# GRAPHIC EXPRESSION AND ITS APPLICATION IN THE EXECUTION OF CERAMIC CLADDING SYSTEMS

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**ABSTRACT**

*There are three reasons to explain why the discipline of architectonic graphic expression has its place in the curriculum of the technical architect. It is required as a language for interpreting project documents, as a skill for elaborating new graphic documents and as a tool for analyzing and defining the execution of construction systems and units.*

*The quality and application of ceramic cladding systems has great impact on the final detail of buildings, which is why, before beginning their execution, their distribution needs to be planned and their layout drawn up in situ so that all the pieces fit together properly. To perform these operations a grounding in geometry and representation is required.*

*Owing to tilers' lack of expertise in this area, this preliminary work is usually overlooked so that compositive results are not as satisfactory as we might hope and they fail to make the most of the pieces which are used.*

*To increase their awareness of this problem, last year the students in their first year of Technical Architecture were given a practical exercise to do as part of their Graphic Expression course. This consisted of a specific case study, which was directly related to professional practice. They had to establish the dimensions of a room in which floor tiles of specific dimensions had to be laid, ensuring a successful compositive result.*

*This article presents an analysis of the results obtained and suggests some strategies for resolving the problems encountered in the design, composition and layout of ceramic cladding systems. Another exercise is also proposed to ensure that students continue to reflect on the subject in future courses.*

## 1. INTRODUCTION

This presentation is a reflection on the role of formats, geometry and composition in the application of ceramic wall and floor tiles. It is intended for students who are studying Graphic Expression in the first year of their Technical Architecture degree and its aim is to provide them with the tools they will need to make decisions concerning the layout and application phases of execution, after the necessary preliminary plans have been drawn up.

This is why last year the following exercise was proposed. Our aim was to potentiate these skills and increase the awareness of future technical architects, who will be responsible for controlling the execution of building projects and consequently of ceramic cladding systems, the idea being to encourage their ability to analyze and reconsider the effects their decisions will have on the final result which is achieved.

We wish to emphasize the importance of graphic expression as a language which is specific to construction and which permits us to "build on paper", predicting the actual task of building so that problems can be detected and different hypotheses can be proposed. Basically this is why the exercises had to be resolved graphically. Nevertheless, in some cases a numerical approach was adopted, using elemental formulae as an aid to solving the exercise.

## 2. THE EXERCISE PROPOSED

After the students and professors visited the Cevisama trade fair in Valencia we saw that we needed to make students aware of the importance of graphical analysis before deciding a layout in situ and prior to applying an element of such common and widespread use, and therefore of such importance, as ceramic floor tiling. The idea was to make students aware of the close link which exists between the subject they were studying, Graphic Expression, and the execution of a building structure.

Rubric for the exercise set to first-year students enrolled in Graphic Expression applied to architectonic building structures (Technical Architecture 2006/07) :

"Given a rectangular surface of 3x4m, you must lay a floor with 40x40cm tiles, marking a perimetral frame parallel to the edges of the tiles. The central part of the composition must have the tiles set at an angle of 45º. Tiles of two different tiles can be used for the composition.

You are asked to study the arrangement of the tiles, basing your evaluation on compositive and economic criteria. An optimal solution will be one which involves cutting the smallest number of pieces and which uses the largest pieces".

*Figure 1. Photo of the 2007 Cevisama Competition*

We included a photo of what we saw at the trade fair, which was an important source of inspiration for this teaching unit. It depicts a tile laying competition.

When the exercise was set, the following reflection was made to the students: The tiler does not start work without first stopping to think what he wants to achieve, and whether aesthetic or economic factors take priority, in other words, the number of pieces he will use and the number of cuts he will make to achieve his purpose. Once the optimal solution is determined, he will reassess his task, either entirely or partially, in situ. To do this he will decide where and how to start, and finally he will lay the tiles. To ensure a good result these are the preliminary steps a good tiler will follow, consciously or unconsciously, and either visualizing the task in his head or placing the pieces in situ to test his ideas.

And this methodology is the same as that which a Technical Architect must follow, if, as the person responsible for the correct execution of work carried out on the building site, he wants to be sure that the final result accords with his intentions. And this is what we ask of our students: to apply their knowledge of geometry, drawing, mathematics and graphic expression so they can put the solution they consider optimal on paper.

## 3. SOLUTIONS OBTAINED

The solutions submitted by the students were enormously diverse and original, ranging from solutions which prioritized economic factors over aesthetic factors and vice versa. There were students who envisaged the ceramic piece as a module and their cuts as clearly defined submodules, and those who took into account whether the size of the pieces resulting from cuts were viable when cutting tiles, and others who took nothing or hardly anything into account.

By way of illustration the analyses some of the students made of the ceramic piece, treated as a module, the way it was cut and divided into submodules, and the economic repercussions, are shown below:

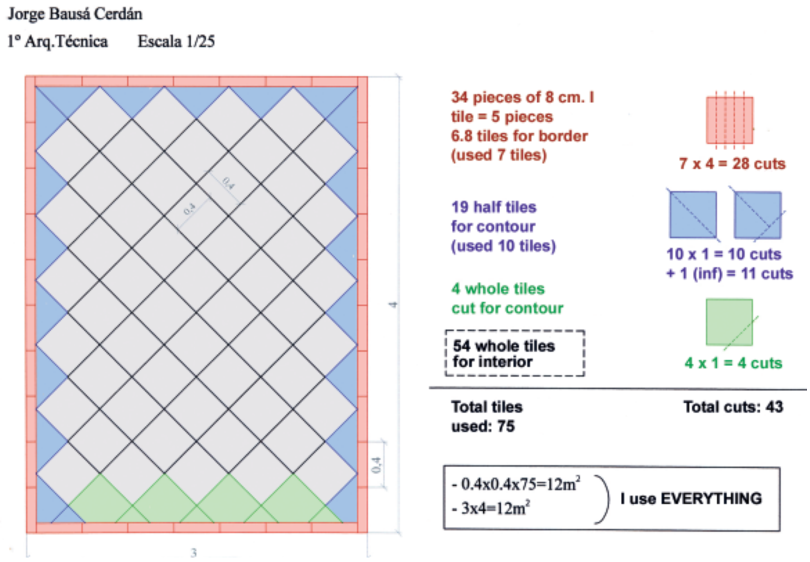



*Figure 2. Example M1*

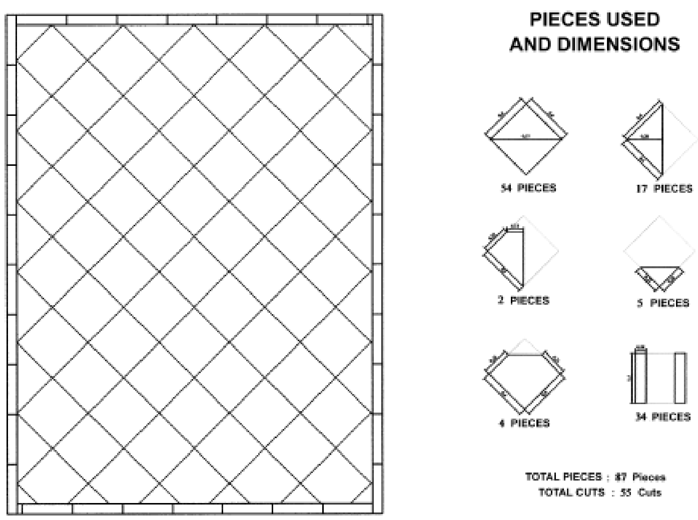



*Figure 3. Example M2*

Some of the exercises completed by our students last year are shown below and the geometric tools used and their economic repercussions are analyzed.

**Example 1:**

Vertexes of centred tiles.

Use of two symmetry axes. Total symmetry.

The size of the perimetral border has been conserved by making cuts in the four pieces which form the corners.

Use of colour.

80 pieces were used, making 40 cuts.

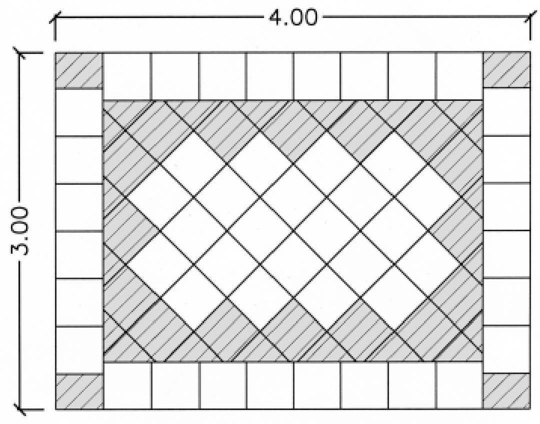



*Figure 4. 40 broken pieces*

**Example 2:**

Vertexes of tiles.

Use of two symmetry axes. Symmetry achieved in the entire composition.

The pieces that form the two smaller perimetral frames have been cut.

Use of colour.

80 pieces were used, making 52 cuts.

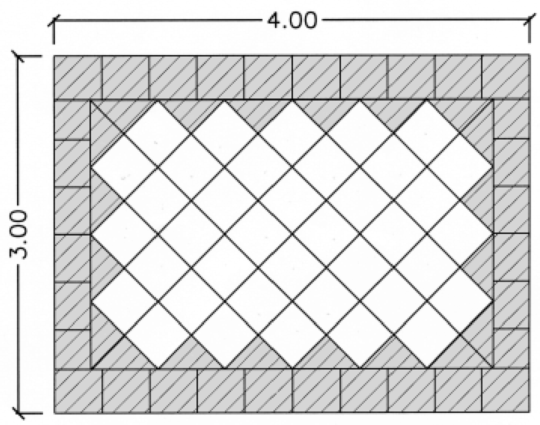



*Figura 5. 52 broken pieces*

**Example 3:**

Symmetry of the transversal axis in the central part of the composition and the perimeter in both directions.

The student has modified the size of the pieces which make up the four sides of the perimeter.

Use of colour.

88 pieces were used and 55 cuts were made.

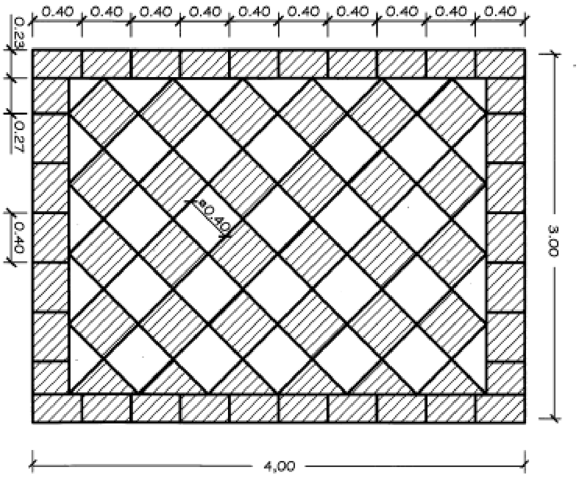



*Figure 6.*

**Example 4:**

Vertexes of centred tiles.

Longitudinal and transversal symmetry of the central part of the composition.

The student has modified the size of the four sides of the perimeter.

Use of colour.

99 pieces were used and 73 cuts were made

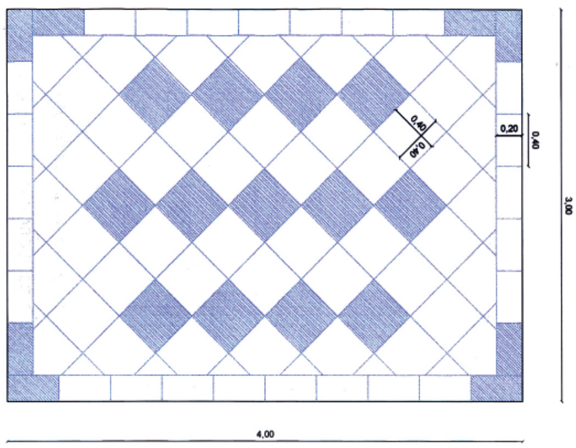



*Figure 7.*

**Example 5:**

Use of two transversal symmetry axes in the central part of the composition and total symmetry in the perimeter pieces.

The size of the four perimetral borders has been modified and the size of the four corner pieces is also different.

Use of colour.

102 pieces were used and 69 cuts were made.

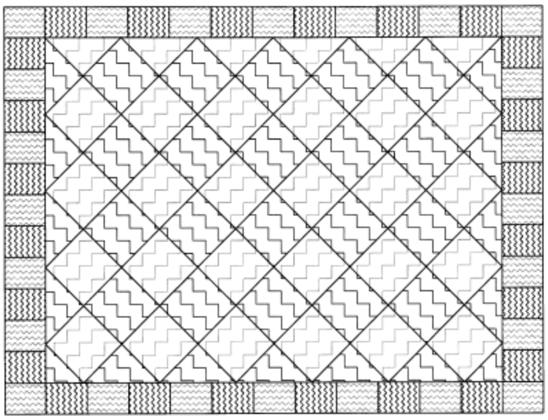


*Figure 8.*

**Example 6:**

Vertexes of centred tiles.

Use of two symmetry axes in the inner composition and lack of symmetry in the perimeter.

The size of the four perimetral borders has been modified.

Use of colour.

74 pieces were used and 66 cuts were made.

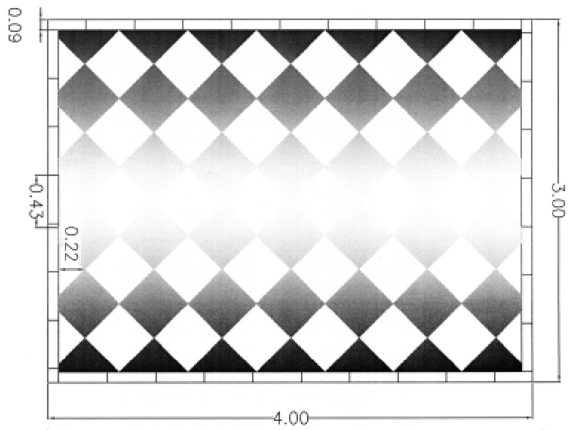



*Figure 9.*

## 3.1. REFLECTION ON THE SOLUTIONS OBTAINED

In order to obtain an optimal compositive solution most of the students decided to modify the perimeter size. However, we noted that both when its size was not modified (Example 1) and when the four sides were modified (Example 6) the cost-effectiveness of the solutions obtained was similar. However, using the same approaches, the cost measured in terms of the number of pieces employed and cuts made can vary widely, although compositively correct results are obtained using either of these approaches.

The basic conclusion we drew from correcting the exercise was the importance of establishing what we want to achieve beforehand, which, in short, will lead to a good layout.

No matter how common the use of ceramic elements is, it is still important, in fact essential, to think through the layout if we want to achieve an aesthetically optimal and, at the same time, cost-effective composition.

A knowledge of geometry and representation, and of the use of modulation throughout the history of building, is indispensable in order to do this.

## 4. DESIGN STRATEGIES FOR OBTAINING A GOOD COMPOSITIVE SOLUTION

1. Before applying any design strategy we must consider the following question:

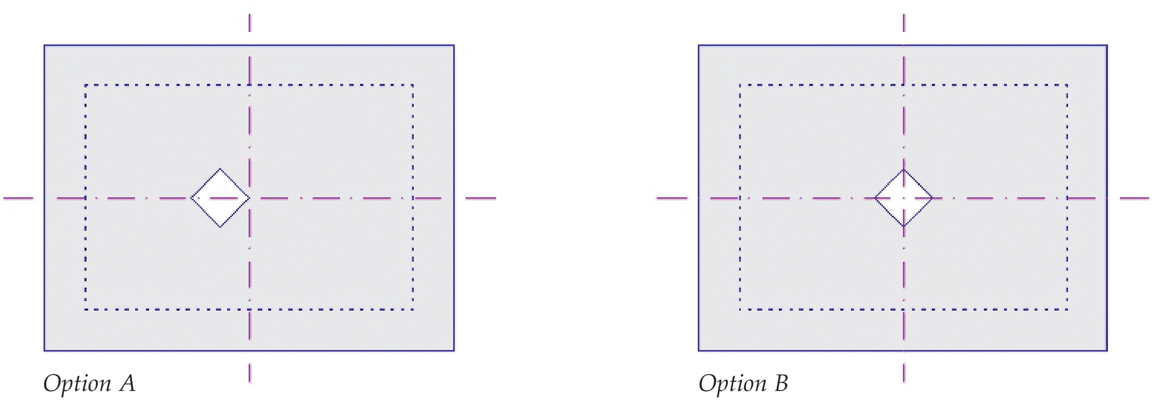
Should design take priority over economic factors? If a balance is kept between these two aspects, we believe the answer is yes. If a client asks for something specific, evidently he will be concerned about the final aesthetic composition, even if this means an increase in the cost of its material execution, as long as this increase is reasonable. And the compositive result, symmetry and aesthetics will be factors we should regard as positive and they will certainly be linked to the cost-effectiveness of the solution proposed if fewer cuts and pieces are employed.

As we have already said, we have to consider the economic cost of using an excessive number of tiles and cuts, and pieces which are too small, owing to the increased risk of breakage and the time wasted. This is why none of these conditions is recommended and in our case they were penalized in the exercises completed by the students.

2. Having established our basic premises, where do we place the first ceramic piece? To do this we resort to axial representation. We will use two axes, a longitudinal axis and a transversal axis, located in the centre of the composition. The first piece will be placed on these two axes, to be exact at the point where they intersect. We have two options:

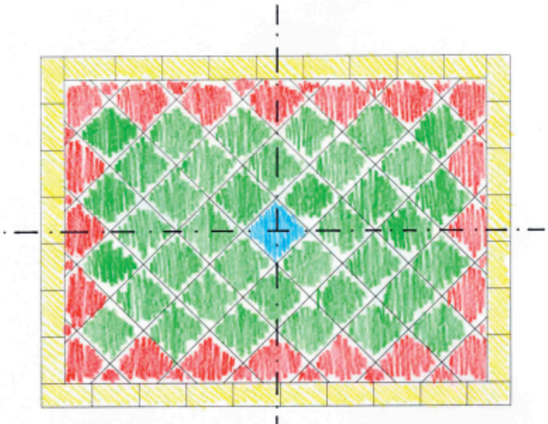
A. We can make the centre of the tile coincide with the intersection of both axes.

B. We can make the vertexes of four tiles coincide with the axial intersection.

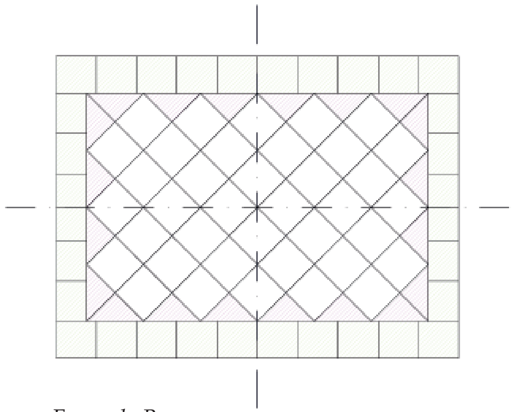


*Option A* *Option B*

*Figure 10.*



Example A



Example B

*Figure 11. Examples submitted by students*

3. A widely used geometric tool is <u>symmetry</u>. Given the shape of the surface for the composition, it seems appropriate to use symmetry. Now we have the option of using one symmetry axis or two, one vertical and the other horizontal, both of them coinciding with the previously marked axes. We also have the option of using total or partial composition symmetry (for the tiles in the inner section or the perimeter).

A table indicating how this tool was used by students is provided below:

| | |
|---|---|
| Use of Symmetry Axes: | |
| The concept of symmetry was not applied | 50% |
| Use of only one symmetry axis | 27% |
| Use of two symmetry axes | 23% |
| Coincidence with the axial intersection: | |
| No coincidence with any relevant point in the tiles | 23% |
| The centre of the first tile coincides with the axial intersection | 23% |
| The vertexes of four tiles coincide with the axial intersection | 54% |

*Table 1.*

4. The third set of questions we need to make refers to the <u>width of the perimeter.</u> Should it coincide with the width of the basic ceramic piece or is it a good idea to modify it? If we decide to change it, how much can it be changed? And on how many sides?

To find the optimal solution to this problem we need to use mathematical equations, which, in this case, where we are dealing with a square piece at an angle of 45º, requires us to make square root calculations.

If *A*x*B* represents the two dimensions of the space in question, *a* and *b* the number of intact pieces in each direction ($a_1$, and $b_1$, at right angles and $a_2$, $b_2$ at an angle of 45º) and L the size of the tile squares, it follows that:

$$A = a_1 \times L + a_2 \times \sqrt{(2 \times L^2)} \qquad B = b_1 \times L + b_2 \times L\sqrt{2}$$

The ideal solution would be for $a_1$, $a_2$, $b_1$ and $b_2$ to be whole numbers.

In our specific case, if there is a single piece on the orthogonal side, $a_1, = b_1 = 1$:

$300 = 2 \cdot 40 + a_2 \cdot 40\sqrt{2}$ $\qquad$ $400 = 2 \cdot 40 + b_2 \cdot 40 \cdot \sqrt{2}$

Assuming that whole numbers are not obtained, we have to find the best solution by cutting pieces, either pieces within the frame or in the inner rectangle, positioning them at an angle of 45º.

Below we can see the percentage of students who opted for each of these solutions.

| | |
|---|---|
| The size of the perimeter pieces was not modified. | 33% |
| The size was modified on two sides of the perimeter (on the shortest sides) | 11% |
| The size was modified on two sides of the perimeter (on the longest sides) | 0% |
| The size was modified on the four sides of the perimeter. | 56% |

*Table 2.*

For our purposes we can regard the optimal solution to be that which requires the smallest number of pieces to be cut and which uses the largest pieces. To achieve this we can either cut the perimeter pieces or those in the central part of the composition

5. Use of colour.

If we look at the total number of solutions submitted, 65% of the students chose to use colour. Some used it in their composition and others in their economic analysis, differentiating pieces which had been cut by using colour, as we saw above.

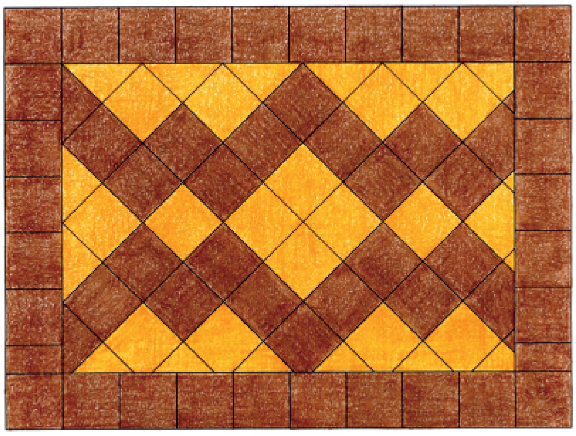


*Figure 12. Example C1*

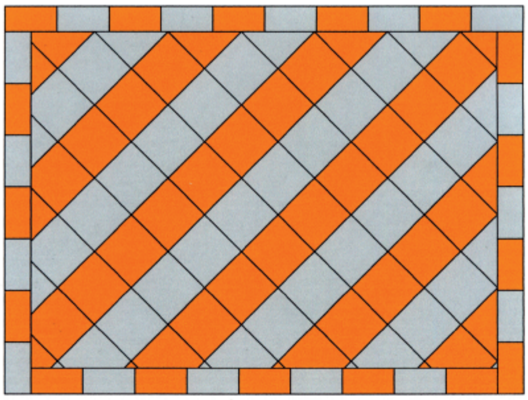


*Figure 13. Example C2*

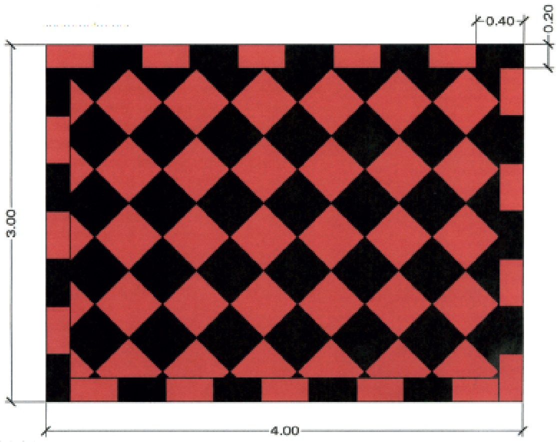



*Figure 14. Example C3*

Here we can resort to using knowledge of visualization, gleaned from the history of architecture and design, to learn about different solutions, the most frequent of which, where square floor tiles of two colours are concerned, is the checkerboard.

## 4.1. STRATEGIES FOR OTHER SITUATIONS

Once we know the strategy for resolving this initial problem, we can apply it or transfer it to other similar problems, which can probably be reduced to symmetry axes that can be used to arrive at a compositive solution.

Some examples could be applied to L-shaped or trapezoidal spaces:

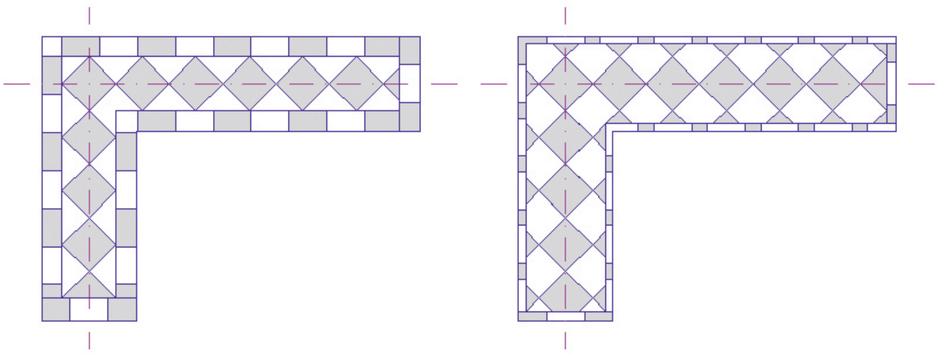


*Figure 15. Examples E1 and E2*

## 5. COMPLEMENTARY TRAINING REQUIRED

The results obtained demonstrate that to address the subject of wall and floor tile layout successfully the subject of modular coordination must be introduced, given that tile application is based on this concept, as it consists of the serial repetition of consecutive pieces of a particular size.

To do this it would be of interest to do a quick review of the subject of dimensional coordination in relation to prefabrication, and the principles of repetition, composition, etc. and their historical evolution.

If we go to the Real Academia de la Lengua Española dictionary we find the second definition of the word module to be as follows: *"Unitary piece or set of pieces which are repeated in a structure of any type to make it easier, more economical and regular to build"*, and its third definition reminds us of the importance and consideration given to dimensional coordination and composition, from details to the most general dimensions, since antiquity:*"Measurement which is used for the proportions of architectonic forms. In ancient Rome it was the semi-diameter of the lower part of a shaft."*

In more recent times it has also been a recurrent theme for an infinite number of studies with the common objective of facilitating the introduction of the best possible aesthetic results into construction.

Ernst Neufert has this to say: *"the dimensions adopted for bricks, and floor and wall tiles, should all belong to the same measurement system in order to facilitate the concordance of the tools used with these materials, and their mutual substitution and combination".*

In his *modulor*, Le Corbusier proposes a dimensional series based on the golden ratio and Fibonacci numbers, which allow different formats to be consecutively linked with lower numbers in the series. He also relates all this to the proportions of the human body, suggesting a direct application for the design of interior spaces.

Together with this introduction, the concepts of modular systems employing basic modules, submodules, multimodules, preferential dimensions, etc., should be taught.

In the case of the application of ceramic cladding systems the principle dimensions for coordination have to be considered: longitude and width, but also the subject of joints, which fit different pieces together, has to be introduced, given that modular dimension is equivalent to the sum of the dimensions of the piece plus two semi-joints.

In relation to all this, attention to the format and type of ceramic cladding systems acquires special importance. There is a great variety on the market and we need to know what is ideal in each case in order to define our choice criteria. Square, rectangular (and in what proportion), hexagonal, triangular formats and so on must be analyzed from the standpoint of geometry and mathematical considerations, and multiplication and division series.

After this theoretical analysis, the difficulty of applying these criteria exactly and the existence of perfect modular spaces have to be addressed. There are many factors which influence the construction of a building and, even with the most perfect approach, a degree of inaccuracy must be allowed for, which means we have to introduce the concept of tolerance. Tolerance must correspond to joints and determines the capacity for adaptation and the deviations which can be permitted.

Once students have been introduced to modular systems, the university curriculum proposing the most ideal theoretical approaches students should attempt to imitate, we cannot leave out the consideration of construction in real situations. Due to multiple factors, modular spaces are rare and often what is most demanded of formats is that they offer flexibility and an ability to adapt to non-modular spaces of any size.

## 6. PROPOSALS FOR FUTURE ACTIVITIES

In order to learn more about the design and layout of ceramic cladding systems we can propose other problems involving both vertical and horizontal cladding systems, which will mean integrating three dimensions into our design.

This is an example of a possible exercise rubric:

The ground plan and elevation of a bathroom, as well as the measurements and position of interior and exterior woodwork and the bath, are provided. The rest of the bathroom furniture will be fitted without affecting the tiling.

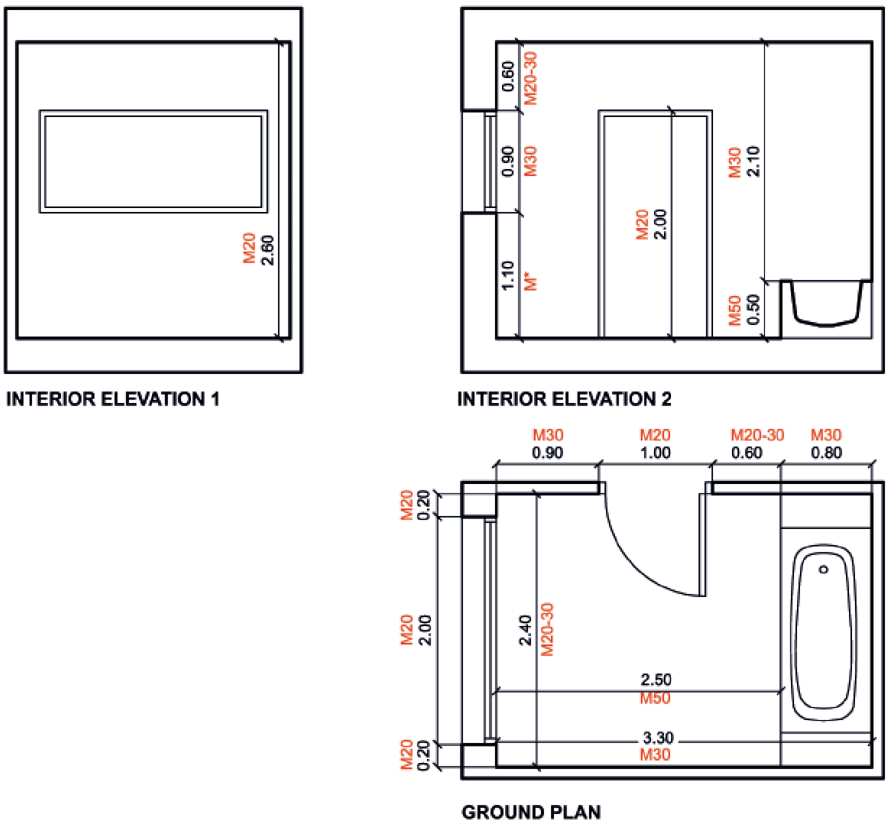



*Figure 16.*

**You are asked to:**

1. Resolve the tiling of the floor and walls with 199mm square tiles, which must be laid employing 1mm joints. Comment on the problems detected and their possible solutions.

2. Resolve the tiling of the floor and walls with 199mm x 299mm rectangular tiles, employing 1mm joints. The optimal solution will be one which requires cutting the smallest number of pieces.

**Comments:**

Section 1: the pieces being 20x20cm square, it is a simple exercise to get students thinking. Problems are encountered more easily with dimensions that fail to coincide with the 20 cm module (Series M20). Solutions tend to try to adopt this module, at least for the exact layout of gaps, false ceilings, etc., if it is not suited to the general measurements.

Section 2: with the introduction of the rectangle the number of solutions is multiplied and a more complex analysis is required. Depending on the two dimensions and the way they combine, double modulation, which increases the number of modular series to be taken into account (Series 20, 30, 50, 60, 70, 80, etc.), may be used.

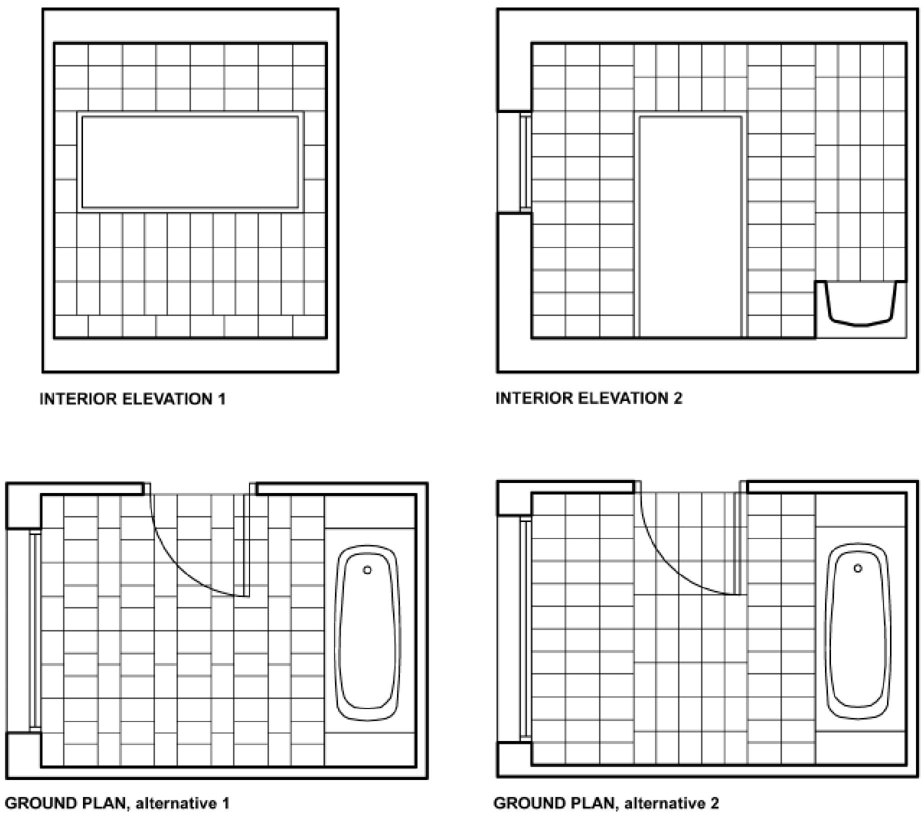
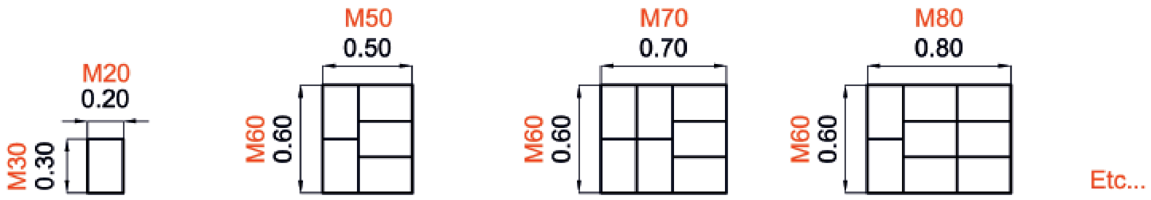



*Figure 17.*

The ideal solution will employ intact pieces.

M20 Series: 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 220, 240, 260, 280, 300, 320, 340, ...
M30 Series: 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, ...
M50 Series: 50, 100, 150, 200, 250, 300, 350, ...
M60 Series: 60, 120, 180, 240, 300, 360, ...
M70 Series: 70, 140, 210, 280, 350, ...




Moreover, we need to consider which of them can be mutually combined to resolve a two-dimensional (A and B) space (whether a ground plan or elevation), as in the drawing included: M20 with M30, M60 with M50, M70, M80, etc.

A more theoretical rationale for the combination of pieces, reduced to mathematical formulae, would be as follows:

Assuming AxB are the two spatial dimensions and a and b the number of intact pieces in each direction (if there are two formats these are subdivided into $a_1$, $a_2$ and $b_1$, $b_2$),

if the pieces are simple and in the same position: $A=ax30$ $B= bx20$ or vice versa

if a combination of pieces at an angle is used: $A =a/2x60$ $B=b_1x20+b_2x30$. For example, in the combination of pieces on the right $A=2/2x60=60$ and $B=1x20+2x30=80$

In this case the exercise permits ideal resolution without cutting any pieces.

We might also comment on the possibility of another type of solution, such as placing pieces at joint breaks or setting them at different angles.

Soon, as part of a multidisciplinary approach, we would like to set a more complete exercise as a competition for students. This exercise will be set at three different levels of difficulty in order to adapt it to architectural students in each academic year. This will mean multiple factors, such as preference for certain formats rather than others, the exact location of partitions and gaps, the height of false ceilings, etc. can be taken into account. Over and above the graphic resolution of the problem, our aim is that in each case the solution provided- the materials used, the building systems, economic estimates, etc.- must be justified from the point of view of the various disciplines the student has studied, thereby responding to the rubric set for each of the course subjects.

## 7. CONCLUSIONS

The exercises which were set allow us to see the application of graphic studies to the design, layout and supervision of the execution of ceramic cladding systems.

They represent an introduction to the subject for students in their 1st year and an attempt to teach them how to approach problems, facilitating guidelines for resolving different cases and basically increasing their awareness so that they can deal with this type of problem in their professional work.

Although the results for this first exercise were not satisfactory in all cases, the methodology for learning which is used seems adequate, given that it makes students think about the problem they need to resolve.

To improve the solutions obtained it might be a good idea to set a second exercise after providing a theoretical explanation of the first one, which would provide clues to resolving the next problem satisfactorily.

The teaching methodology we are defending considers practical exercises an essential part of the learning process. In future courses we plan to present a motivator exercise and, after explaining the basic theory, apply it to new exercises, which are directly related to professional practice.

## 8. ACKNOWLEDGEMENTS

We would like to thank all our students in their first year of Technical Architecture at the UJI of Castellón for the effort and interest they showed in general during their studies in 2006-07 and, in particular, when doing this exercise.

We appreciate and value all the work which was submitted, although given the limited space and time allocated to this presentation we are only able to show some examples of their work: Example M1 by Jorge Bausá Cerdán and M2 by Lucas Barreda Gil, 1 and 2 by Sonia Guarnido Jiménez, 3 by Susana Bernabeu Morales, 4 by Débora Puerta Montes, 5 by Lourdes Palacino López and 6 by Marc Gascón Sabrit, A by Judit García Camañes, B by Mónica Doñate Pérez, C1 by Rocío Soriano Campos, and C2 and C3 by Javier Bort Garavís.

We also wish to thank Ángel Pitarch Roig for his advice, inspiration and dedication, and all his efforts to ensure that this presentation made it here today. Many thanks.

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