

ACTIONS FOR A SUSTAINABLE
WORLD
FROM THEORY TO PRACTICE



BOOK OF PAPERS



**THE 24th INTERNATIONAL
SUSTAINABLE DEVELOPMENT RESEARCH
SOCIETY CONFERENCE**
MESSINA · ITALY JUNE 13/15 2018

The 24th International Sustainable Development Research Society Conference (ISDRS 2018)

ACTIONS FOR A SUSTAINABLE WORLD: FROM THEORY TO PRACTICE

13-15 June 2018, Messina (Italy)

BOOK OF PAPERS

Edited by: The Organizing Committee of the ISDRS 2018 Conference

ISBN 978-88-943228-6-6

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Piazza Pugliatti, 1 – Messina (Italy)

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Ecological tiles from Urban Waste Glass and Construction & Demolition Waste

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Abstract

In 2014 Total Waste generated in the EU-28 by all economic activities and households amounted to 2495 million tonnes (mt), 491 mt of which composed of Construction and Demolition Waste (CDW) (Eurostat, 2017). From the perspective of circular economy, building rubbles and other urban waste should be transformed and reused for the production of second raw materials to obtain new building materials, reducing also the consumption of virgin raw material from quarries and the energy necessary for their transformation into intermediate products for construction. Aim of this work is to evaluate the environmental and economic sustainability to produce tile containing a high quantity of CDW and glass waste. Here we report the results obtained by the ECO TILES EU-Life project aimed at designing ecological grit-tiles (commercially known as *terrazzo* tiles). The project is a collaboration between the University of Camerino (Italy) and the Italian company Grandinetti Ltd. (GRA). The *terrazzo* tiles are cement-based products traditionally made with limestone aggregate and powder, which in ECO TILES are substituted by glass and CDW for up to 70% of the components. The methods adopted for this research activity are the following: analysis of the components and evaluation of the ECO TILES products, full Life Cycle Assessment (LCA), questionnaires and interviews to determine the propensity of consumers to purchase recycled tiles, surveys on a sample of Italian companies producing *terrazzo* tiles and a case study of the production cost of ecological grits per square meter. The project demonstrated the possibility of manufacturing *terrazzo* tiles starting from second raw materials obtained by selected wastes capable of: 1) providing the same technical performance as conventional tiles; 2) improve the production chain from an environmental point of view, shown by the results of Full LCA proving that the environmental impact during their production is significantly lower than the traditional *terrazzo* tiles; 3) maintain economic sustainability for the enterprise and 4) meet market demand for ecological tiles. Consumers think that ECO TILES is an innovative way of recycling waste and are willing to pay an increased sale price than traditional grits. ECO TILES production method can reduce environmental impact and overall improvement of quality of life with production costs comparable to traditional tiles. The results stimulate the adoption of the virtuous circular economy policies in the construction sector: to favour consumer preferences over recycled products, to encourage companies to provide environmental quality assurance for the products and to certify the environmental traceability of raw materials used and production method adopted.

Keywords: Ecological tiles, CDW recycle, Circular economy.

1. Introduction

The construction sector is the most resource intensive in the EU with its heavy impact on the environment. The construction sector produces waste and consumes soil for landfills. The lack of recycling waste materials to produce new materials consumes the geological resources, makes low use of virgin material potential and reduces product life cycle. Focusing on the use of secondary raw materials is as important as ever

Consumers are targeting products manufactured in accordance with environmental friendly processes and sustainable natural raw and/or derivative materials. When selecting domestic interior flooring, consumers are increasingly oriented towards products that meet bio architectural standards, aesthetic quality, tile technical standards and the ability to trace the origins of the raw and derivative products used.

Businesses are also interested in using “*terrazzo*,” ecological tiles for flooring in areas subject to elevated wear and aggressive chemical stress such as schools, railway stations, airports, hospitals, offices, shopping centres etc. as well as the need to adhere to the Green Public Procurement norms.

Valentino Grandinetti, owner of Grandinetti, limited liability company which produces ecological *terrazzo* tile and partner in the research project LIFE EcoTile, reminds us that “*Consumer interest in eco sustainable products is also increasing in the building trade. This is true not only in Italy but in Europe in general. Only recently, a Japanese customer ordered two thousand square metres of EcoTile Standard terrazzo tiles, with coloured base and transparent glaze. On the explicit request of the customer, “terrazzo tiles with glass aggregates” was written on the sales invoice for these tiles*”.

Today the demand for ecological floorings is still limited. Consumers relate more readily to environmental sustainable processes when dealing with food products or ecological parquet flooring as they consider trees raw material produces. However, on the other hand in the case of ecological *terrazzo* tiles consumers find it less easy to trace the source of the raw materials and the reduction of energy needed to extract and manufacture the final product. Overall and in general, a building consists of several products and the environmental sustainability of just the tiles does not seem to convince the consumer of the improvement in internal air and environment quality that the consumer breathes. According to retail tile vendors over the next three to five years, the demand for ecological products is estimated to grow very slowly and is at risk according to current forecasts.

EcoTiles ecological products together with other building sustainable items may be an attractive solution to contribute to and face the refuse handling processes in the construction sector along with the demolition of buildings to reduce consumption of raw virgin quarry products. At a first glance, EcoTile values the presence of urban and industrial green and/or blue glass recycling which contribute to environmental depth and colouring of top levels.

A Single Layer EcoTile contains 77% of its weight as recycled glass granulated and powder. The Double Layer EcoTile adds a second layer to the bottom level which is composed of 35% cement and 75% construction and demolition waste CDW in the building sector (ceramic and brick work, construction and demolition waste) recycling derived materials.

In fact, EcoTile began life as a traditional *terrazzo* tile. Known throughout the world under different names (*terrazzo* tiles, baldosa, etc.) *terrazzo* tile was one of the first flooring solutions created from the chips resulting from the marble/limestone industry, mixed with cement and coloured with pigments. *Terrazzo* was originally invented by Venetian construction workers around 1500, which started using waste marble from extraction activities as aggregate.

Eco Tiles production process complies with tradition and is eco sustainable. The materials used, granulated materials were originally poor products. Energy consumption was limited for all operations. Recycling reduced the impact on the environment to meet Global Warming Potential (GWP), by 19% for single-layered tiles and 11% for double-layered tiles in comparison with traditional *terrazzo* tiles.

Table 1. Generation of waste by waste category, tonne, 2014.

		European Union		Italy	
Total Waste	TW	2 494 700 000		159 107 169	
Metal wastes, ferrous		75 130 000	15.3%	8 365 509	15.3%
Metal wastes, non-ferrous		8 730 000	1.8%	1 049 595	1.9%
Metal wastes, mixed ferrous and non-ferrous		13 230 000	2.7%	541 474	1.0%
Glass wastes		18 500 000	3.8%	2 731 525	5.0%
Plastic wastes		17 040 000	3.5%	3 342 544	6.1%
Wood wastes		50 280 000	10.2%	4 421 054	8.1%
Mineral waste from construction and demolition	MW	308 470 000	62.8%	34 225 640	62.6%
Total Construction and Demolition Waste CDW	TCDW	491 380 000	100.0%	54 677 341	100.0%
<i>MW / TW</i>		<i>12.37%</i>		<i>21.51%</i>	
<i>CDW / TW</i>		<i>19.70%</i>		<i>34.37%</i>	

Last update 26.10.17, Extracted on 23.02.18, Source of data Eurostat, UNIT Tonne, HAZARD Hazardous and non-hazardous - Total, NACE_R2 All NACE activities plus households, TIME 2014.

In 2014 Total Waste generated in the EU-28 by all economic activities and households amounted to 2495 million tonnes (mt) (Table 1), 491 mt of which composed of Total Construction and Demolition Waste CDW (Eurostat, 2017; EC, 2000). The percentage of Mineral waste from construction and demolition (MW) on Total Waste (TW) is 12.37%, whereas the percentage of CDW on TW is 19.70%. In 2014 Total Waste generated in Italy amounted to 159 mt, of which 55 mt as Total CDW. The percentage amount of MW on TW is 21.51%, instead the percentage of CDW on TW is 34.37%. As it might be expected, the

overall amount of waste generated can be related to some extent to the population and economic size of a country. In general, the smallest EU Member States generally reported the lowest levels of waste generation, the larger ones the highest.

The share of different economic activities and of households in total waste generation in 2014 in the EU-28 is composed as follows: construction contributed 34.7 % of the total, followed by mining and quarrying (28.2 %), manufacturing (10.2 %), waste and water services (9.1 %) and households (8.3 %). The remaining 9.5 % was waste generated from other economic activities, mainly services (3.9 %) and energy (3.7 %) (Eurostat, 2017). A lot of the waste from mining and quarrying and from construction and demolition is classified as major mineral wastes (Eurostat, 2017), accounting for almost 2/3 (65.8% or 3.2 tonnes per inhabitant) of the total waste generated in the EU-28 in 2014. The relative share of major mineral wastes in the total waste generated varies considerably between EU Member States, which may reflect, at least to some degree, different economic structures. In general, the EU Member States that had higher shares of major mineral wastes were those characterized as having sizeable mining and quarrying activities - such as Bulgaria (90.05%), Sweden (88.96%), Romania (88.29%) and Finland (85.72%) – and/or construction and demolition activities, such as Luxembourg (87.28%), Liechtenstein (92.48%) and Serbia (85.00%) (Eurostat, 2017). Major mineral wastes accounted for less than 1/5 of all waste generated in Croatia (17.75%), Portugal (15.58%), Norway (17.68%) and the Former Yugoslav Republic of Macedonia (5.42%) (Eurostat, 2017). Italy is in an intermediate position and shows a value of 32.31%.

These data show that there is an urgent need for EU countries to start dealing in a more comprehensive manner towards ways to reduce the production of this waste but also to find new applications for its recycle. In fact, from the perspective of circular economy, building rubbles and other urban waste should be transformed and reused for the production of second raw materials to obtain new building materials, reducing also the consumption of virgin raw material from quarries and the energy necessary for their transformation into intermediate products for construction.

In construction, circular economy involves reducing the demand for non-renewable virgin materials, limiting the production of waste and maximizing the value of recovered materials used. However, from the viewpoint of the environment as a whole, circularity needs to be examined across other systems, including energy, water, operational waste management, ecology, food, etc.

The Circular Economy Package (CEP) increases the durability and recyclability of building components using building design improvements and pre-demolition and renovation waste audits (Wojciech 2017). CEP promotes the best practices throughout the Protocol and Pre-demolition/renovation audits. Construction and demolition waste (CDW) treating Recycling of CDW encouraged by a mandatory target - achievable target of 70% by 2020 for all member states (Waste Framework Directive WFD; EP 2008) - of sector actions of the CEP Action Plan and promoting the best practices in recycling of CDW.

The Action Plan implementation will boost the EU's competitiveness by protecting against resource scarcity and volatile prices, helping create new business opportunities through innovative and more efficient production methods (EC 2017a) and will save energy and prevent over-exploitation of finite resources.

The Action Plan has been organized into five key areas of action (plastics, critical raw materials, food waste, biomass and bio-based products and construction and demolition waste) and five priority sectors. Measures covering the whole life-cycle of products from production and consumption to waste management and the market for recovered secondary raw materials.

As far as the climate is concerned the following efforts to encourage clean air in buildings have been implemented. Construction of new buildings or retrofitting buildings to render them more energy-efficient, rethink construction and demolition practices and to take into account broader resource efficiency aspects. The aim is to generate less construction and demolition waste and to facilitate materials recycling (Wojciech 2017).

CDW has been identified by the EU Commission as a priority of the CEP Action Plan due to the huge amounts generated without excavation soil and the high potential for re-use and recycling embodied in these materials. Only 50% of CDW is

recycled today in the EU (Wojciech 2017). In the CEP Action Plan the recycling of material within the construction sector is encouraged.

However, from the point of view of Fellner et al. (2017) it is unclear to what extent recycled materials can contribute to overall demand and whether circularity is realistic in this sector. Fellner et al. (2017) stated that the EU's material stock is still increasing at a significant rate, indicating material inputs into the economy are much larger than outputs. For a circular economy this implies an inherent limitation for the substitution of primary raw material through secondary ones.

CDW management underlines the lack of confidence in CDW quality (EC 2017b). This is a main hurdle for CDW management in the EU. Uncertainty about the quality and safety of secondary raw materials in comparison to virgin materials is a barrier to the development of markets for these types of materials. The CEP Action Plan (EC 2017a) is addressing this through the development of EU-wide quality standards for secondary raw materials and assessment of how chemical products and waste legislation can best work together. Moreover, a better knowledge and monitoring of CDW management actual practices needs to improve data/statistics collection and consistency with EUROSTAT (Wojciech 2017).

Europe still lacks structured networks for the collection and re-use of CDW and manufacturing waste in a formal value chain (as is the case of glass or metal waste).

The LIFE ECO TILES project promises full compliance with European directives and regulations to fully respond to the recommendation of art.1(55) to adhere to the sustainable use of resources and energy economy for construction works, their materials and components in Regulation No 305-2011 on the Marketing of Construction Products (Construction Products Regulation). The LIFE ECO TILES project meets the Energy Performance of Buildings Directive (COM 2008/780) whose main objective is to promote the cost-effective improvement of the overall energy performance of buildings, included embodied energy. LIFE ECO TILES is in line with WFD 2008/98/EC (EP 2008) adding value to CDW management in saving the natural resources, low material consumption, low transport costs, low emissions, low cost for landfills and preserving the environment and human health. LIFE ECO TILES aims to reduce extension of landfill area for CDW, reducing environmental impact derived e for this reasons satisfies quality and control measures of the EU Landfill Directive (1999/31/EC), aiming at limiting the impact of toxic, hazardous waste and disposing it safely.

LIFE ECO TILES aims to offer building productions that contribute to the reduction of refuse in building construction and demolition destined for landfills. In the Italian Region of the Marche and following an earthquake in 2016, the CDW dramatically increased and represented a notable environmental problem; this problem was highlighted and due in part to the minimal efforts to reuse this rubble.

2. Materials and Methods

2.1 Materials

Three different typologies of ecological tiles were designed following precise dimensional and aesthetic parameters, and respecting the technical norms of the *terrazzo* tiles. More specifically, the “standard” ECO TILE correspond to a traditional plain *terrazzo* tile where, however, up to 77% of the mixing components are obtained from secondary raw materials (Figure 1). The “extra ware” ECO TILES are designed to enhance the performance of the product in terms of resistance to abrasion, absorption, etc. by adding glass powder or ceramic waste to the mix, thus creating products for specific high traffic environments. The “design” ECO TILES are customizable in a wide range of colours and patterns in order to fit every consumer's request, both aesthetically and architecturally. Each typology is available into several subtypes in order to take into consideration the quantity of waste aggregate included, the inclusion of different waste powders, a variety of design stiles. All the types are also available in both the single layer and double layer versions (Figure 2).

The Single Layer tiles are made of just one layer, polished at the surface, composed of recycled glass fragments, cement, pigment and a powdered material (where marble and quartz powder can be substituted by ceramic or glass waste). The Double

Layer tile adds to the bottom a second layer composed of a mix of 25% cement and 75% grinded CDW. The Single Layer tile is thinner, lighter and it is more suitable for the preparation of the “design” tiles. Double Layer tiles are heavier and sturdier, a perfect fit for the “extra ware” type and for high traffic environments.

Some demonstrative samples were produced in order to survey customers and stakeholders appreciation for this novel tile product. The survey lead to a general positive response on the ECO TILES demo products and interesting remarks which helped to improve the demo production towards approaching the industrial phase.

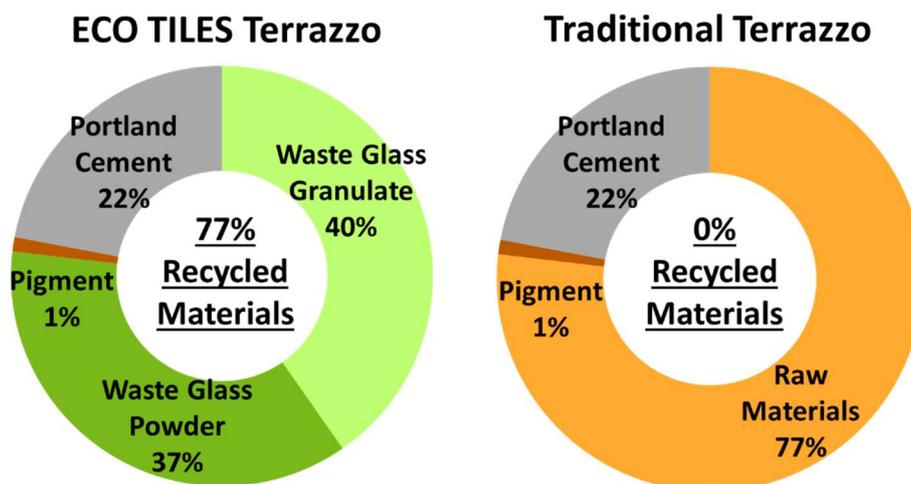


Figure 1. Calculation of raw material usage in a single-layer ECO TILES ecological tile and a traditional terrazzo tile.

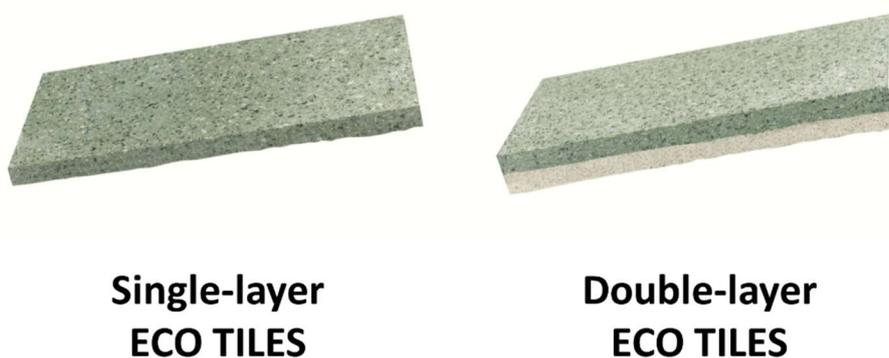


Figure 2. On the left, a Single Layer tile containing up to 77 % of recycled secondary raw materials and, right, a Double Layer tile that adds at the bottom a second layer composed of a mix of 25% cement and 75% grinded CDW.

2.2. Life Cycle Assessment (LCA)

A full LCA analysis has been carried out on the ECO TILES products. As the Life Cycle Assessment must evaluate potential environmental impact of technological systems, it must take into account environmental impact of main sources consumed in

production phases, as well as the by products and wastes that are main outputs of the production process phases. For these reasons it generally starts with the compilation of relevant environmental changes during the life cycle of a product which have any impacting (negative) effect on environment and human health. One of main parameter to describe the environmental impacts is referred as the Global Warming Potential (GWP) measured as kgCO₂eq emitted by a process, which it is estimated and calculated for all the exchanges with environment. The environmental impact of process exchange is expressed in terms of kilograms of CO₂ that would cause similar impact in atmosphere.

The leading standards used for performing LCA analysis are ISO 14040 and 14044. In particular, ISO 14040 outlines the general principles and framework, while ISO 14044 provides requirements and guidelines. The CCalC software tool used to perform the LCA in this research allows for the model being built to follow the ISO standards closely (Goedkoop et al., 2010). The CCalC software, a specific tool developed by University of Manchester reviewed with the collaboration of several industries, is based on two databases for material and energy inventories, the specifically developed CCalC database and the Ecoinvent database. The two databases tabulate a detailed inventory of system inputs and outputs, determining the impact of each of these on the environment using an impact assessment method made available to the analyst.

The ECO TILES LCA study took in consideration the environmental impacts of all the phases going from the raw material supplying to the realization and disposal of end-of-life tiles for both traditional and ecological *terrazzo* tile. The traditional process was analysed from quarry operation, related to the production of marble, to realisation of *terrazzo* tiles and final disposal. For example, the ECO TILES process starts from the operations needed to make urban waste glass and CDW suitable for reuse, and then considers all the steps needed to create the final ECO TILES product. Particular attention was given to the transportation phase of the components from the vendors to the tile producing company, which accounts for a large part of the GWP values. For this analysis the usage phase was not taken into account since there is no difference in application between the traditional tiles and the ECO TILES final products.

However, the end of life phase is also a central point of the analysis, since in the traditional process the post-consumer tiles are landfilled, while the ECO TILES technology will be based on the recycling of construction & demolition waste, thus representing the main innovation and one of the most environmentally-friendly aspects of the project.

2.3 Market and economic analysis

Market analysis scenario was inferred by analysing the demand and the supply of the ECO TILES products. A survey about the demand by general consumers of conventional and ecological tiles was conducted using two main channels: evaluation questionnaires and face-to-face interviews with leading Italian experts/retailers in the field of high quality decorative materials.

A series of questionnaires were redacted and distributed by the ECO TILES team, in 2016-17, in order to evaluate the interest in new ecological grit production. A total of six different versions of the questionnaire were prepared: three versions corresponding to different target economic subjects (residential private customers, distributors and architects) were designed, each available in Italian and in English. The distinction of the targets was crucial in order to have an overview of the economic subjects involved in the commercial phases of tile life: the distributor or tile retailer, the architect or tile aesthetic evaluator and consumer consultant, the customer or tile end-user.

In order to understand and thus foresee at least partially the trends of ecological-tiles market demand on consumers' attitude towards traditional and ecological cement-tile, complementary to the questionnaires, interviews were carried out, using a list of structured questions, to four leading Italian retailers in the field of grit and high quality decorative materials. The retailers were prone to the introduction in the market of ecologically-sound products. To correctly merge and compare the information collected during the interviews and the data gathered with the questionnaires, the questions in the interviews followed the same pattern of topics as the questionnaires. However, during the interviews additional issues that were not considered by the questionnaires emerged, which added useful information to the survey.

The objective of the analysis consists in the illustration of the main characteristics of a sector that is characterized by the heterogeneity of the companies and the difficulty of the collection of the specific statistical economic data. No actual commercial classification regarding *terrazzo* tiles firms exists. The closest market macro-category, to which *terrazzo* tiles are included, is the Hard Flooring category (HFC). Italy and Spain contribute respectively for the 41% and 34% to the whole European natural and agglomerated stones market (GPP, 2011). These data outline the relevance of the Italian stone tile production in the European market, but hardly defines the share volume and variety of the Italian *terrazzo*-tile production. To overcome these difficulties, we analyzed a representative sample of companies producing cement-based HFC materials in Italy. Fourteen companies were selected following the advice of experts in the field of indoor flooring. The data, relative to the period 2014-2016, were retrieved on October 2016 from CCIAA, the Italian institution that keeps updated the National Companies Register made mandatory and established since 1993.

To verify the economic sustainability of ECO TILES production, production cost for 1 m² of ecological tile has been calculated. The analysis approach consists in attributing market prices to the production factors used, variable costs and fixed costs. Sometimes, due to the lack of accurate data on the physical quantities of the factor used and/or accounting data, some values have been estimated based on the manufacturer's experience. The data collection was conducted by the authors primarily at the Grandinetti Srl headquarters during targeted visits. These visits had also the purpose of checking, along with the manufacturer, the correctness of the collected data and the economic sustainability of the mid-term and final results in view of the production cost analysis. The production cost analysis results refer to 1 m² of ECO TILES in 2016. The analysis was conducted on the following production phases: a) artefact production and mixing; b) curing (20 days); c) polishing and packaging; and d) commercial and administration activities.

3. Results and Discussion

In order to verify if the technical performances and aesthetical appeal of ECO TILES products are comparable, or even improved compared to traditional *terrazzo* tiles, two batches of demo tiles were produced and tested according to the UNI EN 13748-1, the norms commonly used for traditional *terrazzo* tiles. The first batch of demo products were tested indoor at the production factory of Grandinetti Srl and a preliminary screening of the following technical parameters was performed: a) geometrical requirements, b) surface characteristics and appearance, c) absorption capacity. The results of the internal testing allowed to 1) discard the demo tiles which did not meet the geometrical requirements of the UNI standards, 2) avoid the use of the secondary raw materials that did not suit the production chain, 3) discard patterns and colour matchings which revealed to be aesthetically not suitable for the market.

Additionally the first batch of demo tiles was used as sample to survey the aesthetical appeal of the items and the consumer's attitude toward eco-friendly flooring products (Figure 3). The interviewed people stress out and appreciated the importance of an eco-friendly approach on tile production and the relevance of this industrial innovation on tile market landscape. They also generally appreciated the look of the tiles while stressing out the importance of providing a wider range of motifs and colour, i.e. an increased customization of the product, in order to get a better appeal to the market. The preference for the "design" variety resides in the inner potential of changing colours, grain sizes, motifs and patterns.

The results allowed to proceed to a tuning of the production, taking into account the following parameters: technical adjustments regarding the tile size, aggregate type and grain size, powder type and grain size, cement quantity and type, use of pigments, use of CDW. For example, tile made of CDW required several trials, before reaching the final version, i.e. the inclusion of CDW in the lower layer of the double layer tiles. In fact, the high compositional heterogeneity of CDW required a strict control of the grain size in order to obtain a suitable product.

The second batch is composed by the demo tiles that passed all the indoor technical tests and aesthetical evaluations, thus the most suitable to undergo to the industrial production. For this reason this batch was tested again by an external specialized certification centre the University of Bologna Ceramic Centre. The performed tests were a) shape tolerance control, b) water

absorption, c) thermal conductivity, d) mechanical strength and d) slip resistance. The tests revealed that the ECO TILES parameters are in line with the UNI EN 13748-1 requirements and comparable with the mechanical tests performed on traditional tiles by the company.

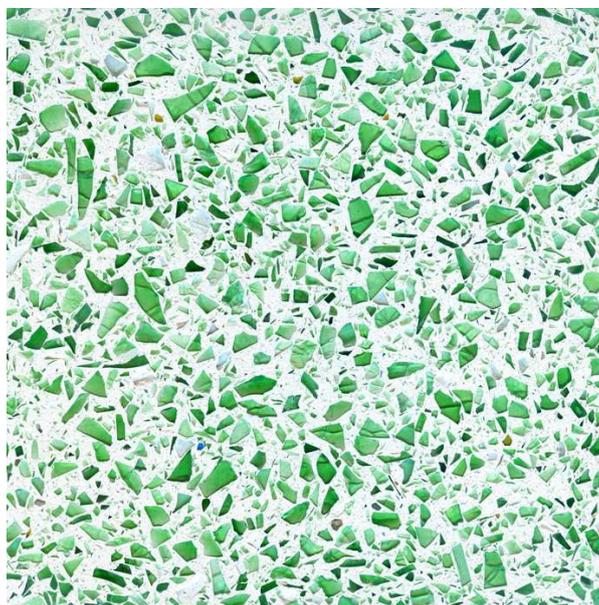


Figure 3. ECO TILES "Fiasco" model.

The results of the LCA analysis on ECO TILES showed that the innovative manufacturing techniques and raw material replacement with recycled glass and CDW allows to reduce the global warming potential (GWP) by 19% for single-layered tiles and 11% for double-layered tiles in comparison with traditional *terrazzo* tiles. These results acquire even a higher value considering that the tiles production by the Grandinetti company (both traditional and ECOTILES) makes use of the innovative technique such as the “microcamere-curing”. This manufacturing process has recently developed and patented by the Grandinetti Company, allowing to drastically reducing the energy consumption associated to the curing process. The innovative system allows the cementitious mixes to “cure” without using additional steaming but allowing its natural hardening cycle (approx. 20 days). As a matter of fact, the company has patented a dedicated partitioned aluminium tray (“microcamere-curing”) on which the *terrazzo* tiles are deposited after the press. The tray is designed to allow the creation of a sealed chamber once the trays are piled up one on top of the other. This way, the tile is left to cure using its own humidity and heat. This allows the cement mix to dry without risk of excessive shrinking due to fast drying, thus obtaining a final product of very high quality. This system allows to avoid completely (100%) the energy required in the drying step, thus reducing consistently the overall energy consumption (roughly 20% of the entire production process) as well as the time required for the curing process, with benefits for the producer.

While these results are encouraging, there is still margin to improve in future iteration of the production. For instance the ECO TILES project team is currently working on a local network of supplier in order to reduce CO₂ emissions due to transportation of the materials used, which is a factor highly influencing both the economic and environmental impact of the tile production. Additionally, recent publications by this research group (e.g. Perugini et al., 2014) already explored the possibility to: i) save up to 55% of clinker Portland and CO₂ emission in cement production, with equal mechanical performance at 28 days of maturation; ii) produce cements with good durability, high leaching and sulphate resistance, thanks to the pozzolanic activity of fine grinded ceramic waste.

According to retailers, market demand for traditional cement-tiles is however modest: from a minimum of 5-10% to a maximum of 20% of the entire tile market, which in Italy is dominated by ceramic tiles. The geographic areas with an higher

demand in Italy are the metropolitan areas of the largest cities, like Milan and Rome. However, cement based tiles are also in demand in non-urban/rural areas where old housings flooring are made of *terrazzo* tiles. In this context, the restoring of old buildings and towns represent a market where the demand is growing with time, and the interest for *terrazzo* tiles is increasing for the applications in the bio-architecture and the need to satisfy the Green Public Procurement (GPP).

The demand market area for the cement-tiles depends mostly on the proximity to the retailer and the selling price. Mostly, the consumers who decide to buy cement tiles are located in the same region of the retailer. Surprisingly, consumers purchasing cement-tiles for their vacation homes, such as in Apulia, or on the Lazio coast, in Tuscany and in Veneto, are mainly non-Italian European citizens: this high interest is certainly related to the high number of foreign people buying and restoring old country houses, as a phenomenon wide-spread in many small towns. A lower selling price coupled with the high quality of the product encourages tile purchase by Italian and non-Italian customers even outside the retailer's region.

According to the results of the questionnaires and the point of view of retailers, the main buying factors of traditional *terrazzo* tiles are, in descending order of importance, their aesthetic quality, level of the commercial promotion, the price, the competition of replacement products and the level of technical performance (high resistance over time). For consumers aware of the importance of protecting the environment, the environmentally-sustainable production method and the use of natural materials are considered a plus in favour of the ECO TILES.

In general, the price of cement based tiles, compared to that of ceramic tiles, is greater, especially for decorated ones. However, consumers seems not to worry about the high cost associated to the purchase of cement-based tiles, because they perceive this product as an investment and not as a luxury commodity, especially if the customer receives an adequate explanation of the value of the materials used in the mix and the characteristics of the production techniques. Consumers are willing, in fact, to spend more for a product with high durability, because the purchase of cement-tiles is regarded as *una tantum* expense in the family life, thanks to the possibility of renovating the look of the tiles by polishing the surface, as happens for most of the flooring placed 100-200 years old buildings. According to the consumers, the *terrazzo* tile possible replacement products, on the high-price side, are granite, marble, parquet and azulejos tiles, whereas the low price substitute products are glazed gres and marble-resin compounds containing also recycled material. To date, there are no substitutes to cement-based tiles in the market. According to the retailers, among the no-cement-based products, we can mention some total/partial ecological solutions suitable for paving, like: 1) glazed stoneware composed of up to 40% of high-performance glass (Polis Ceramiche Relux TM, 2018); 2) wood floorings made up of refurbished wood and 3) hemp and lime conglomerates.

The results of the questionnaires and interviews confirm that the idea of the ecological product is very appreciated. From a technical point of view, the majority of consumers expects from an ecological product a quality higher than that of the traditional products, as well as a sturdier and more resistant product. From an aesthetic point of view, the respondents of the questionnaires and the retailers interviewed found the prototypes of the ECO TILES attractive and trendy. Finally, from the point of view of environmental sustainability, respondents to the questionnaires said they appreciated the positive effects on the environment resulting from the adoption of the ecological production method. However, there is a widespread difficulty by the consumers to perceive easily the environmentally sustainable process leading to the production of an ecological tile: i.e. low-energy production technique, alternative sources of raw materials such as recycled glass and materials obtained from waste and/or demolition of buildings. As a matter of fact, consumers are more prone to perceive the concept of organic food or ecological parquet, because they understand crops and trees as eco-friendly raw material sources. This suggests that there is a need to educate the consumer to processes and materials related to the building materials to favour a better penetration in the market.

For the same purchase price, the consumers clearly stated their willingness to buy ecological tiles over a traditional tile. Moreover, in the case of a price increase of the ECO TILES compared to the traditional one, 63% of the interviewed consumers are willing to pay from 7.6% to 16.7% more for an ecological tile. Resellers suggest a higher price increase interval, from 10%

to 25%. However, these consumers claim that the product is accompanied by a certification/insurance on the second raw materials used.

The analysis of the Italian compartment of the *terrazzo* tiles has shown that half of the companies involved are "industry leaders", characterized by quality production and openness to the foreign market. A third of the companies, on the other hand, are characterised by the sale of lower prices products and by the marked export vocation (quantity strategy). Finally, the residual part of the companies highlights the production of "marble-resin-epoxy agglomerates" for the production of flooring and slabs.

According to the data reported by the companies of the sample to CCIAA, the primary production item is represented by grit-tiles for flooring (tiles) and covering or industrial applications (73% of the total), thus confirming the high level of specialization of the Italian firms in grit-tiles production. The secondary production item is "Other products and services", such as: furnishings, agglomerates, complements, cement, marble, marble-cement. This second product is tied to the first for the materials it employs.

The Italian companies involved in the *terrazzo* tiles production are rather small, having an average number of workers per sampled company of 12.86.

The firms quantity production and turnover amount was estimated based on the number of the company workers, using the following assumption: average production m^2 1,600 per worker per year; average turnover € 60,000 per worker per year. In the period 2014-2016, the total average production per year of the companies of the sample amounts to m^2 238,933.33 for a turnover of € 8.960,000.00. The quantity of tiles produced on average per year per company amounts to m^2 20,587.33 for a turnover per company of just under € 800,000. The most productive company contributes for the 22.4% of the total supply. The first four companies by production account for a cumulative 65.8% of the total supply. Their geographical locations, in order of importance, are the provinces of Verona, Ancona, Rome and Modena.

The result of the cost production analysis is useful to estimate a company's ability to succeed in the market with a novel ecological product. The production cost analysis is referred to a square meter ($1 m^2$) of "standard" ECO TILES tile with size 20x20x1.2 cm, polished on the surface, white colour as background with green glass granulate. Weights is 37.5 kg for $1 m^2$ of tile. Thickness before polishing is 1.5 cm. The annual production quantity ranges from a minimum of m^2 15,000 to a maximum of m^2 25,000. The maximum value represents also the maximum production capacity of the plant that can be achieved if justified by a similar market demand. The total effective net production of tiles offered on the market is m^2 16,000 per year. The level of processing waste (or swarf) has been estimated to about 20% of the total production. Transport and shipping cost are not included, therefore tile transport costs are charged to the customer.

The total production ECO TILES cost has been evaluated as € 31.01 per m^2 . The cost items in common to all the operative phases are the following: raw materials (primary or recycled), energy, labour, equipment and buildings capital (maintenance and depreciation), monetary capital payed in advance and loan interests and taxes. The cost of the mixing and molding phase (first production phase) amounts to € 12.60. The consumption of raw materials (mirror glass, cement and water) constitute the 44.76% of the costs for this phase. Labour cost affects 8.17% of the total costs in the mixing and molding phase, thus indicating the high capital investment needed for this operational phase. The cost for administrative and sales activities (third production phase) amounts at € 11.21, while labour costs account for the 48.26% (€ 5.41), of which less than a third is used for sales. Polishing and packaging phase accounts for € 6.90. The curing phase (second production phase) only for € 0.30.

According to retailers, the average forecasted sales price of ECO TILES is € 45.00, with a minimum price of € 30.00 and maximum of € 60.00. According to the manufacture, presumably the average price of an ECO TILES polished tile will reach € 50.00 per m^2 . These prices are not significantly different from those of conventional polished plain tile already in production, according to the manufacturer's point of view. ECO TILES sale price is instead considerably lower than a hand-made decorated *terrazzo* tile, which average sale price may reach up to € 165.00. The difference between the average forecasted sales price

sets for the market (€ 45.00) and the total production cost (€ 31.01) is positive. At the time of this study, the ecological tile is not yet available on the market and prices therefore are not listed yet.

It is important to take into account the existence of possible market risks of relevant entity. From a technical point of view, the production of ECO TILES may run out of secondary (recycled) raw materials for the desired quantity and quality. For example, the manufacturer of the case study is forced to supply glass fragments from an extra-region supplier. The little demand for secondary raw materials with a high degree of purity can be a relevant difficulty.

From the market point of view, the sale price of ECO TILES may deviate from the one extracted from this analysis. Now, market demand may still be poor due to the persistency of the economic crisis. The company would still be able to cover the variable costs and a large part of the fixed costs and would allow it to withstand for a period of time pending a recovery of the market even if the selling price falls to a minimum value of € 30.00 per m².

4. Conclusions

The valuable features of the results obtained for the ECO TILES production are: reduced environmental impact, innovative way of recycling waste, appreciated tile design and consumers interested to ecological products.

From an environmental point of view, the improvement derived from adopting an ECO TILES approach in the production of *terrazzo* tiles are clear. Most of the aspects are related to the use of recycled waste materials as replacement of mined raw material, coupled with innovative production processes adopted, at the moment exclusively, by the Grandinetti company. An ECO TILES tile can contain up to 77% of recycled materials for a Single layer tile and 76% for a Double layer and LCA results show that the combined use of these two innovations contributes to a reduction in emission of kg CO₂ equivalents of 19% for a Single Layer tile and 11% for a Double Layer tile if compared to a traditional *terrazzo* tile. Additionally, for each m² of ECO TILES produced 28.5 kg of waste materials (including glass, ceramic and CWD) are recycled (considering that 1 m² of tile weights 37.5 kg and that thickness before polishing is 1.5 cm). Hypothetically, if the entire annual tile supply of the Grandinetti company (m² 20.000) is converted into ECO TILES the quantity of recycled waste material would amount to 570 tons. If this good practice of producing tiles using waste material is adopted in every tile producing companies considered (m² 238.933.33) the waste reduction and recycling may reach up to about 6.810 tons, a small but relevant quantity of waste recycled by producing only a reduced quantity of CO₂ in the process and thus, generally speaking, contributing to improve the life quality of EU citizens.

The results of ECO TILES support, therefore, the adoption of the following virtuous circular economy policies in the construction sector: 1) to favour consumer preferences over recycled products; 2) to encourage companies to provide environmental quality certification assurance for the products used and 3) to certify the environmental traceability of items to be identified as an eco-friendly product (raw, secondary material and products). Incentive actions to steer consumer preference for recycled products are widespread, see building regulations, regulations and notices issued by Italian Municipalities, Provinces and Regions (Legambiente, 2016). In this sense, for example, it is encouraging the recent approval of the Marche Region (Italy) of the "Technical-legal document, aimed at the reuse of Recycled Aggregates" for the construction of public works or of public interest or private reconstruction to maximize the use of substances that coming from the recovery of non-hazardous inert waste (Regione Marche, 2017). The Deliberation identifies the basic technical-normative references for the recovery of the "recycled aggregates" produced by the collection, selection and sorting cycle, and the start-up of the recovery and treatment of the rubble produced by the 2016 seismic crisis which struck a large area in Central Italy. The use of a minimum percentage of materials (15%) coming from waste recovery/recycling is required and a system of incentives and rewards for the use of higher percentage is established, creating the basis for wider diffusion of environmentally-friendly building materials, like ECO TILES.

Acknowledgments: Thanks goes to Grandinetti Ltd. and the management staff for the sharing the data reported in this work. This work was supported by the Life project ECOTILES (LIFE14-ENV_IT_000801) and FAR grants to EP.

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