DESIGN TOOLS ENABLING BETTER EVALUATION AND DESIGN OF CERAMIC PRODUCTS

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1. STATE OF DESIGN TECHNOLOGIES AND THEIR APPLICATION IN CERAMICS

Rapid Prototyping or Machining (RP/RM) refers to the physical models made from a design using a specific class of technologies. RP systems produce models and prototypes in a rapid way based on CAD models in computer 3D and/or 3D files made by digitisation systems (inverse engineering).

Many companies use RP to reproduce models, prototypes or components, and to subsequently develop products ranging from industrial machines to small items of our daily life, from aeroplane parts to surgical equipment. RP is a great help in the design and development process of new products, and many companies use these techniques to shorten development times. With the possibility of using a three-dimensional model, companies reduce times and costs when planning, making decisions or developing a product, and are better equipped to avoid problems regarding production, quality or positioning in the market. For most firms, RP is an important strategic tool rather than a simple technology.

These applications are fundamental to understanding the great possibilities, present and future, of this product design and development process, particularly in Spain. In this decade that has just commenced, Spain is expected to adopt these technologies[1]. in a much more widespread way than in the past. The implementation of these systems is continuously expanding and ever more companies and organisations are acquiring or implementing this technology in their processes.

There is great interest in these technologies in different parts of Europe and North America, and in their application in ceramics. Starting from CAD design we find several systems that are currently in service or in an upgrading or technological development process. Examples of these technologies are found in fields of great technological interest such as microelectronics, bioceramics, etc., as well as in traditional industries, such as decorative porcelain ware. Without going into great depth, it would be useful to describe the current state of these technologies and the centre(s) working with them[2]:

a) SFF (Solid Freeform Fabrication) is a method developed in Sweden through IVF research and industrial development. The technique, which is currently in the development process, will allow creating bodies with complex dimensional variables. It is based on the formation of granules, which after particle sintering, develop the model. Various Swedish companies appear to be involved in this project. Also in Sweden, the Institute of Ceramics is analysing the possible links to enable conjugating these sintering systems with automatic CNC systems. Both projects intend to compare possibilities of these systems with traditional systems and current technologies.

b) Another technique already starting to be marketed is the Steam Roller, which produces functional prototypes using ceramic coatings in a similar way to lamination (layer by layer) of many RP systems. It is generated without any tool or mould.

c) Extrusion Freeform Fabrication (EFF) and ceramic fused deposition (CFD) are also being jointly used for the development of prototypes by deposition and solidification of ceramic materials. This process is based on an adapted commercial RP technique (the Stratasys 3D Modeler)[3], with which good dimensional tolerances and physical properties have been obtained. The feature that they highlight as most positive is the use of different ceramic materials (silicon, alumina, and zirconium).

d) Another system started up in France is the PHENIX 900, which uses a sintering process based on a source laser, and achieves complex pieces that reach a dimension with a level of the accuracy around +/-50μm. The mechanical characteristics of the ceramic pieces obtained after minimal post-processing operations are comparable to those made by traditional production processes.

[1] PROF. JÜRGEN G. HEINRICH, of the TU of Clausthal (Germany) is carrying out experiments in the field of decorative porcelain and tableware, based on selective laser sintering.

[2] This is just to observe that it has been attempted to go ore profoundly into some of these referenced development. This has cost us time and provided no clarification except for those set out in this paper, and we think that apart from the efforts of the Fraunhofer-Institute and the R&D support of RP by the companies themselves, the rest are direct or indirect applications of systems already found in the market.

[3] CHARLES GASDASKA, RICHARD CLANCY AND VIKRAM JAMALABAD, ALLIED SIGNAL I&T, MORRISTOWN, NJ. These researchers developed models using silicon nitride prepared using FDM based on a Stratasys 1650 Modeler. Symposium V: Solid Freeform and Additive Fabrication Nov 30 - Dec 1, 1998.

The maximum volume of the prototyped piece is 250x250x300 mm. The company says they are able to develop models, pre-series and moulds.

e) Besides these experiences there are experiences applied to the ceramic field, from prototyping processes using sintering technologies and stereolithography[4] marketed through 3Dsystems, to the investigations of Centres like the Fraunhofer-Institute for applied materials research, which are developing new specific applications of RP supported by Technology Assessment & Transfer, Inc., combining both systems (SLS and SLA). Besides this European Institute, the company Ceramic Composites, Inc. is involved in the development of two RP technologies for the direct production of ceramic and metal components. One is a technique based on certain photopolymerisation techniques and the other on the lamination of object manufacturing (LOM) process. As we can observe in the different environments, the importance is growing of the development of these practically emergent technologies (not yet fifteen years old), for work in elaborating ceramic materials by prototype development.

2. STATE OF THEIR INTRODUCTION IN SPAIN AND IN THE CERAMIC SECTOR

In 1996 ALICER presented the sectoral results of a study carried out on the ceramic floor and wall tile sector. Already in this study important shortcomings were noted in the whole design process, from product planning to product promotion and launching[5]. During this whole development, the cycle or process through which the different projects of lines or models to be proposed pass slows down, leading to departmental interference and what is more significant, delays or problems in decision-taking with regard to going ahead with the project. There is a general absence of design structures throughout the whole sector, although in the measure in which a tacit concern exists to innovate in terms of competitiveness (sector with great exporting activity), to provide the product with greater value (above traditional R&D) and to generate short and middle-term profits, we can say that the sector is progressively evolving in a positive sense, although much remains to be done, since design has become the most important tool for the Spanish entrepreneur to achieve this innovation. For this reason, it is important for Spain to place itself in a key position, by considering the introduction of innovative design techniques from a strategic point of view (the best variable of competitiveness is to use design as a value for differentiating one product from another), showing technological development or traditional value forming those products, and without any doubt, make that traditional design effect effective where it is necessary to reconcile producer needs with consumer demands, to avoid "ugliness does not sell"[6].

[4] RAJEEV GARG, ROBERTO K. PRUD'HOMME, AND ILHAN A. AKSAY. Ceramic processing in stereolithography, Department of chemical engineering and the Institute of materials of Princeton, University of Princeton, Princeton NJ. Also the experiments of Gabriel T-M. Chu, G.Allen Brady, Weiguo Miao, J. W. Halloran, department of materials science and engineering; Scott J. Hollister, departments of the biomedical engineering, surgery and industrial engineering; Diann Brei, department of industrial engineering and applied mechanics, University of Michigan, Ann Arbor, MI. Ceramic SFF by direct and indirect stereolithography. Symposium V: Solid Freeform and Additive Fabrication Nov 30 - Dec 1, 1998.

[5] ALICER. Study on design management in the ceramic sector. 1996. Results of their conclusions concerning the planning, design, development and product launch phases.

[6] LOEWY. Raymond. Ugliness does not sell. Ed. Iberian. Barcelona, 1955. This book is considered one of the few testimonies translated into Spanish of design as such and on the practice of design, based on the experience of one of the major representatives of American styling, since the 30s heading one of the highest rated outside design firms of the XXth century, with almost 250 clients, designing products from packagings (Lucky Strike) to aeroplanes, decorating facilities and offices, as well as designing decorative objects (Rosenthal ceramics).

Returning to the study by ALICER, it can be observed that in general in the ceramic sector, the operating objectives are not met which allow speaking of design as an innovation process: first they are not optimised and organised, secondly, client needs are not kept in mind in a systematic way (nor are market studies carried out, sales staff are the only persons that contribute subjective or verbal information, "businessman's" self-sufficiency) and thirdly, design and product development times are not shortened and methods for reducing these times are not applied. We can say that for the most part, the actions developed in this sense do not favour innovation and much less, business strategies.

Proceeding further with this study, we can observe that prototyping works are of an essential importance for the companies in the sector, forming their technical and aesthetic verification, although the resources generally used for this come from the colour producing company (to which they subcontract design and which have small pre-series lines), while usually their experience in this matter is still very artisanal and expensive (especially economically). The prototype is so important that multiple tests are run before it is put into production, its production cost is studied and the decision is taken to carry out a certain design when an entire series of specifications has been satisfied (commercial, aesthetic and technical) since work started on the prototype. However, times spent are long, and despite recession problems / sales of 95, adequate measures, studies or methods have not yet been established for incorporation into the companies to facilitate reducing costs and times[7].

Taking this reduction in times as a variable to be developed[8], let us consider the importance in all the sectors of the introduction of rapid prototyping or the improvement of the development phase centred on the prototype as a tool, which not only facilitates technological, but also strategic solutions, since it becomes a common and comprehensible language in which all the internal and external agents act in a company.

According to the OPTI (Observatory of Industrial Technological Perspectives) for the traditional sectors, design technologies are still limited by their cost and complexity, erroneously considered high or their expectations are not understood to be sufficiently covered[9]. With these technologies (CAD-CAM, rapid Prototyping, Inverse Engineering, etc.) we are able to optimise design times and costs, something very important for the ceramic sector where the fashion factor has a great impact, and in whose companies design resources are becoming more and more important. Returning to the OPTI, for this reason Spain lies below the European average (scientific-technological capacity, innovation, production and commercialisation).

Comparatively, in spite of the position of the sector before these obstacles, the field of ceramics demands and/or produces the most prototypes in its design processes, and if

[7] We understand that organisations like ASCER or QUALICER from a business point of view, or ITC or ALICER carry out continuous work (sometimes involving enormous effort) aimed at improving quality, training and technological development to incorporate the phenomenon of innovation in the companies. The results, according to the CEV, in the Valencian Community reflect inter-sectorally that companies do not use these mechanisms effectively, the expenditure in R+D+I being 6.6% of the national total and the degree of innovation intensity is 1.12% in the case of Valencia, despite being industrially one of the most active Communities in Spain and that as Objective 1 of the EU, we have received important public support for improving our technological and industrial capacity. Sources: State of R+D+I in the Valencian Community. Ed. CEV - Bancaja. 1999. Indicators in the newspaper EL PAÍS - Valencian Community. Friday, 13/07/2001, p. 13.

[8] ASCAMM. Industrial design and reduction of Time to Market. DDI, 1995.

[9] OPTI. OPTI. Strategic technological lines: Design in the traditional sectors. MINER - EOI, 1999.

we speak of the Valencian case, we transfer its reality to the national calculation, the sector (ceramics 1.80%) heads the rest of the industrial SME sectors, where they would presumably be more profitable, such as plastics (1.11%, separating the case of toys 1.30%) or the metallurgical sector (1.35%)[10]. In Spain the figures still swing between correct application of prototyping in about 11% of the SMEs, although we could add 28% of companies that habitually use it.

In the case of traditional sectors such as ceramics, perhaps more than in the furniture industry, where the solution is less complex, or in the case of other not so traditional models as in the metalworking industry, while the demands of industrial production and development are in some cases already being reinforced through these technologies, this is where the prototyping is not only acquiring greater industrial interest not just on a national but also on an international scale. In the national context the results of the sector demonstrate that it partakes of a fully artisanal dependence, with some clearly missing connections between CAD processes and automation or production in the process, which added to a general unfamiliarity with these technologies, delay the development and launching of the product, generating weaknesses in position and competitiveness in such a dynamic activity, marked by the rhythm of ever shorter tendencies and life cycles.

3. PRODUCT DIGITISATION PROCESS

The tile profile is basically captured in digitisation systems by means of two methods. However, it is to be noted that each of these types of data capture (which is their differentiating factor) has its own advantages or disadvantages. These are basically:

a.- By contact: the information on the profile is captured by a pick-up, capture time is longer than with the laser method. However the advantage is that the captured data are better, due to the continuity of the surfaces being captured.

Figure 1.

[10] MARTÍNEZ TORÁN, MANUEL; SENA, AMPARO. Diagnostics on Design Management in the Valencian Community. DDI-IMPIVA, 1996 (unpublished).

b.- By laser: the greatest advantage of this type of capture is the data acquisition speed, but other problems are usually encountered such as the fidelity of the quality to be digitised. This capture type usually has to be accompanied by a process for altering and improving the data acquired, and it cannot always be applied.

3D digitisation has allowed us to obtain a tile surface whose capture has been carried out by a contact system. Based on the capture of the information, its mesh can be processed (depending on the data obtained) with greater or lesser difficulty. If the surface is sufficiently united, a CAD program that allows processing will enable us to retouch, modify, re-size or simply make it a stl file (the standard one) for producing a RP. If the surface is not sufficiently united or processed, the process of healing and making the 3D solid will demand more expensive post-processing time and require specific software.

This file was passed on to us as a binary stl by e-mail, since we confided absolutely in the scanned model, and we were able to open it in a Rhino 3D modelling software and confirm its structure. We also used a stl repairer that definitively confirms the capacity of the file to be directly prototyped.

Figure 2.

With this we confirm that digitisation systems not only contribute to developing variables of computerised dimensional metrology, but also to transferring information from a physical model, a texture or a pre-existing design, though not developed in 3D, and to transforming it into any standard IGS, DXF, etc., file including a STL. This does not promote the copy by the copy situation; it facilitates computerising historical models, analysis of different textures or virtual design alternatives, to use the advantages of concentrating files on a computer and employing them in different phases of the development or production of a model, to improve and optimise the development of moulds and even to design them based on computer parameters, without forgetting the possible modifications, corrections or improvements of the digitised texture. If we furthermore complete the cycle with a print of the model on a concept level, such as when make a 2D print or plot for confirmation, we are strengthening the capacities of the design cycle by producing a tangible model. For this we will use a solid printer.

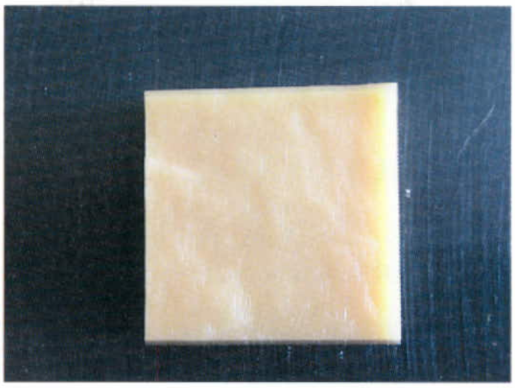

Figure 3.

4. 3D MODEL PRINT

As for the Thermojet technology, as a 3D model printing system its operation is extremely simple: after creating the design of a new product in a CAD program, the relevant data (file in stl format) are entered through a computer net. Next, and in a matter of a few hours, a 3D print is made of the conceptual models. While traditional methods of making prototypes can take weeks or even months, the 3D printing equipment creates three-dimensional pieces with great accuracy in a few hours, providing the design process with much greater flexibility and substantially reducing the time and cost involved in putting new products out onto the market. The system accumulates and sequentially processes works coming from multiple workstations, just like the office printers and plotters connected in a network.

Figure 4.

The piece that appears prototyped in 3D has been made, because of its height and the accuracy parameters that we wanted to use, in approximately one and a half hours. During this time the piece was subjected to a thermal process. Its physical properties are very similar to a wax that solidifies as it is deposited layer by layer, in a very similar way to the ink-jet system of the ink-jet printers, moving the z axis of the injector. This process in turn generates a series of post-processing facilities and yields the model, since a structural material is generated initially that facilitates its separation from the tray without any problems. With this piece we can already begin the process of making the mould through semi-artisanal processes, and we shall look at the qualities of the system.

5. POST-PROCESSING OF MOULD PRODUCTION BY CASTING

The mould production process enables making a cast which is done to verify its effectiveness in stoneware and in porcelain, though not as a biscuit. This could have been done, but on having carried out this experiment with a small 40x40 mm model, the results would confuse the material with the texture. And the texture was the objective sought.

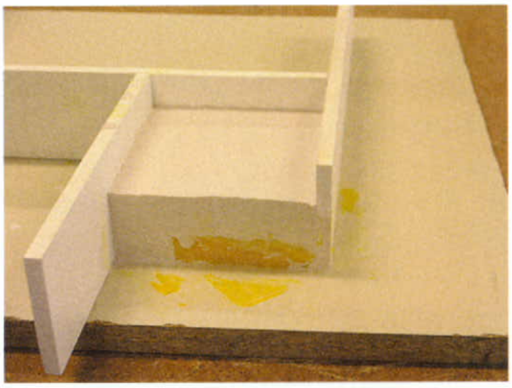

Figure 5.

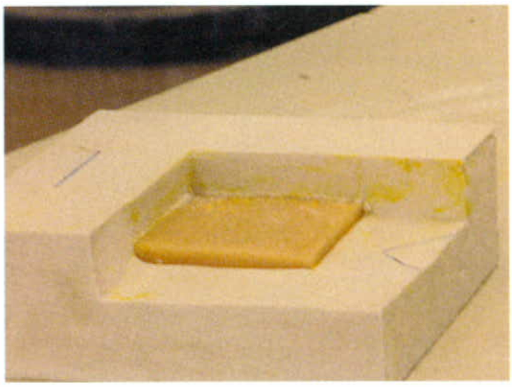

Figure 6.

The improvement of quality and costs of the ceramic process are key features targeted in this development. The plaster moulds that exhibit dimensional stability, a longer useful life, porosity and consistent strength, constitute an important part of the success. If this is so for production, it is no less the case for the mould prototype. The mould is developed with Almod 70 or 75, and without needing Exaduro[11] it sets in the

[11] Both Almod and Exaduro are commercial products of BPB Fórmula. In this case Almod was used without needing Exaduro, since it was not sought to develop a mould of great strength for firing or industrial development.

same day. The mould is designed first keeping in mind the stoneware and/or porcelain cast, with as first reference the texture. Once the face of the mould has been made from the "master" prototype, to which we apply a soap mixture and oil, on one side we include a plasticene extension, which after elimination will serve as trough. Once this mould has semi-set, we prepare the plaster cast of the other part. After setting, the mould is mounted without exceeding 70-80° so that it does not calcine, and in each case a stoneware cast and a porcelain cast is correspondingly prepared.

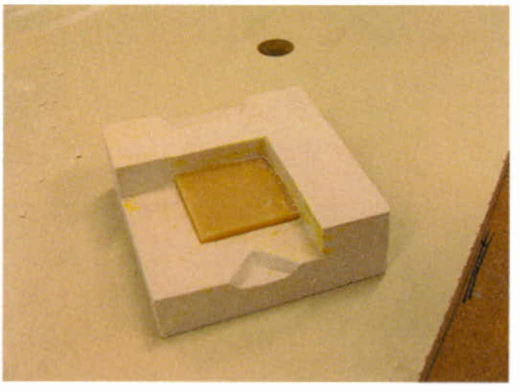

Figure 7.

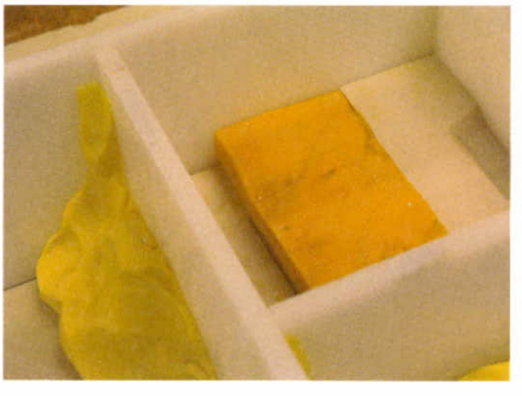

Figure 8.

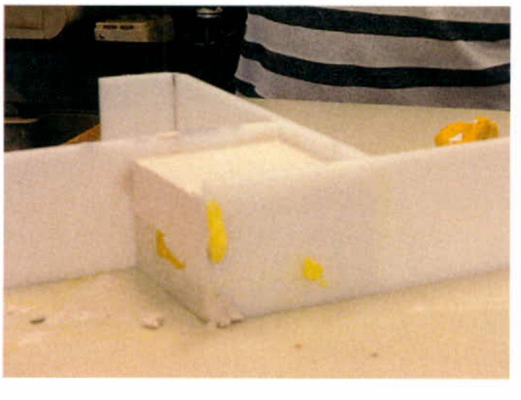

Figure 9.

Figure 10.

Figure 11.

Figure 12.

After treatment in the firing kiln (around 1270º) the prototype pieces are obtained. From the time we obtain the CAD file, depending on the complexity of the piece, the process takes from three to five days. We intend to transfer this process to the case of decorative ceramics, after further testing. At the end of this paper it will be possible to observe in more detail the samples and results obtained.

6. REDUCTION OF DESIGN AND DEVELOPMENT TIMES

With these tests we wish to highlight that one of the key phases in reducing the time that elapses until a product reaches the market, is the making of prototypes since it shortens the cycles of changes by trial and error. The resulting benefits, which later affect product cost, are:

Time. The first company to successfully put a product out onto the market enjoys a period of high sales margins.

Market share. The longer it takes for a product to appear, the lower will its market share be, and hence the lower its absolute profitability.

Useful life of the product. The more time passes in taking decisions on developing a product, the greater are the possibilities that market needs will change.

Development capacity and financial costs. There are many resources that will not start capitalising until the product is launched. This immobilisation paralyses other projects and lowers the competitive capacity. Shortening times frees financial resources, besides enlarging the capacity to generate new projects with equal means.

Ceramic products need to have ever higher levels of quality. This requires having prototypes that efficiently fulfil the functions for which they have been made. The construction of models or prototypes is unavoidable in many research projects and/or new product developments for the companies in the sector. The techniques for conducting the tests and prototypes contribute efficiently to reducing costs, shortening times and assuring results during the development of new products.

These design technologies enable designers and engineers that need to produce rapid, economic models in 3D to validate and communicate the design during the development of the product; the 3D print gives rise to a similar physical model to a three-dimensional drawing, but with the added advantage of a tangible design that can be handled. 3D digitisation allows interacting with RP systems to generate a machining program (CNC) or to transfer the geometric file to a graphic format. In general the different design systems and technologies enable:

- Visualising models for designers and engineers
- Making a model for moulders and heads of workshops
- Analysis of requirements
- Presentation of proposals
- Verifying production suitability
- Corroborating functional applications
- Reference for other types of rapid machining or precision developments
- Design evaluations
- User or client test

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