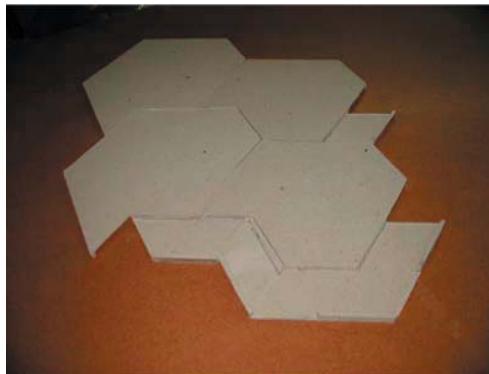


Figure 1. The Hexagon system: hand made and milled physical models.





Figure 2. The Move system: tile and roof example.



Figure 3. The Niu system: main tile, and roofs with hidden and visible water-draining channels.

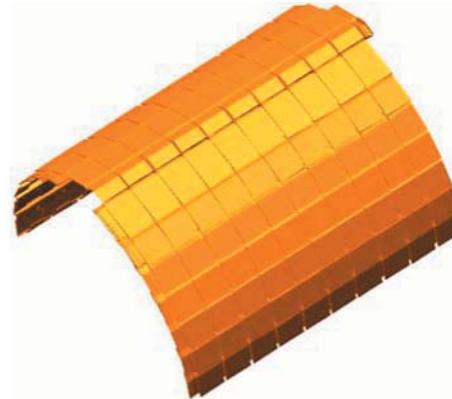
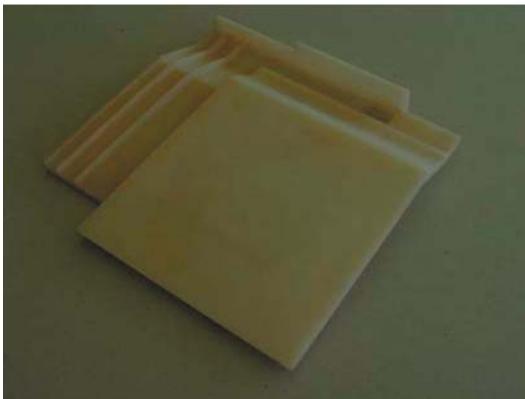


Figure 4. The Face system: rapid prototype of the main tile and roof example.



Figure 5. The Unda system: tile and roof example.

was to study how digital technologies could help students in this endeavor. Results showed that, in addition to possessing an aesthetic appealing, the proposed systems were innovative and competitive when compared to traditional ones. They fall into two different categories. The first includes systems whose forms derive from those of traditional systems by parametric variation thereby innovating in terms of aesthetics and function (Face, Niu, and Move). The second category encompasses systems that represent a rupture with existing references either by departing from different basic shapes or by implying a different placing system (Hexagon and Unda). The functional advantages over traditional systems rely on better water-proofing and thermal insulation performances, on the lower number of tiles per square meter, on the lighter overall weight of the roof, or on simpler assembly processes.

The use of digital technologies was important at three levels. First, the use of modeling techniques enabled students to model and to transform the complex shapes of the tiles in a way that is more efficient and productive than traditional media. In addition, the use of visualization techniques permitted students to gain a better understanding of the shape and functioning of the interlocking of the tiles. Both techniques also were important to control the overall shape of the roofs allowed

originated by the tiles. Second, the understanding of the tile and roof systems was considerably improved when students produced physical models either by hand or by rapid prototyping. The latter was particularly important to control the interlocking aspects of the tiles, but the high cost of the prototypes discouraged students to use these techniques in early stages of the design process. Third, the use of simulation techniques by some of the students enabled them to study the thermal and structural performances of tiles and roofs. Unfortunately, these techniques were little used because increased complexity and time constraints discourage students to use them.

In summary, final designs emerged in response to aesthetic and functional requirements as much as to production constraints. Students had to balance formal freedom with 3D modeling and fabrication constraints due to the need to work within the available technology. The final solutions are particularly elegant outcomes of this process. The fact that they led to five patent requests also shows that they have commercial value. In the end, it shows that innovation pays-off and that it could help ceramics factories to expand their business.

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