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# Experimental and Theoretical Modelling of Waste Produced by the Marble Industry of Tepexi de Rodríguez

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**Abstract**

Tepexi de Rodríguez is one of the municipalities with the highest rate of extreme poverty in Mexico. The agriculture and the marble extraction industry are the major sources of employment. This region has more than 15 processing factories of marble, where poor safety conditions of work, low salaries and pollution are common denominator. The marble residues deposit in the ground without control, deteriorate the vegetation, causes desertification and affect the health of the population. Actually, there aren´t researches about the amount of waste generated by this industry in Tepexi. The objective of this work was analyze theoretically through statistical formulas the amount of waste generate in the marble transformation and compare to the real residues obtain in a field test. The results show that 87% of the raw material is discarded, generate more than 60,000 cubic meters of waste per year. With this results, can be proposed that the blocks will be standardize, optimizing the raw material by 25% or more, decreasing the amount of residues and advantage the development of industry with a sustainable approach.

*Keyword:* Waste reduction, pollution, sustainable development, marble industry

## 1. Introduction

The Mixteca is a cultural, economic and political zone integrated by Mexican states: Puebla, Guerrero and Oaxaca. It is located in the south of the country and covers an area of approximately 40 thousand square kilometers. The habitants of this region call themselves *Ñuu Savii* (rain village), but commonly are known as Mixtecos (Mindek, 2003). The Mixteca is subdivided in three areas: "Mixteca Baja" (northwest of the state of Oaxaca and southwest of Puebla), "Mixteca Alta" (northeastern of Guerrero and west of Oaxaca) and "Mixteca de la Costa" (shared by the states of Guerrero and Oaxaca) (Guerrero et al., 2010). In spite of the richness with which it counts the region, according to the last census realized by the INEGI in 2010 the Mixteca Baja is one of the poorest population of Mexico (CONAPO, 2010).

The main economic activities of the place are: agriculture and the extraction and transformation of marble. The agriculture presents difficulties, the farmers depend on weather conditions for the achievement of their crops. The scarcity of rain, the snowfalls or drought causes losses, so that the population to depend on a single crop or activity does not guarantee their economic stability (Ramirez, 1998). In the other hand, the case of our study, the extraction and transformation of marble is limited, it requires economic investment and the acquisition of machinery is not affordable for the entire population.

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Most people work with minimum wages, few health and safety conditions (Garces et al., 2005). Annually in the area of Tepexi de Rodríguez is generated approximately $145,560\ m^3$ of waste (Cortes, 2015). These residues put them outdoors causing erosion and infertility in fields (Figure 1) and through decades of exploitation, these dumps have affected the visual environment of the municipality.

*Fig. 1 The ecological damage of the marble waste.*

The marbles are carbonated sedimentary rocks (mainly limestone) that a process of metamorphosis have reached a high degree of crystallization. Nevertheless, this denomination has extended to other semi-crystalline rocks, with or without calcium carbonate, supporting the polishing acquiring a brightness, like the green marbles. They consist of streamers without calcium carbonate, or the travertine that are sedimentary limestone rocks not metamorphic, or some type of limestone. Under microscope does not have structural orientation, is very compact, has more hardness, resistance and durability that the limestone (Secretaría de Economía, 2015).

There are various types of marble benches in Tepexi de Rodriguez. The "Dorado Tepexi" and "Travertino" marbles are the most abundant in the region, so these two types of marble are the most processed within the factories of the region. In the village there are more than 15 factories which work in an inadequate way, with various problems, such as working conditions, low wages, long hours and a culture that is not committed to the concept of sustainability. These factories have been working for over 50 years, so a change in their culture is a great challenge, they consider it a threat or an attack. But it really is an opportunity to standardize the work and optimize performance through a better use of raw materials (Baraza & Estrella, 2008).

The objective of this work was analyze theoretically through statistical formulas the amount of waste generate in the marble transformation and compare to the real residues obtain in a field test with the finality to demonstrate that when the raw material is extracted without using an extraction methodology the productivity of the factories decreases.

## 2. Methodology

Theoretical and practical studies were carried out concerning the production of marble tiles and the wastes generated by the nature of this work. The purpose is to compare the results obtained with those expected and thus to define whether or not an adequate handling of the raw material is being carried out. This study will define the current state of productivity of marble manufacturing factories and their relation to the environment.

### 2.1 Theoretical modelling

The marble block (raw material) is randomly extracted, for which it lacks a regular figure and is susceptible to generate much waste in a non-controllable way (Yeşilay et al., 2017) (Figure 2). To calculate the optimal production of each block it was decided to apply formulas that work using averages, in this way would obtain a new model with the volume of the block and its measures.

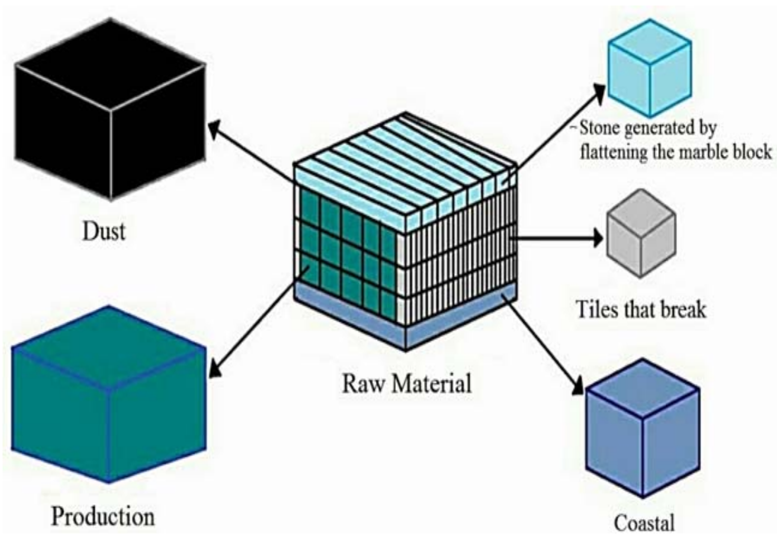


*Fig. 2 Graphical representation of the raw material and its derivates.*

Then the derivatives of the raw material and the formulas used to calculate their volume are defined.

*1. Volume of dust generated by the vertical disk during the process of flattening the marble block.*

The flattening process is performed in order to obtain layers with a uniform height, it is proposed to use the equation 1:

$$B = \bar{X}\bar{R}\left(\frac{\bar{Y}}{n+m}\right)n \quad (1)$$

*2. Dust generated by both discs during the process of cutting the layers.*

A layer of the marble block is defined as a group of sheets that share characteristics, with the aim of producing similar tiles. The equation 2 describes the dust residues generated in this process:

$$C = \left(\bar{X}L\left(\frac{\bar{Y}}{n+f}\right)nd\right) + (p\bar{X}\bar{Y}(d+1)) \quad (2)$$

*3. Volume of dust generated by polishing of tiles.*

Since the polishing process consist of roughing the marble. The equation 3 describes the dust that generates by this process:

$$H = L\bar{X}(f-i)(\left(\frac{\bar{Y}}{n+f}\right)+1)d \quad (3)$$

*4. Volume of dust generated by cutting the tiles.*

Cutting the marble is necessary for it to have a regular shape, in addition to the tiles being able to tie together. The equation 4 describes the dust generated by the cut:

$$J = Ld(k+1)w\left(\frac{\bar{Y}}{n+f}\right)i \quad (4)$$

*5. Volume of tiles that break.*

The tiles that break currently used to produce smaller tiles than ordinary ones. To calculate its volume the equation 5 is applied:

$$V = \bar{X}\bar{Y}\bar{Z} - ((\propto * i) + A + B + C + G + H + J) \quad (5)$$

6. *Volume of the coastal (commonly named).*

It is a stone plate that is left over when finishing processing the block marble. Its volume can be calculated with equation 6:

$$G = (\bar{Z} - \bar{R} - (Ld) - (p(d+1)))\bar{X}\bar{Y} \quad (6)$$

7. *Volume of stone generated by flattening the marble block.*

Due to its dimensions this waste becomes little appropriate to obtain a benefit of it, sometimes can be bought by some workshop or are used as fill in large fields. Its volume can be calculated with equation 7:

$$A = (\bar{X}\bar{Y}(\bar{R}-p)) - B \quad (7)$$

*8. Production.*

Is necessary to calculate the volume of production, to make a comparison of actual and expected production. Its volume can be calculated with equation 8:

$$Q = LLkdi\left(\frac{\bar{Y}}{n+f}\right) \quad (8)$$

Where the variables can be divided into the following items

Concepts:

$B =$ Volume of dust generatedby the vertical disk during the process of flattening the marble block, $C=$ Dust generated by both discs during the process of cutting the layers, $H =$ Volume of dust generated by polishing tiles, $J =$ Volume of dust generated by cutting the tiles, $V =$ Volume of tiles that break, $G =$ Volume of the coastal, $A =$ Volume of stone generated by flattening the marble block, $Q=$ Production.

Machinery factors:

$n =$ Width disk vertical, $p =$ thickness of the disk horizontal, $W =$ width disk remove short the tiles.

Raw material factors:

$\bar{X}=$ Average block length, $\bar{Y}=$ Average block width, $\bar{Z}=$ block high average.

Process factors:

$\bar{R}=$ Average height from the flattened, $m =$ Flattened ingot widt, $f =$ Width of the tile

before polishing, $L =$ High of layers, $d =$ Number of layers, $i$= Width of the tile after polishing, $k =$ Tiles obtained by slab, $\propto$= Square meters of tiles total.
This theoretical model was previously evaluated (García et al., 2016), however the equations presented here were modified with the purpose of adjusting them to the reality of the waste generated.
Know the volume of the block, became a relevant factor to determinate the maximum that can be obtained from each one, in a theoretical way and the actual percentage that is taken advantage of each block. In this way, can calculate the average amount of wasted generate in the factories just for the reason that raw material is not standardized. The formulas were applied in three different factories. The use of raw material is random in the three factories, so it is not relevant to make a comparative, because there is no methodology to acquire raw material and the purchase of this is completely random.

## 3. Experimental Measurements

*Fig. 3 Block measurement.*

Measurements were made on the dimensions of the marble block (Figure 3), the dimensions of the finished product and on objects that have a direct relationship in the tile manufacturing process, especially the cutting discs that are the ones that make the slab thinning.
When measuring these blocks was a big problem and this is that the blocks did not have a regular figure, besides there were notable differences between one block of marble and another. Due to this it was decided to analyze marble blocks individually and compare them with the theoretical model to make a comparison between the real and the ideal. Because the raw material is not standardized the factories have a great uncertainty about their production since there is no methodology for the acquisition of raw material.

## 4. Results

Next the results obtained in the following Table 1 are shown:

**Table 1:** ANOVA

| SUMARY | | | | | | |
|---|---|---|---|---|---|---|
| *Groups* | *Count* | *Sum* | *Average* | *Variance* | | |
| Theoretical | 16 | 5.337846 | 0.333615 | 0.00167 | | |
| Real production | 16 | 2.66 | 0.16625 | 0.004251 | | |
| ANOVA | | | | | | |
| *Source of variation* | *Ss* | *df* | *MS* | *F* | *P-value* | *F crit* |
| Between Groups | 0.224089 | 1 | 0.224089 | 75.673 | 1.057E-09 | 4.170876 |
| Within Groups | 0.088838 | 30 | 0.002961 | | | |
| Total | 0.312927 | 31 | | | | |

An analysis of variance was carried out in order to compare the theoretical results with respect to the practical ones, because the F is higher than the F crit, we decided to reject the null hypothesis, for which we can affirm that there is no trend of the theoretical model of the blocks with respect to the actual production of each block of marble.
By calculating the monthly production of the marble manufacturing factories, it is concluded that at present they produce approximately $1{,}152\ m^3$ monthly of tiles.
However, if the factories produce that volume of finished product that corresponds to 16% of the block of marble would mean that they are producing 84% of the waste that is equivalent to $6{,}048\ m^3$ of monthly residues. This means they produce 5 times more waste than tiles.
The raw material is being used 16% if the blocks had a regular shape would be used up to 32% on average (Figure 4), this means producing double with the same amount of marble, thus increasing its performance.

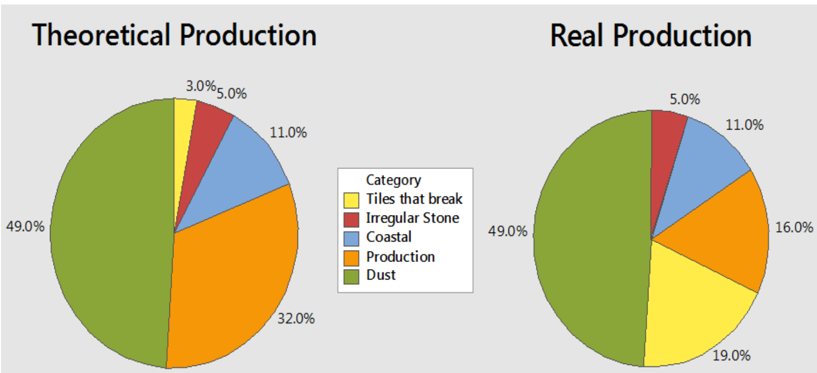

*Fig. 4 Theoretical and real expected output of the raw material.*

In addition to all this, there are cases in which it can be extracted with the desired dimensions, when this happens it will be possible to use up to 40% of marble if the average extraction is normalized, in some circumstances it will be possible to take advantage of more and in others less, That will depend directly on how sophisticated the work team.

## 5. Discussion

Theoretical data showed that on average the raw material used by the marble manufacturing industry should produce on average 32 % of tiles compared to the volume of the block. Unfortunately, the practical measurements showed that only 16 % of production is produced on average compared to the total volume of each block. This situation arises because the entrepreneurs prefer to buy amorphous blocks because they are cheaper in the market, these blocks are the result of fissures in the marble benches by the use of explosives to carry out their extraction.

Because the raw material lacks specific dimensions and a standardized form, it can be said that really, the use of the raw material of each factory it was just a case of luck and really the three companies are in the same situation and that is why we cannot say that one is better than the other. Analyzing the data collected in a general way we can observe that the marble block lacks a regular figure so it reduces the production of the factory by an average of 16%.

At present there is a controversy about whether or not the mining industry has the capacity to be sustainable (Aukour & Al-Qinna, 2008). Irrespective of whether or not these companies have this ability, it can be assured that a methodology is needed in the region for waste management, one of the duration of the quarries and a standardization of the raw material to optimize the production and use of these resources (Letelier et al., 2005). The acceptance of this methodology presents a great challenge for the factories, since in some cases it proposes a change in the machinery and other factors that influence the extraction (Bacarji et al., 2013), the advantage in the change of the machinery is that the item would become safer in addition to these tools decrease the extraction costs and reduce environmental impact.

## 6. Conclusion

The bad agreement was seen between our analytical model and experimental results, with a big difference, since, the marble factories produce as a finished product that corresponds to 16 % of the block of marble, are producing 84 % of the waste that is equivalent to $6{,}048\ m^3$ of monthly residues.

The poor relation between the data is due directly to the fact that the raw material has a lack of a regular figure, which is why there are losses greater than expected, Due to this the industry of marble manufacturing within the village becomes an area with a very large area of opportunity. The larger benefit would be reflected in our ecosystem, as it would drastically reduce the production of waste, and economically speaking it could produce up to 5 times more per block in some cases.

The direct benefit to the environment is that now more will be produced with less raw material, since a block of marble was used at least 8 %, and can now be used up to 40 %, thanks to which it will be possible to reduce production of waste could also optimize the marble banks, know their life time and could be standardized and optimized times within the factories.

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