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cascade approach on recycling for marble and granite product design

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ABSTRACT

The present article presents the main results of a research project that aimed to establish guidelines on sustainable design for marble and granite products, a non-renewable material. The study was carried out within an association of 13 small and medium companies in Brazil. During the investigation it was identified a significant lack of literature on these materials which could support the design process, particularly regarding the issue of recycling. The study has unveiled the potential of applying in this sector the "cascade approach for recycling" where it is anticipated destinations to all possible wastage for the entire life cycle of a given product.

1. Introduction

This case study was originally set to provide design support to 13 Brazilian small and medium companies specialized on manufacturing marble and granite products. It was carried out in the State of Paraná, the 4th largest granite producer in Brazil, with a 6% share of the national production.

Marble and Granite products have received relatively little attention of the design research community despite its great economical, social and environmental impacts. It is estimated that the total economic impact of the business around this material within countries is worth around US$ 18 billion. The export business of finished products based on marble and granite generates around US$ 12 billions/year along with US$ 10 billion/year generated from the machine production other complementary products/services. Currently the world market in this sector represents 65 million tons per year from which 80% of the finished products are tiles for walls and floors, 15% are funeral pieces and 5% general products [1].

Brazil has around 500 different types of commercial stones, including granites, marbles and quartz, distributed throughout 1300 quarries. The national production includes 60% of granite stones and 20% of marble and travertine. The country produces 1.4% of the world total volume of processed stones and occupies the 6th position in terms of export volume [3]. In 2004 the highest flow of Brazilian export stone products were directed to the USA with 71% of the total monetary value [2].

The majority of marble and granite companies in Brazil that produces finished products present a deficient and out-of-date manufacturing infrastructure when compared to Italian or Chinese competitors. Most of these companies are family owned and tend to focus their activities solely on the local market which usually demands a limited range of products. This situation along with the almost total absence of design professionals working on the product development process on this sector results on products with poor value added.

In this context, the Design and Sustainability Research Center at Paraná Federal University, in partnership with the Marble and Granite Manufacturers Association, set a one year long research project with the aim of disseminating a new paradigm on product development on this sector. Since natural stone is a non-renewable material the focus of researchers was on generating design concepts that contemplate creative solutions for the waste generated during the production process and, also, enabled an extension of product and material life cycle. The focus was the generation of solutions for the production waste integrated on the solution of the main product, which is named here "cascade approach for recycling".

2. Life cycle design: expanding the life of marble and granite

A key issue when thinking on developing solutions for waste of any industrial sector is to understand the life cycle of each material. Nowadays there are a large number of new methods for environmental impact assessment of products which enable a full assessment of the input and output between the *technosphere* and the *geosphere* or *biosphere*. However, there is little data to support any study on marble and granite and even fewer data considering its life cycle which leaves the focus of designers mostly on

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the key concepts and principles of sustainable design to support their decisions.

Most authors in the field of sustainable design [2,8,4,9] agree that the LCD – Life Cycle Design – leading principles include:

- The extension of the design horizon: from product design to the (systemic) design of the product life cycle stages.
- A new design *reference*: from product design to product *function* design.

Within this framework products have to be designed considering all phases of the life cycle. All activities related to the product, from the production of materials to its distribution, to its use and finally its disposal, are considered as a single unit. This leads to a shift from the design of the product to the design of the product-system, as the whole of processes characterizing its life cycle.

The second criterion of LCD is to design referring at the *function* delivered by the product, more than from the physical product itself [8,9]. In fact it is in relation to this function (functional unit) that it is possible (e.g. with LCA) to assess whether the environmental impact has been reduced and how. Function, a fundamental and historic theme in the culture and practice of design, acquires in this context a new meaning and a new vitality in this perspective where sustainability and satisfaction of the end user are simultaneous goals.

The approaches for achieving Life Cycle Design, according to Manzini & Vezzoli [5] includes:

- Material consumption reduction;
- Energy consumption reduction;
- Toxicity and harmfulness reduction;
- Bio-compatibility and resources conservation;
- Product life optimisation (extension and use intensification);
- Material life extension;
- Design for disassembly.

Since marble and granite come from non-renewable sources the focus of the present study was on the approaches for "material life extension", particularly the scrapped material, which otherwise would ending up in landfills or as concrete aggregate. The "cascade approach" is one of these approaches and involves [5]:

- Arrange and facilitate the recycling in components with lower/different mechanical requirements.
- Arrange and facilitate the recycling in components with lower/different aesthetical requirements.
- Arrange and facilitate energy material recovery.

Recycling secondary raw materials such as the production waste of marble and granite manufacturers presents various environmental advantages. Firstly it avoids the environmental impact of disposing of materials in landfills. That is particularly relevant in South America where there is great lack of adequate waste management in most cities. Furthermore, resources are made available for the production of new stone based products, avoiding the impact from the extraction and processing of a corresponding quantity of materials from virgin natural resources.

Also, from an environmental point of view design for the extension of the lifespan of materials through a cascade approach does not mean simply choosing materials with efficient recycling or combustion technologies. A designer must devise solutions that facilitate all the stages of recycling and re-design, facilitate collection and transport after use, facilitate the identification of materials, minimize the number of incompatible materials, facilitate separation of incompatible materials and facilitate their cleaning.

From an economical point of view the cascade approach also offers various advantages, particularly on those sectors such as stone manufacturing where there is growing prices for raw material and increasing difficulties to access material sources due to the enforcement of tougher environmental legislation. In other sectors, the legislation has forced the adoption of end-of-use logistics and that has induced a more intensive use of the cascade approach as a design strategy. In Europe, for instance, the take-back laws require the manufacturer to take part in the recovery process, making them to be involved in the "end-of-life" phase of their products' life cycles [6]. Thus, an important economical benefit of the cascade approach is the possibility of income generation though new businesses at the end-of-use stage.

Indeed, according to Kumar et al. [4] when the product reaches the end-of-use there are two possible destinations (a) sell the product on a secondary market (its market viability could address the entire product or its parts) (b) sell the product for reprocessing the raw material. Material reclaimers also have the option to send the material to landfill. However, this is an option to be avoided as landfill sites become increasingly difficult to implement, particularly in those regions close to large urban areas, and it is not consistent with the principles of sustainability. Hence, planning such destinations already at the design stage offers the opportunity of increasing the economical value of the material's life cycle extension.

3. Research method

The study of creative solutions for the waste generated during the production of marble and granite product demanded a real world situation. In this research the real world setting was supplied by the Union of Marble and Granite Producers of the Paraná State (SIMAGRAN), Brazil. This union comprises 13 small companies that have never export and intended to increase their competitiveness through the application of sustainable design on their products.

The case study involved two main phases where the first phase involved the characterization of the waste on all 13 marble and granite companies. This phase included a detailed evaluation of their current solutions on waste-based products designed by the company owners themselves. Characterizing waste was a challenge since there was a large variety of shapes and to tackle this problem the authors have adopted Wong's [10] design elements as the analytical structure.

The second phase involved the development of products with LCD principles with special attention on avoiding waste or generating design solutions that could enhance its value. The range of products went from bathroom sinks and living tables to children games. The idea of this phase was to provoke the companies on the effectiveness of adopting a cascade approach to their waste and, by doing that, increase the external validity of the concept.

4. Results and analysis

4.1. First phase: waste characterization

Usually marble and granite boards present a rectangular shape where 400×200 cm is the most common dimension. The design and manufacturing process followed a make-to-order style with operations initiated only when there was a firm order from a client. On the other hand, in order to provide the requested products in short time each company maintain a large quantity of raw material. The immediate consequence is a visible surface deterioration due to long storage, although this deterioration is reversible through additional polishing.

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The sidelines of these boards presented a fractured structure due to the use of explosives on the cutting process on quarries. As a consequence the material on these areas presented weak structural qualities and always ended up as a scrap material (see illustration on the next Figure). The technology adopted to process the stone boards on all 13 companies presented a reduced variety of machines. Saw machines were the most common equipment to cut the stone both on straight lines as well as curved or elliptical ones Fig. 1.

The design solutions and the technology adopted by these companies generated a large amount of waste. Most waste was composed of small peaces with dimensions between 10 and 20 cm with irregular shape and always with 2 cm of thickness. Smaller stones were discharged to containers and then used as raw material for construction work or to produce wall finishing such as mosaics.

The precision of the cutting process relied heavily on the experience of the operator. As a consequence, even on those cases where the waste could achieve a homogeneous shape the waste was highly variable. The finishing phase generated a large amount of waste on small and irregular shapes, particularly on curved areas. However, it was at the initial phase of the manufacturing process that produced the most usable residues. The shaded areas on Fig. 2 illustrate the typical shapes of waste derived from bathroom and kitchen products. The larger peaces presented better condition on their side lines and, in turn, better perspectives for re-processing.

It is important to notice that the profit margin obtained on the main stone product was so large, often beyond 30% that most companies did not look at the economical value of their waste. In fact, most of them give away their waste in exchange solely for its transport away from their factory. During the dialogs with company directors it was there was clearly a lack of environmental conscientiousness regarding the impact of stone extraction. Only on two companies the study has revealed a pre-planned set of solutions for this waste, as Fig. 3 – illustrates.

Company directors revealed that the most advantageous solution for their waste so far was to produce small mosaic panels such as the one presented in the next figure. The process was rather simple since involved only cutting and gluing operations over a cardboard base. These mosaic panels could be customized to specific designs arrangements and required the same mortar used to fix normal ceramic tiles. Some of these panels received further polishing when the client demanded flat surfaces but the trend at the time of this research was to present the imperfection of the stone as a value adding attribute.

It is important to mention that the Brazilian market lacks machines dedicated to process these particular tasks on stone waste and the prices for buying such machines on the international market were prohibitive at the time of the research. As a result the research team witnessed a widespread practice of improvising manufacturing operations.

Base on this field investigation the research team has concluded that most product design solutions already in use by the companies were requiring excessive additional processing and, worse, often demanding the use of a polyester resin to produce glassy surfaces. Thus, the focus of next phase of the research was on the developing design solutions for waste recycling, focused on the typical shapes illustrated on Fig. 2. Such solutions have to demand a minimum amount of additional processing and, at the same time, avoid polyester resin or any other additional material.

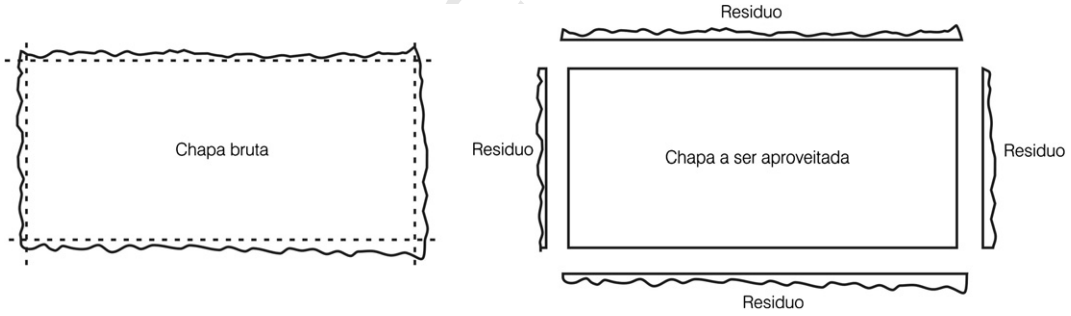

Fig. 1. Typical aspect of fractured structure cutted in every marble/granite board.

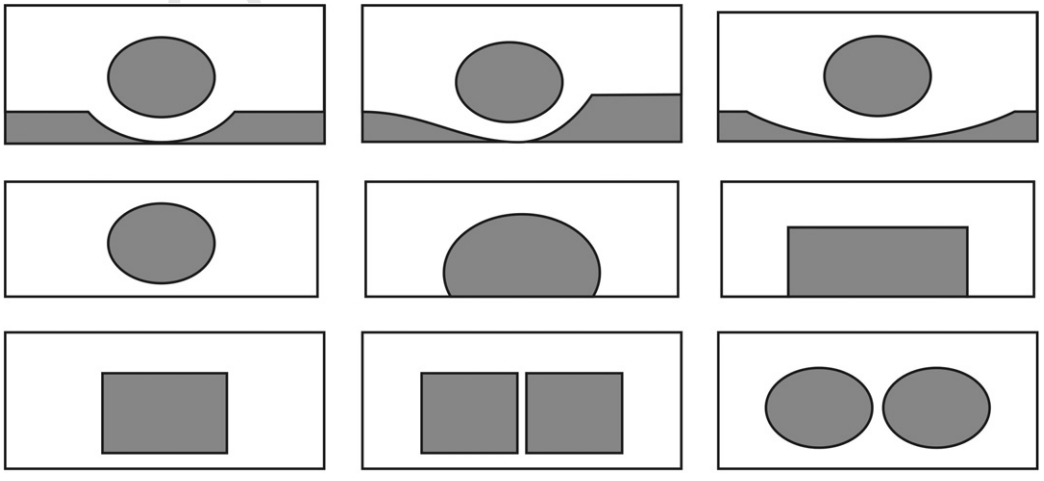

Fig. 2. Typical shapes of waste derived from kitchen and bathroom sink production.

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Fig. 3. Example of a waste-based product designed within one of the companies (vase and a Table).

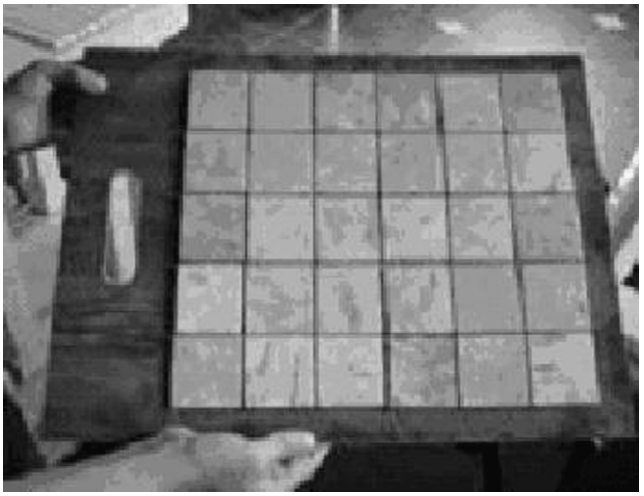

Fig. 4. Panels of mosaics produced from waste of stone.

Fig. 5. Example of produce designed with a focus on the cascade approach.

4.2. Second phase: development of sample products

This phase focused on the design of solutions for export markets, particularly the American and Canadian markets, following a demand from the partner companies. The field research that set the product requirements for these markets involved a literature review, market research on the internet and support from experts of export agencies in Brazil. Twenty-seven design solutions resulted from the design process and the partner companies chose to produce 13 of these solutions. One of them is illustrated on the Fig. 3 below.

The left image represents the virtual product in its original concept and the right image is the product actually produced by the companies and presented at the NeoCon East Exhibition, on the Baltimore Convention Center, Maryland, USA. The theme of the exhibition was "Inspiring Solutions for the Design and Management of the Built Environment". That exhibition enabled the researchers to validate the quality of the design solutions regarding its proximity to client expectations Figs. 4 and 5.

The planning of recycling solutions for the waste generated on the production of these products focused on two groups of waste. The first group includes that waste originated on pieces of stone located outside of the product perimeter. These stones were very irregular and it would be difficult to make commitments to clients regarding shapes, colors and the exact dimension of products. Every product produced out of these waste would have at least a number of subtle differences from other similar products even within the same design solution (see on Fig. 6 a sample of products that have been created by the research team).

Finally, for the inner part of the main product perimeter the research team has developed a number of pre-set solutions that could be adopted by these companies when anticipating what to do with the waste generated with the production of their main product. Next figure illustrates a product developed for public toilet using waste from the marble/granite circle that comes out of every sink produced on the partner companies. It is important to point out that the directors of the partner companies declare that the origin of the raw material was never questioned by the customers. They pointed that design and stone color was the most common buying criteria for these waste-based products Fig. 7.

These solutions took advantage of the highly specialized skills of the stone workers. Also, these products have shown that it was possible to avoid or drastically reduce polyester resin used on the surface of previous products developed by the partner companies. What was considered as stone defects by the workers and company directors was re-positioned by the researchers and presented as a value adding attribute. Instead of attempting to hide the natural texture and color irregularities, for instance, the design team focused on alternatives to present these irregularities as signs of a unique product.

The solutions also include the use of carvings that replicate ancient petroglyphs over the irregular areas. The design team has searched for solutions that avoided the use of epoxy to bind stone components since it makes more difficult future changes in the product and reduces the opportunity for reusing stone components. Such goal was achieved by the intensive use of mortise, notches and wood/metal frameworks around the stone components.

Some of these "defects" included cracks on the stone surface derived from the extraction process. The rusticity of the surface has a

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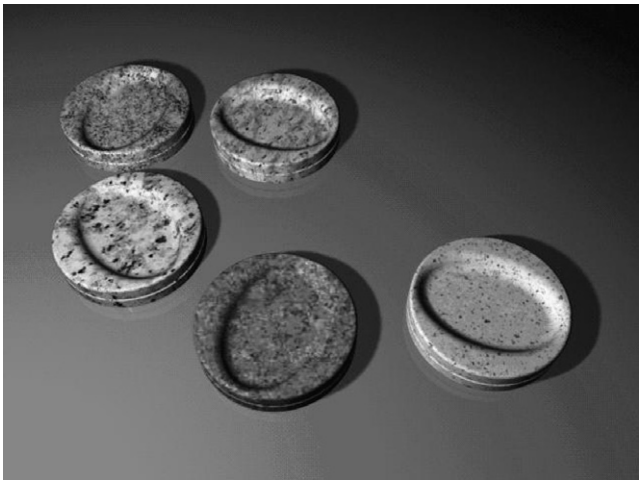

Fig. 6. Products developed for waste with irregular shape.

Fig. 7. Product developed with waste with more regular shape.

niche in the market for those people that appreciate the uniqueness of their product and the reference to the random aspects of stone surfaces in nature. Indeed, prior to this project it was common to observe workers polishing stone waste in both sides or polishing every single part of the waste-based product. The project developed a number of design solutions that used the irregular surfaces as a value adding attribute of a product and, at the same time, reducing the amount of resources used during the production process.

5. Conclusion

Since marble and granite come from a non-renewable source and with significant environmental impact during the extraction process, research efforts should be directed towards the actual reduction of stone production and consumption. That could be achieved by enabling an extension of the life cycle of stone based products or their substitution by materials obtained from renewable sources. In the meantime, as the research has shown, there is an urgent need for involving designers to tackle the issue of the waste that is certain to occur and where it is already known its shape and volume.

This project unveiled an important educative insight: marble and granite products have an important advantage in terms of disseminating some of the sustainable design principles because there is a very short lead time between the idea generation and the actual delivery of the end product. Thus, the validation of design solutions can be achieved in very short term, allowing designers to improve their solutions and enhance the implementation of sustainable design principles. For instance, in one of the companies it was possible to finalise the design process, from concept to the end product, in just one day.

This project unveiled that in a make-to-order industry such as the marble and granite sector, there is a clear opportunity to establish on-the-shelf solutions for waste, allowing a full implementation of a "cascade approach" for waste, at least on the manufacturing stage. However, there is relatively reduced literature regarding this material and further research is required in order to support this industry in the quest for a more sustainable approach for product development, particularly at the end of the life cycle of a building. Also, it was not identified guidelines on the literature that effectively enable easy repair of granite/marble based products throughout their life cycle as well as the implications of considering stone foreseeable pathologies already at the design stage.

The greater impact of design research in this situation would be on the initial stages of the creative process, focusing on how to achieve the requirements of the client and, at the same time, obtaining a sustainable product. A higher level of modularization and solutions that enable easier production and assembly are examples of design solutions that could contribute to achieve these goals.

6. Uncited reference

[7]. Q1

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