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The implementation of circular economy in the Portuguese natural stone sector

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Master in Management

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Department(s) of Marketing, Strategy and Operation

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Abstract

This Pedagogical Case project was created from an initial case study in a medium enterprise from the ornamental stones industry. The observation and perception of ornamental/natural stones sector processes, from extraction to processing, brought new approaches on the case. Thus, a decision was taken to develop a Pedagogical Case Study hoping to give an understanding of resource scarcity, sustainability, circular economy and the natural stone production. After introducing the terminology and basic concepts the Portuguese natural stone manufacturer Solancis is presented to underline its exemplary position of environmentally responsible operation. Key elements are highlighted and based on current research in the fields of environmental impact analysis of life cycle assessments and the construction sector with building information modelling in order to propose an innovative business strategy in the natural stone industry. Resulting benefits can be observed in all three dimensions of sustainability and guide to overcome the current challenges of implementing the concept.

Energy intensive processes such as the quarrying could be smoothed through circular economy and lower environmental impacts, lower costs and benefit the surrounding communities.

The burdens currently are the standardization of the natural stone products and designing them for reuse, consumer behaviour and awareness regarding environmental impacts of products.

Penetrating an untouched gap in the market and the resulting marketable image of the products in connection with the necessity of turning the business towards circular economy to ensure long-term sustainable production, which is not dependable on a depleting resource fortifies the potential and necessity of this strategy.

Keywords:

JEL Classification: I125 (Education and Economic Development), Q01 Sustainable Development, Q3 (Nonrenewable Resources), Q56 (Sustainability), Q53 (Recycling – Circular economy)

Resumo

Este trabalho foi criado de um estudo de caso iniciado em uma média empresa do sector da Indústria da pedra. A observação e percepção dos processos da extração até ao processamento, trouxe a possibilidade de uma nova abordagem ao caso. Assim, foi desenvolvido um Caso Pedagógico, visando de compreender a escassez de recursos, sustentabilidade, economia-circular e a produção de pedra natural. Após de introduzir a terminologia e conceitos básicos, o fabricante português Solancis é apresentado como exemplar de operação ambientalmente responsável. Os elementos chave são destacados e baseados na investigação actual nos campos da análise de impacto ambiental, das avaliações do ciclo-de-vida e do sector da construção com modelação da informação da construção, a fim de propor uma estratégia de negócio inovadora nesta indústria. Os benefícios resultantes podem ser observados nas dimensões da sustentabilidade e guiar para superar os desafios da implementação do conceito.

Processos intensivos em energia, como a pedreira, podem ser atenuados através da economia-circular e de menores impactos ambientais,menores custos e benefícios para as comunidades do entorno.

Os encargos são a padronização dos produtos de pedra natural e o desenho deles para reutilização, o comportamento dos consumidores e a conscientização sobre os impactos ambientais dos produtos.

Penetrar uma lacuna intocada no mercado e a resultante imagem comercial dos produtos em conexão com a necessidade de virar o negócio para a economia circular para assegurar uma produção sustentável a longo prazo, que não é dependente de um esgotamento de recursos fortalece o potencial e a necessidade desta estratégia.

Palavras-chave:

JEL Classificação: I125 (Education and Economic Development), Q01 Sustainable Development, Q3 (Nonrenewable Resources), Q56 (Sustainability), Q53 (Recycling – Circular economy)

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List of abbreviations

B

BIM ....Building Information Modeling

C

CNC.. *Computer numerical control*

D

DGEG .... *Directorate General for Energy and Geology*

E

EU...*European Union*

I

ISO .... *International Organization for Standardization*

O

OEC...*The Observatory of Economic Complexity*

U

UN .... *United Nations*

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Chapter 1: **The case**

1.1 PRESENTATION OF THE SUBJECT

Today's natural stone production is turning green, but the traditional operational strategy leaves room for doubt in relation to the degree of long-term sustainable action with its scarce and finite resources. The development of new business models might be a solution to provide help in order to turn the business sustainable in the long term and to help facing the challenges the future and the nature has set for us. Instead of quarrying further stone and removing natural resources from the nature an imaginable solution would be to apply the concept of circular economy to reuse, recycle and reduce stone products instead of holding onto the mentality of a throw-away society.

Consequences of unsustainable action can be witnessed in a variety of fields like the extinction of animals due to human caused reduction in the animal's natural habitat, global warming through the rising quantities of greenhouse gases in the atmosphere, plastic pollution in the ocean due to poor waste management and the very recent bush fires in Australia to name a few of them (Fischer, 2020; Mc Curry, 2017; Powell, 2019; Wabnitz & Wallace, 2010;).

Sustainability is one of the EU parliament's trending topic nowadays which is rising in importance. A complex variety of goals have been set in the three dimensions of sustainability (environmental, social & economic) which should be achieved globally by 2030 (European Commission, 2019). The recentness of this topic still leads to inconsistencies and discrepancies in the perception of sustainability as we can already see in the different terms and definitions that are used like sustainability, stake holding firm, corporate social responsibility, corporate sustainability and corporate citizenship (Valor, 2015). Eu directives are therefore still rather recommending than regulating sustainable actions since the measuring of sustainability remains complex and hard to conduct (European Commission, 2019).

The construction sector is currently facing delays and longer construction times in some parts of the world because the availability of natural resources such as stone is decreasing. Land is progressively protected and declared as nature reserve by the state in order to preserve nature and lower environmental impacts which stands in conflict with the quarrying of natural resources (DTS, 2018). Taking into consideration, that our world population will increase to a number of 9.8 billion humans in 2050 and 11.2 billion in 2100 the importance of conscious resource utilisation becomes evident (UN, 2017). For the additional 3.6 billion people, who will be living on earth until the end of this century, housing will need to be built. New infrastructure will need to be developed and the existing buildings will need to be updated and renovated as well.

In order to overcome the challenge of natural resource scarcity in the field of natural stone production an innovative concept, which envisions circular economy as a viable solution to this problem, should be developed. The Portuguese limestone production facility of Solancis in the district of Leiria will be reviewed in regard to it's degree of sustainable action during the production processes and a new business strategy will be formulated as well.

1.2 NATURAL STONE

The following chapter will take a closer look at the material of natural stone regarding it's definition, the different materials, locations of the resource as well as the markets.

1.2.1 Definition

Firstly, the term natural stone should be precisely defined in order to get an understanding of the object of investigation. Whereas there exist many different scientific definitions of stones, this case study will stick to the commercial perspective. Natural stone should be understood as: "A stone that has been quarried and cut, but not crushed into chips or reconstituted into cast stone" (Natural Stone, 2018). The definition therefore excludes manmade materials such as concrete, porcelain or other engineered or artificial building materials even if they may contain natural ingredients. The stone can be cut or even get surface treatments and still be considered natural as long as it has not been internally modified in it's composition. Stone is formed in a process which can take over a million of years of metamorphism, sedimentation or solidification of molten material (Bellstone, 2020; Genuine Stone® Definition – Natural Stone Council, 2020). Regarding the regeneration rate of natural stone, the resource is therefore regarded as a non-renewable recourse. Natural stones from a commercial point of view are classified into nine typologies namely: Granite, Limestone, Marble, Onyx, Quartzite, Sandstone, Serpentine, Slate, Soapstone, and Travertine (Natural Stone Scientific Versus Commercial Definitions, 2018).

1.2.2 Materials

For this study we will focus on the three categories granite, limestone and marble which are the main resources of internationally traded natural stones in Portugal (Lopes & Martins, 2014).

Granite

Granite is formed through the solidification of magma when it reaches the surface of our planet where it cools down. In order to be classified as granite the natural stone needs to contain 10%-50%. The quarrying of the material takes the energy of 14.125,9 MJ per m³ and the following processing of the stone takes another 88.286,67 MJ per m³. Regarding the water footprint granite consumes 11.496,5 l per m³ in the quarrying and 1.216.493 l per m³ in the further processing of the stone. The global warming potential in form of CO2 emissions per cubic meter of granite lays in 494,4 kg for the quarrying and 1836,4 kg for the processing (Granite Life Cycle Inventory – Natural Stone Council, 2008). Depending on the use and maintenance of the material, granite can endure between 100 years up to a lifetime and is therefore suitable for reuse in form of re-installation on new buildings (Study of life expectancy of home components, 2007). The density of the material is at roughly 2560 kg/ m³ and the compressive strength is at 10.34 MPa (ASTM C615 / C615M - 18e1 Standard Specification for Granite Dimension Stone, 2018).

Limestone

Limestone groups to the sedimentary stones and is made of calcium carbonate and can further contain magnesium or calcium. Shells and skeletons of marine organisms are forming this material in many stacked layers which are then bonded to each other through pressure and heat that is created through earthquakes and similar processes. The quarrying of the material takes the energy of 3.390,21 MJ per m³and the following processing of the stone takes another 812.23,73 MJ per m³. Regarding the water footprint limestone consumes 8.421,88 l per m³ in the quarrying and 1.336.806 l per m³in the further processing of the stone. The global warming potential in form of CO2 emissions per cubic meter of limestone is at 1.306,64 kg for the quarrying and 1.589,16 kg for the processing (Limestone Life Cycle Inventory – Natural Stone Council, 2008). Depending on the use and maintenance of the material, limestone can endure up to a lifetime and is therefore suitable for reuse in form of re-installation on new buildings (Study of life expectancy of home components, 2007). The density of the material varies between 1760-2560 kg/ m³ and the compressive strength differs between 12-55 MPa depending on the type and composition or classification of the limestone (ASTM C568 - 08a Standard Specification for Limestone Dimension Stone, 2014).

Marble

Marble accounts to the metamorphic rocks and is formed in the same way limestone is formed with the difference, that the heat when marble is created is a lot higher. Therefore, the structure of the marble is comparable to crystals and consists of calcite, dolomite and aragonite. The total production of marble tiles embodies 698-1.414 MJ/ m³ depending on the thickness of the tiles. Regarding the global warming potential, the production of one cubic meter of marble tiles sets free 314,8 kg. Depending on the use and maintenance of the material, marble can endure up to a lifetime and is therefore suitable for reuse in form of re-installation on new buildings (Study of life expectancy of home components, 2007). The density of the material is between 2590-2800 kg/ m³ and the compressive strength is at 7 MPa depending on the type and composition or classification of the marble (ASTM C503 / C503M - 15 Standard Specification for Marble Dimension Stone, 2015; Traverso, Rizzo, & Finkbeiner, 2009).

Practical differences

Since all the materials which were just described are natural stones with similar characteristics it can be challenging to distinguish them from each other. The following table (table 1) is supposed to help to set the materials apart regarding their typical use, appearance and characteristics as well as to understand some of each resource's unique properties.

	Marble	Limestone	Granite
Outdoor suitability	Sealing necessary	Sealing optional	Sealing optional
Appearance	Veining patterns	Smooth & fine-grained	Distinctive grains
Predominant colour	White	Cream	Grey
Characteristics	Fossils in patterns	Consists of marine shellfish	Highly resistant and tough materials
Popular monuments	Taj Mahal	Pyramids	Mount Rushmore

Table 1: Practical differences between the natural stone materials of marble, limestone and granite (own table based on: "Surrey Marble and Granite", 2016).

1.2.3 Locations of resource deposits and markets

Portugal

Portugal is a country which is rich in natural resources and especially natural stone (as seen in figure 1). While you can find the biggest part of the granite deposits in the northern part of the country, the deposits of limestone and marble are located in the mid-section and the south of the country. It is estimated, that Portugal owns 409,5 Million cubic meters of ornamental stone resources over a surface area of 337,9 km^2 which will last a couple hundred years under current forecasts in demand (Carvalho, Lisboa, Casal Moura, Carvalho, Sousa & Leite, 2013; Lopes & Martins, 2014).

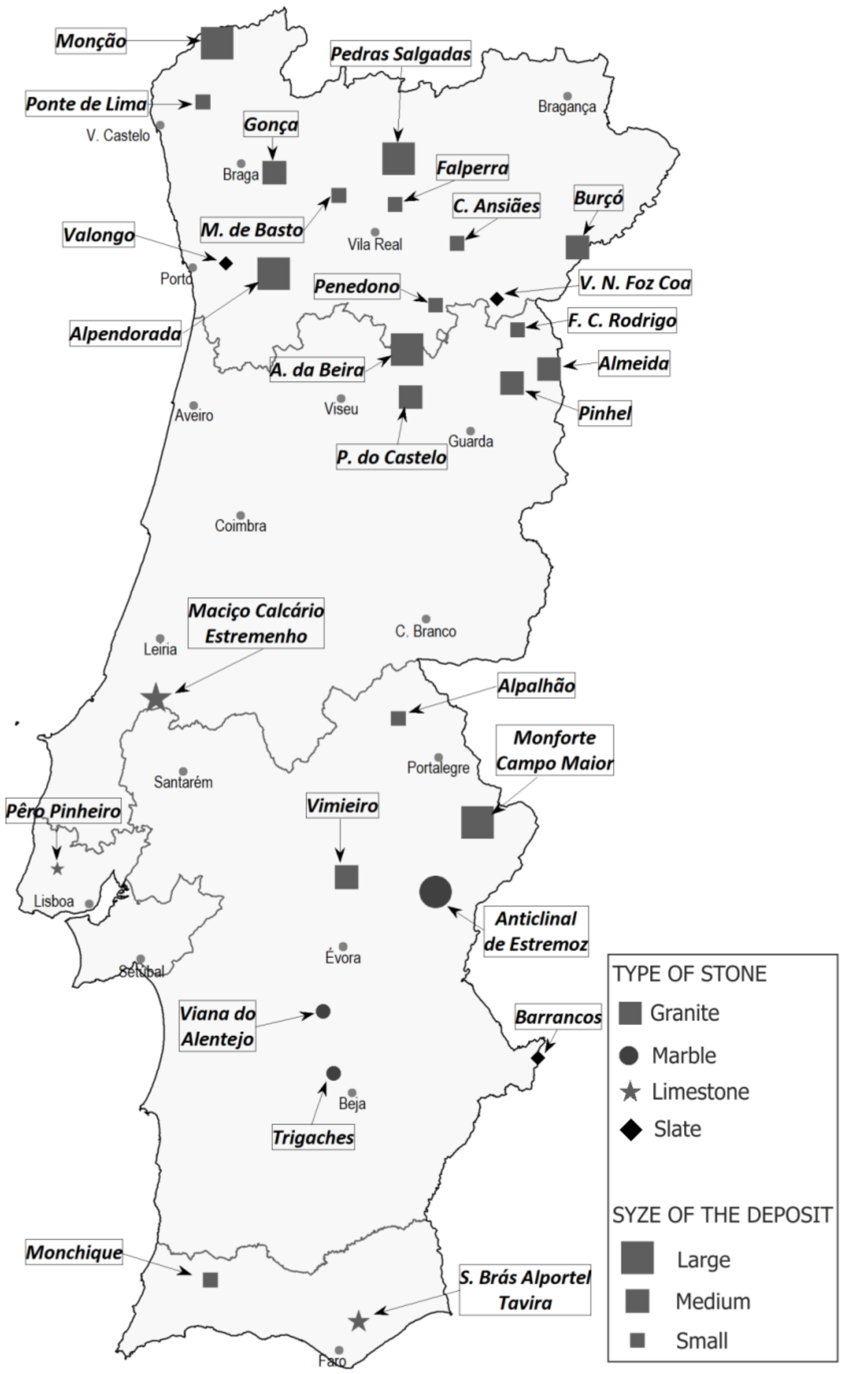

Figure 1: Resource deposits of ornamental stone in Portugal (Carvalho et. al, 2013).

<u>Portuguese market</u>

The amount of produced natural stone in Portugal has increased over the last years. The granite production experienced a steady growth in production of over 20 % from 2016 to 2017 and over 10 % in the following year, reaching 1543,5 thousand tons of material in 2018 (DGEG, 2019).

The amount of produced limestone in Portugal showed an increase of 30 % from 2016 to 2017 and a decrease of 5 % in the next, resulting in a volume of 811,1 thousand tons of material at the end of 2018 (DGEG, 2019).

From 2016 to 2017 the production of marble went up by 10 % and fell by 9 % to a production volume of 173,3 thousand tons in 2018 when comparing to the year before (DGEG, 2019).

Overall the produced amount of stone material increased by 471,5 thousand tons or 20% from 2016 to 2017 and 99,9 thousand tons or 4 % from 2017 to 2018 (as seen in figure 2).

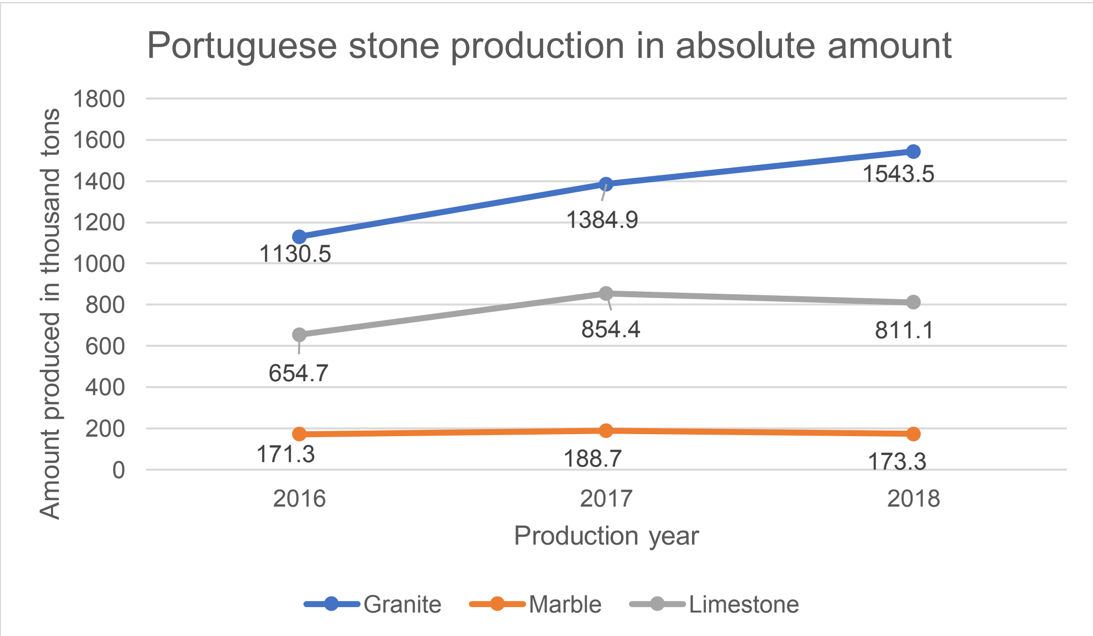

Figure 2: Production volume of granite, limestone and marble in Portugal from 2016 to 2018 (own diagram based on: DGEG, 2019).

When looking at the development of the monetary turnover of the natural stone production in Portugal there is also a total average increase to be observed. The limestone production had a steady growth over the years of 2016 to 2018 with relative increases of 6 % and nearly 16 %, resulting in a value of 74,9 million Euro. While the production volume fell from 2017 to 2018 the value in Euro still increased. This can be accounted to price fluctuations of the traded goods and also the processing of the stone material which defines the prices (DGEG, 2019).

From 2016 to 2017 the value of the produced amount of granite grew by nearly 20% and fell in the following year by 4 %, reaching a value of 43,4 million Euro. Also here we can

witness a contrary development of production amount and value which can be explained with variances in overall prices or the degree of processing (DGEG, 2019).
The value of produced marble had a gain of nearly 10 % between 2016 and 2017 and a loss of 16 % with a value of 29,4 million Euro in 2018. Discrepancies in the changes of produced amount and value are also here to explain with altering prices or degrees of processing (DGEG, 2019).

The total value of the produced natural stone in Portugal increased by 14,7 million Euro or 10 % from 2016 to 2017 and 3,6 million Euro or 2,5 % in the following year 2018. Figure 3 further illustrates the development of Portugal's monetary value of natural stone production over the time span of 2016 till 2018.

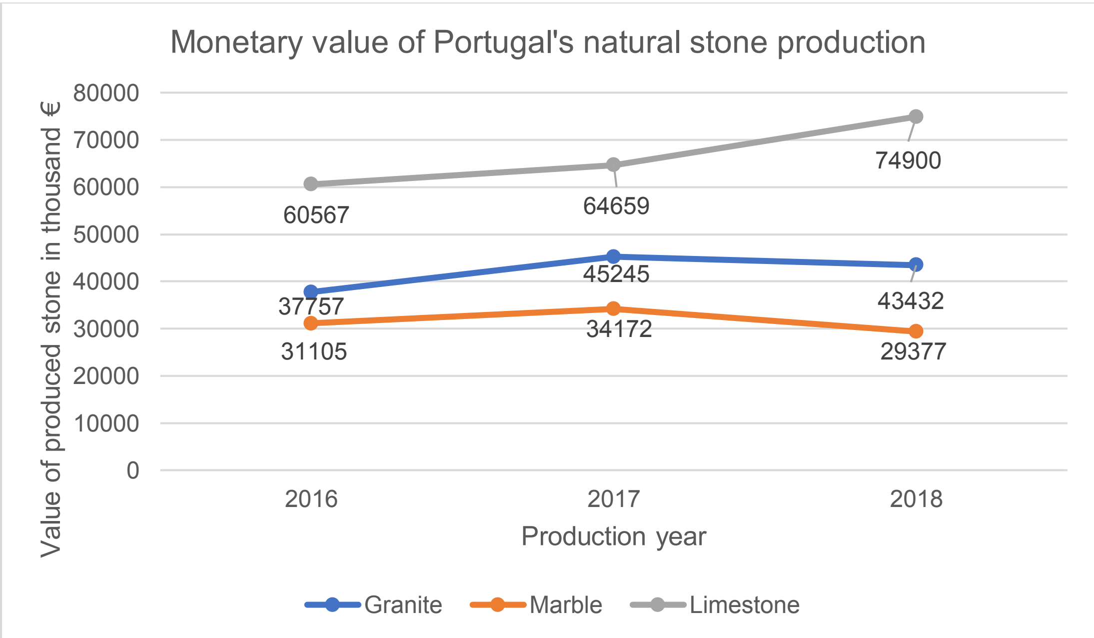

Figure 3: Value of production volume of granite, limestone and marble in Portugal from 2016 to 2018 (own diagram based on: DGEG, 2019).

Global stone markets

In order to get an overview over the global stone markets and their size the 5 biggest traders are going to be set into focus and compared to the total market size as well as the Portuguese market.

Marble

On the global marble market in 2017, the biggest exporting countries were Turkey with a value of 1,8 billion Euro, Italy with a value of 1,3 billion Euro, China with a value of 1 billion Euro, Greece with a value of 419 million Euro and Spain with a value of 318 million Euro

(StoneNews, 2018) (as seen in figure 4). Portugal exported in comparison to the biggest exporters marble worth 91 million Euro in 2018 (StoneNews, 2019).

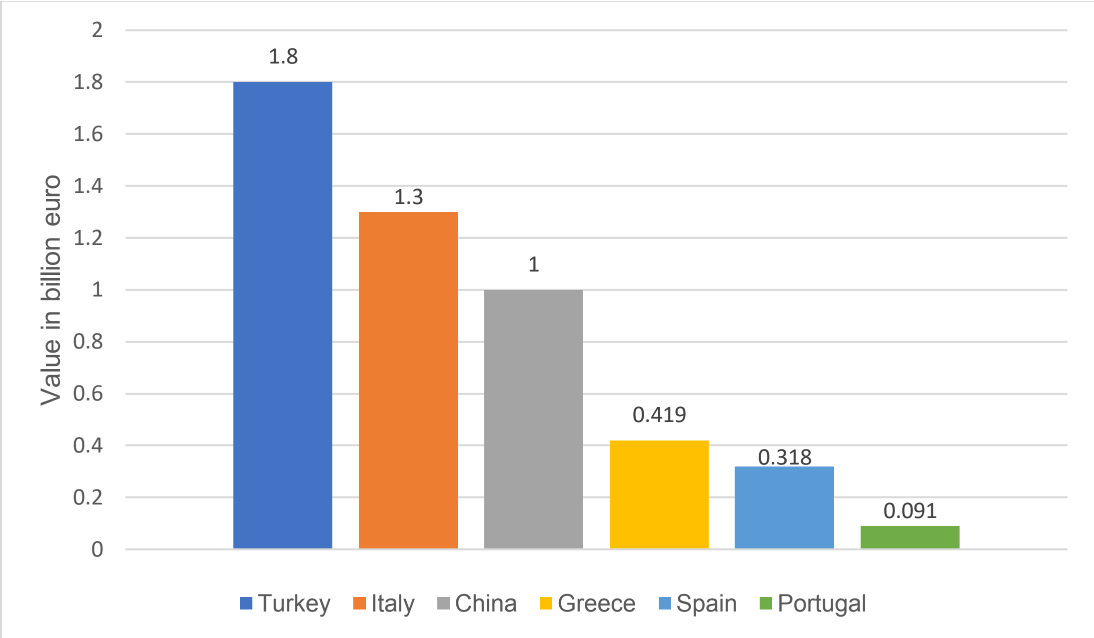

Figure 4: Value of globally traded marble of the 5 biggest traders worldwide and Portugal for comparison (own diagram based on: StoneNews, 2019).

Granite

The global granite market traded a total value of 1,73 billion Euro in the year of 2017. When it comes to the granite markets the biggest players regarding the export are India with 45 % market share (781,4 million Euro), Serbia with 8,7 % market share (149 million Euro), Norway with 8,5 % market share (146,3 million Euro), Brazil with 4,9 % market share (85,3 million Euro) and South Africa with 4,2 % market share (72,6 million Euro). Portugal has in comparison to the 5 biggest traders on the global market a share of 2,6 % (44,2 million Euro) (OEC - Granite (HS92: 2516) Product Trade, Exporters and Importers, 2017). For further illustration of the distribution of market shares in the export values of granite consult figure 5.

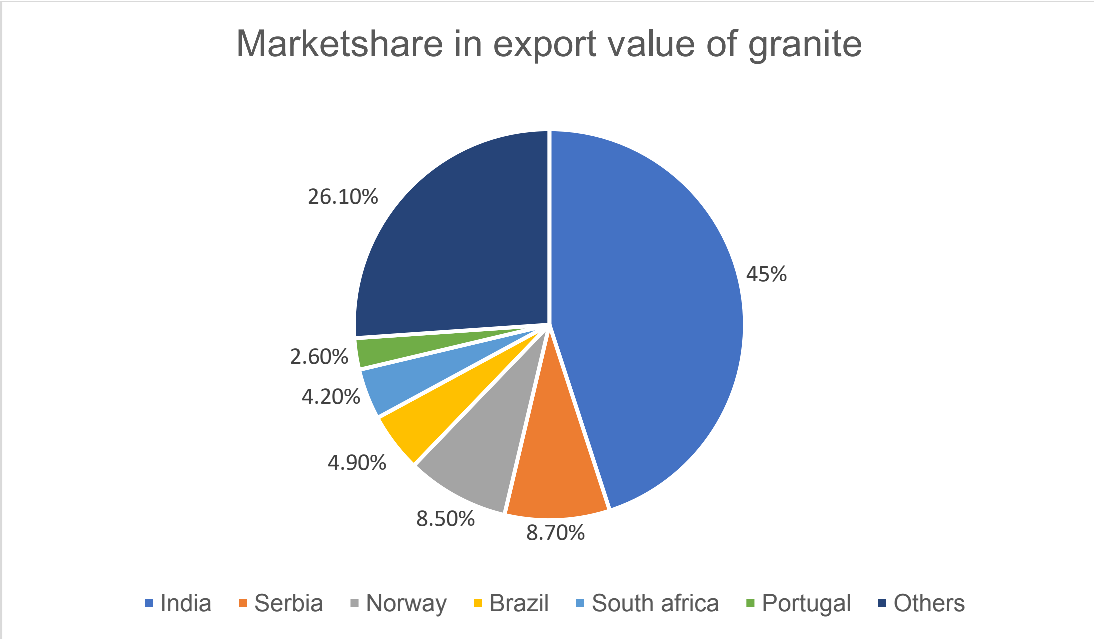

Figure 5: Market shares of the 5 biggest granite traders worldwide and Portugal for comparison (own diagram based on: OEC - Granite (HS92: 2516) Product Trade, Exporters and Importers, 2017).

<u>Limestone</u>

The global limestone market traded a total value of 740,5 million Euro in the year of 2017. The biggest players on the market regarding the export are United Arab Emirate with 35 % market share (256,2 million Euro), Malaysia with 11 % market share (79,1 million Euro), Japan with 7,3 % market share (54 million Euro), Spain with 6,5 % market share (48,4 million Euro) and India with 5,4 % market share (40,1 million Euro). Portugal has in comparison to the 5 biggest traders on the global market a share of 0,03 % (267 thousand Euro) (OEC - Limestone (HS92: 2521) Product Trade, Exporters and Importers, 2017). For further illustration of the distribution of market shares in the export values of limestone consult figure 6.

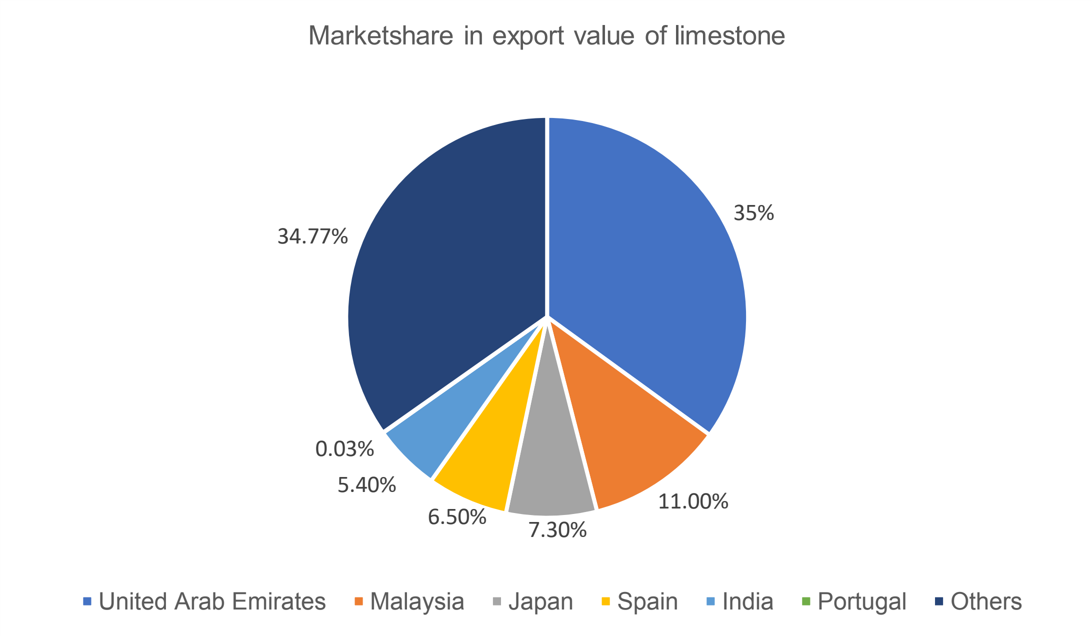

Figure 6: Market shares of the 5 biggest limestone traders worldwide and Portugal for comparison (own diagram based on: OEC - Limestone (HS92: 2521) Product Trade, Exporters and Importers, 2017).

1.3 SUSTAINABILITY

The following chapter will start with a brief definition or explanation of the term sustainability. It will be broken down into it's three dimensions and their relationship to each other. After that concepts of strong sustainability and weak sustainability will be put into perspective in order to introduce the topic of circular economy.

1.3.1.1 Definitions

Starting with the most general term which will be defined, we are taking a closer look at "sustainable". From an etymological perspective the word sustainability derives from the Latin expression "sustinere"[1] which translates to endure, hold up or furnish with the intention to support. The oxford dictionary further specifies: "involving the use of natural products and energy in a way that does not harm the environment"[2].

As the next step the term sustainability will be defined from a corporate point of view. The history of the terminology lies in the Brundtland report which was published in 1987 at the World Commission on Environment and Development. Corporate sustainable development

[1] Sustain Origin and meaning of sustain by Online Etymology Dictionary, 2020
[2] Sustainable adjective - Definition, pictures, pronunciation and usage notes Oxford Advanced Learner's Dictionary, 2020

embodies the ethical idea of meeting present needs while maintaining environmental protection in order to preserve the possibility of future generations to meet their needs without compromise (Robèrt, Schmidt-Bleek, Aloisi de Larderel, Basile, Jansen, Kuehr & Wackernagel., 2002).

1.3.1.2 The triple bottom line

As seen in the broad definition of the word sustainability one can imagine how complex it is and how many facets it has, since it touches social, environmental and economic topics and tries to put them into relation to each other (Elkington, 2002). Various models have been developed in order to grasp the complexity such as a three- and a five-dimensional concept as well as a three-level model (Bervar & Bertoncelj, 2016; Cavagnaro & Curiel, 2012; Ilić Krstić, 2018). For the purpose of this work the three dimensional concept of sustainability (as seen in figure 7) will be followed as it covers the most important fields of an economic, social and environmental point of view.

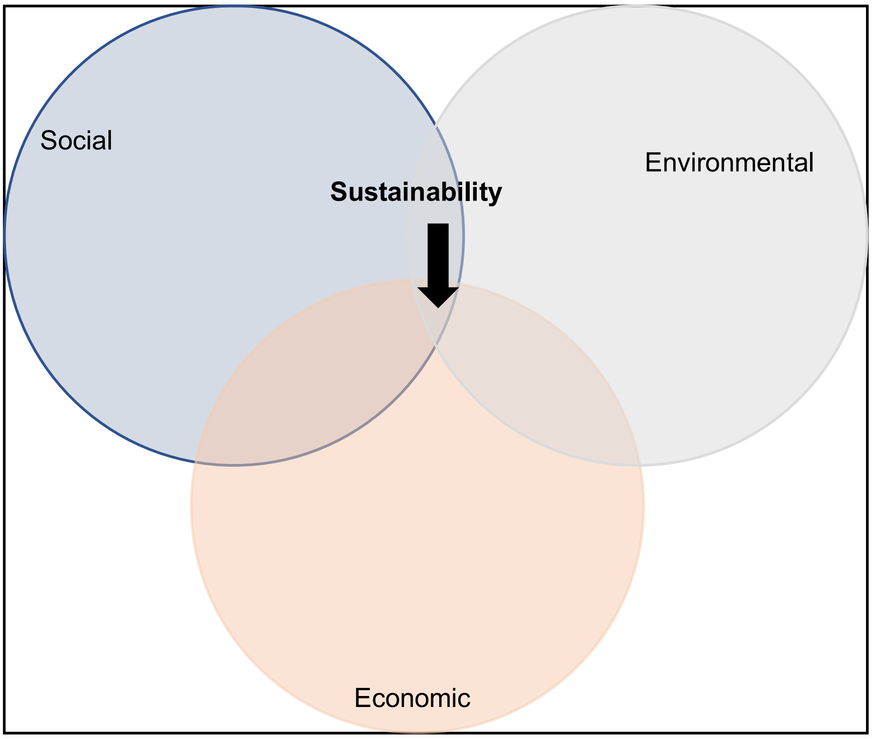

Figure 7: Three-dimensional concept of sustainability (own figure based on: Elkington, 2002).

Economic dimension

The economic goal of sustainability is to reach enduring and long-term financial benefits under the basic efficiency principle of using a minimal amount of goods to produce the biggest value possible. Those goals reach from economic growth and stability over high degree of employment to reducing the state quota (Abschlußbericht der Enquete-Kommission „Schutz des Menschen und der Umwelt - Ziele und Rahmenbedingungen einer nachhaltig zukunftsverträglichen Entwicklung". Konzept Nachhaltigkeit. Vom Leitbild zur Umsetzung, 1998)3. Furthermore, does sustainable economic action also mean to ensure the financing of research and development (Rodriguez, Roman, Sturhahn & Terry, 2002). Main key indicators for the degree of economic sustainability therefore are financial reports and variables like growth rate, profits, return on investment and many more.

Social dimension

In the social dimension of sustainability, the focus lies on positive effects for the society. Values like solidarity, democracy, securing the rule of law and freedom as well as social justice contribute all to the perception of social sustainability (Abschlußbericht der Enquete-Kommission „Schutz des Menschen und der Umwelt - Ziele und Rahmenbedingungen einer nachhaltig zukunftsverträglichen Entwicklung" Konzept Nachhaltigkeit. Vom Leitbild zur Umsetzung, 1998). Rodriguez et. al, 2002 expands the notion of the social dimension with the additional factors of adequate standards of living and education of the society. Measuring the social sustainability performance is more challenging, because it is harder to quantify as we are also measuring qualitative variables. Key performance indicators in corporations can be security practices, education and training, cultural and gender diversity in employment, safety and health, as well as many more (Nikolau et al., 2019).

Environmental dimension

The environmental dimension of sustainability tackles the issue of preserving the nature. Object of preservation in this case is our whole ecosystem with all it's species and natural resources. Goal is not to interfere with our ecosystems beyond of its limits. In this way we protect our natural means of survival and our health. This therefore also includes a responsible use of resources protecting all life including animals and plants since these are also the base for a healthy human life in the long-term. Non-renewable resources like natural stone should only be used to the extent that a physically and functionally equivalent substitute is created in

[3] Final Report of the Enquete Commission "Protection of Man and the Environment - Objectives and Framework Conditions for Sustainable Development" *). Sustainability concept. From mission statement to implementation 1998

the form of renewable resources (Abschlußbericht der Enquete-Kommission „Schutz des Menschen und der Umwelt - Ziele und Rahmenbedingungen einer nachhaltig zukunftsverträglichen Entwicklung" *). Konzept Nachhaltigkeit. Vom Leitbild zur Umsetzung, 1998). Typical key-performance indicators are life cycle assesments which quantify embodied resources and emissions in order to produce a certain product like for example energy and water consumption, emission of greenhouse gases, impacts on biodiversity or resulting waste (Nikolau, Tsalis & Evangelinos, 2019).

1.3.1.3 Circular economy

The general concept of circular economy roots back to 1966 and can be summarised by the idea of Kenneth Boulding who compared our planet with a spaceship, which has a limited amount of resources and limitations regarding waste and emission capacities. In order to make this system work in the long-term a system in the form of an ecological cycle needs to be implemented which reproduces the needed resources from the waste and emissions under the input of energy (Boulding, 2019).

There are several strategic and conceptual approaches to overcome the ecological challenges of sustainable development (Weltkommission Für Umwelt Und Entwicklung, 1987)[4]. Some of these approaches are based on the goods we are seeking to preserve or the effects of human activities on the environment, including, for example, strategies for climate or marine protection. Besides that, there are strategies that focus on the cause like resource efficiency, industrial ecology and circular economy.

The first evidence for the use of the term 'circular economy' and its development into an economic concept comes from David W. Pearce in 1990 (Pearce & Turner, 1990). The principles of circular economy, which relies on closing material cycles to reduce the use of environmental reservoirs, as a counter-draft to a linear flow economy, were the subject of environmental discussions in the 1990s and 2000s (Eyerer, 1996; Pflaum, 1998; Zahn & Dogan, 1996).

Principle of the concept (as seen in figure 8) is it to prevent waste and to reuse all goods. Products are designed for disassembly and reuse in order to minimize big amounts of embodied resources like water or energy like we can find in recycled materials. Not all goods can rotate in the same economic cycle and differences have to be made. We differentiate between durable components of goods and consumable components. Consumable goods (organic components) in circular economy are designed to be the least non-toxic in order to return them to the biosphere for biological degradation and natural circulation. All goods which

[4] World Commission on Environment and Development, 1987

are manmade and of technical composition are unsuitable for biological degradation and therefore introduced into another economic circle. Good within this circle are designed for reuse and suitable for upgrades specially when it comes to electronical hardware such as computers. Since also for these circular processes energy is needed there is another and last circle within the concept of circular economy namely the energy circle. The energy used should be renewable energy and not fossil fuel based to further diminish resource dependency (McDonough & Braungart, 2002).

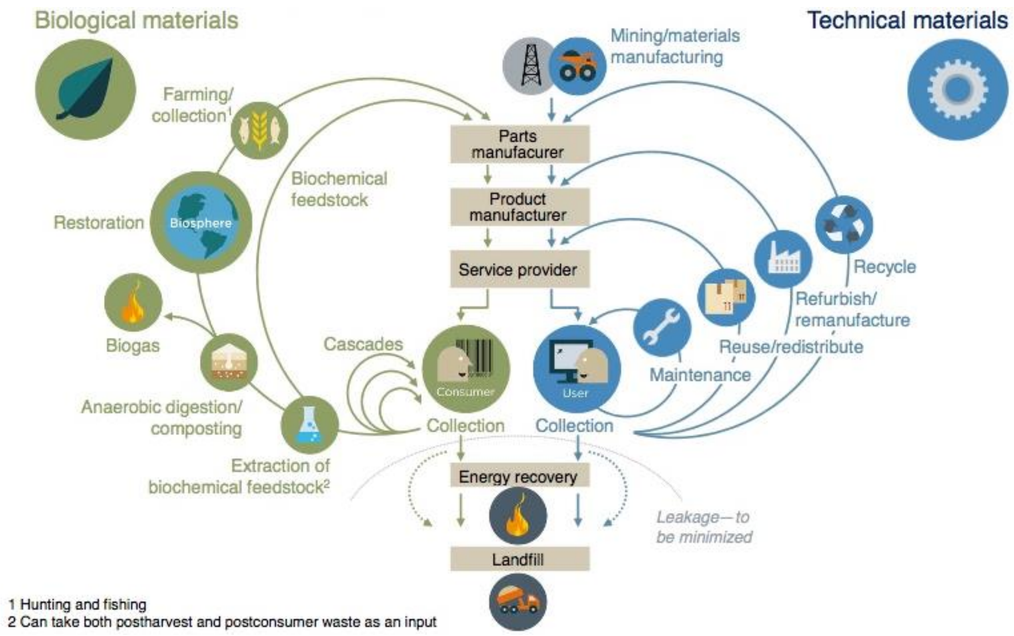

Figure 8: The circular economy (McDonough & Braungart, 2002).

The model underlines the potential of four principles of value creation. First there is the principle that with wider circles the energy and resource consumption of the loop increases. While small circles bring goods back to circulation through maintenance, big circles take steps recycling, where material is broken down into their smallest components and used as raw material which is then brought back together. The next principle is the longer goods can circulate in the loops the lower the energy and material consumption for keeping the goods in the loop. Thirdly value is created through cascaded use when a material is diversified in its reuse across the stages in the value chain. Lastly the principle of introducing only pure materials into the loops in order to facilitate disassembly and improve circulation (McDonough & Braungart, 2002).

1.4 NATURAL STONE PRODUCTION AT THE EXAMPLE OF SOLANCIS

Solancis is a Portuguese limestone manufacturer located in the district of Santárem which is going to be taken as an example for the local stone production. As a sustainability aware company Solancis will be broken down into its sustainable thinking and operation in the fields of processes, projects and sustainability management.

1.4.1.1 The company and it's history

The companies' history root back until the beginning of 1900 where José Oliveira Delgado started operating a quarry where stone material was extracted by manual operated saws and also processed. When the business was passed to next generation through heritage in 1920 the trading started and first machinery was introduced by Silvino Oliveira Delgado. The first milestone of the company was reached by the following generation when Manuel Costa Oliveira Delgado at seventeen year of age, received a work order for Lisbon's football club Benfica where they installed their stone products in the stadium 'Èstadio da Luz'. The company Solancis was originally founded by 7 parties in year of 1969. In the early nineties the company was handed over to the current generation which is now running one of the national sectors most important companies. Nowadays the company set their operational focus on exportation with 90% of all products being sold abroad and only the remaining 10% being used for the national market ("History | SOLANCIS", 2020).

1.4.1.2 Quarries

Solancis operates in eleven quarries in central Portugal (as seen in figure 9). All quarries extract limestone of different categories. The material differs by geological location in their colours (black, white, beige, blue, gray and pink), grain and vain structure, appearance of shell fragments, small fossils or other rock types as well as their use in construction applications. Variations between the categories are to explain with the different compositions of the materials as well as the densities which were set when the limestone was formed ("Quarries | SOLANCIS", 2020).

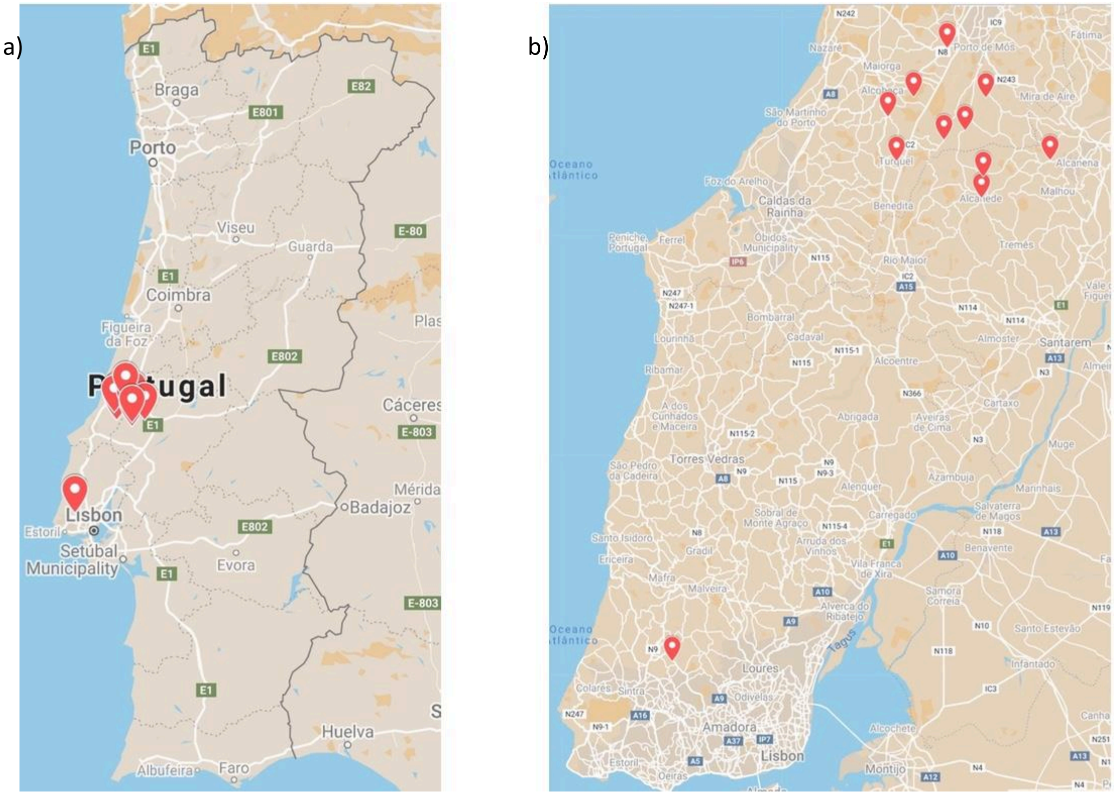

Figure 9: Locations on Google Maps of Solancis quarries in Portugal; a) on a national scale; b) on the scale of central Portugal (own figure based on: "Quarries | SOLANCIS", 2020).

1.4.1.3 Production processes

Solancis' production processes reach from the extraction till the processing of the stone material. As presented by Patricia Henriques from Solancis' marketing department on a company tour on the 5ht of December 2019 the quarries (as seen in figure 10) are operated by 3-4 workers which extract the material by cutting out blocks, which are cut into smaller slabs after holes are drilled into the block to set up the diamond wire saw. Those are then classified and transferred into inventory and transported to the processing facility when demanded ("Quarries | SOLANCIS", 2020).

Figure 10: Illustration of one of Solancis' quarries (own illustration).

Once the limestone reaches the processing facilities it is being examined for it`s most efficient cut for the desired dimensions in length, width and thickness. By cutting a block (as seen in figure 11) into several slabs the grain patterns and the course of the veins are oriented (Limestone production | SOLANCIS” 2020).

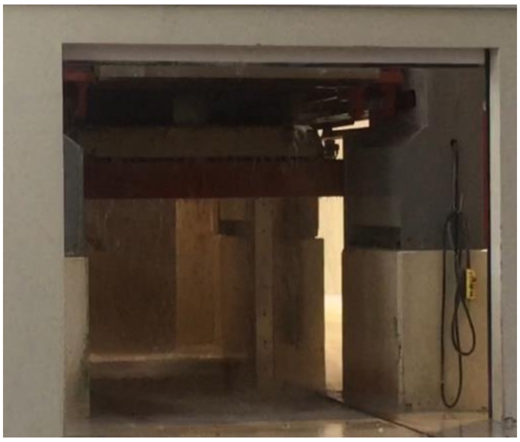

Figure 11: Multi saw at Solancis cutting multiple slabs simultaneously(own illustration).

In the next step the surface will be evened out in a polishing machine (as seen in figure 12) and the thickness of the product will be defined (Limestone production | SOLANCIS” 2020).

Figure 12: Illustration of a worker changing abrasives in the polishing machines at Solancis (own illustration).

Now the limestone slabs will be digitalized and classified in order to match material with the same characteristics in appearance in order to find material with coherent patterns that can be cut into tiles and be sold together (as seen in figure 13). The tiles are cut with veins, patterns and grain structures as well as cracks and weak spots predefining the cut-out, taking appearance and structural strength into consideration simultaneously and again digitalizing the product (Limestone production | SOLANCIS” 2020).

Figure 13: Worker at Solancis scanning limestone for weak spots before final cut (own illustration).

Lastly the surface will be treated which can vary from a brushed, scratched and hammered over flamed (as seen in figure 14) or sandblasted till a polished finish (Limestone production | SOLANCIS”, 2020).

Figure 14: Limestone receiving flamed surface treatment (own illustration).

Besides these classical processes Solancis can also produce more complex constructions using a computer numerical control mil[5] (as seen in Figure 15). Several axis (three or five axis machines) provide an increased independence in regards to the movement of the mil which then can sculpture elaborated shapes (“Limestone production | SOLANCIS”, 2020).

Figure 15: CNC mill at Solancis cutting a piece (own illustration).

Have products been cut into shape by a CNC mill or are specific finishes needed to complete the product the last step is done by hand (as seen in Figure 16). Edges and

[5] A system used in manufacturing, in which computers operate the tools and machines (“Computer numerical control | meaning in the Cambridge English Dictionary” n.d.).

imperfections are filed away by workers with handheld tools (“Limestone production | SOLANCIS”, 2020).

Figure 16: Worker at Solancis finishing a product with handheld tools (own illustration).

After grouping all products of one order together and verifying their coherence in appearance and fit to each other the stones are packaged in custom wood boxes (as seen in Figure 17) which are also produced on sight in order to guarantee adequate safety measures for the upcoming logistical processes (“Limestone production | SOLANCIS”, 2020).

Figure 17: Construction of transport boxes for the limestone (own illustration).

In order to summarize the stone sector’s most common production techniques and processes the following figure (figure 18) breaks down the usual practices of the industry.

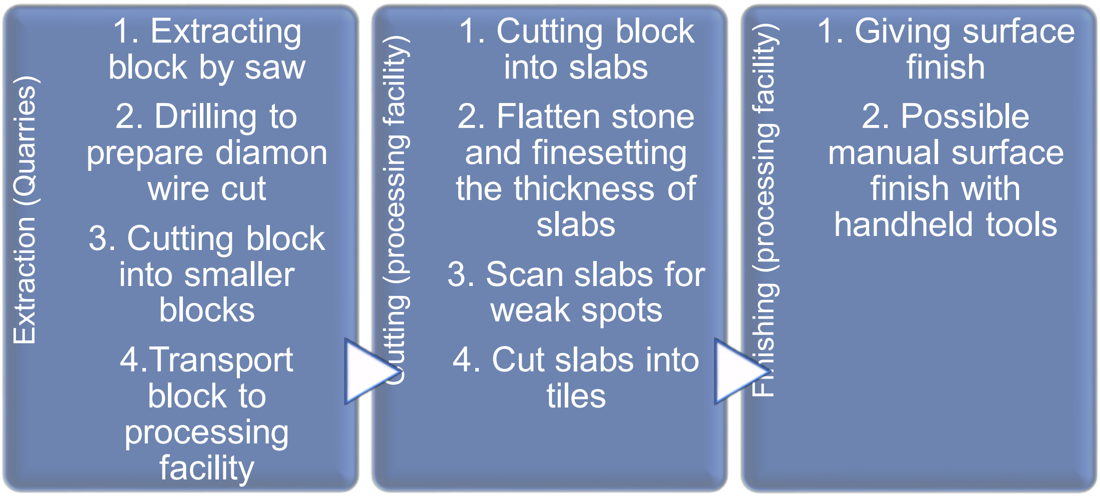

Figure 18: Scheme summing up most common natural stone production steps and techniques (own figure based on: interview with Henrique Patrícia the head of marketing at Solancis, 2019).

1.4.1.4 Projects at Solancis

Solancis realised a number of projects within the last years in order to stay competitive in dynamic and global market, to be innovative and to increase efficiency in operations.

The flexstone project introduced a prototype machine into the manufacturing facilities of Solancis which helped to optimize production processes, control and measure production cost in order to provide estimated costs for the client, improve design of products, create new products as well as provide material samples without having to shut down the automatic production lines ("PROJETO N. POCI-01-0247-FEDER-006375", 2017)[6].

Another project which was run by Solancis was neamed "Manufacturing the Future" ("PROJETO N. POCI-02-0853-FEDER-015076", 2017)[7]. Purpose of this project was it to improve the company's competitiveness and to increase the production capacity by 25% through automatization while following the lean principle which embodies the idea of making more with less and in less time. Renovations and extensions of the installations have been concluded in the fields of subproduct and waste treatment, control and optimization of energy consumption, infrastructure for transport of loads as well as communication systems ("PROJETO N. POCI-02-0853-FEDER-015076", 2017).

[6] http://www.c3i.ipportalegre.pt/uploads/Flexibilidade_intencao_compra.pdf, obtained 20th of February, 2020

[7] https://bit.ly/3cOeH3z, obtained 20th of February, 2020

“Calcitec” is a project which facilitated the predictability of highly demanded blue colours in limestone in the quarries as well as chromatic alterations of material (“Projeto CALCITEC”, 2017).

Solancis is also involved in a project called “INOVWALL” which develops modular walls for the use in sustainable and eco-effcient construction and rehabilitation (“INOVWALL”, 2020).[8]

The INstone project by Solancis explores the use of smart systems in natural stone products to control sensors, light and heating systems as well as general application in smart housing (“INStone”, 2017).

Inovstone 4.0 has been Solancis’ latest project. The objective is to turn the ornamental stone sector more dynamic and to strengthen its competitiveness in regards to the procurement models in the form of Building Information Model (“PROJETO N. 24535”, 2018)[9].

1.4.1.5 Sustainability at Solancis

In this chapter the focus will be set on Solancis’ sustainability management in regard to its three dimensions.

Social sustainability measures

Within the social dimension, one of the measures are the staff events at Solancis according to Henriques, Patrícia the marketing head of the company. On occaisions like the holiday seasons events are organized for the employees to strengthen team bonding and group cohesion (Henriques, 2019). Furthermore, some of the company’s projects are contributing to the social dimension of sustainability. The lean approach of flexstone established a zero-waste mentality and the implemented residual transport system (as seen in figure 19) lead the working spaces (at the quarries and the processing facility) to be completely clean and preventing injuries through tripping over secondary material as well as preventing high air dust concentrations which can lead to respiratory diseases.

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[8] http://www.itecons.uc.pt/projectos/inovwall/index.php?module=sec&id=798, obtained 20th of February, 2020

[9] https://sites.fct.unl.pt/inovstone4_0/files/projeto_inovstone_4.0_unl_fct_1.pdf, obtained 20th of February, 2020

Figure 19: Collection point for underground transport system of secondary products.

Moreover, did the "Manufacturing in the Future" project facilitate the transport of heavy loads through the use of a manual crane system from the extraction till the processing and therefore decrease physical effort for the workers and also lower the probability of transport related accidents. The ISO 45001 for occupational health and safety are also followed by Solancis to protect the employees ("Sustainability | SOLANCIS", 2015).

Economic sustainability measures

From an economic perspective there are also sustainability measures to see in Solancis projects. Process optimization and acceleration through renovating the facilities and automatization as well as cutting energy costs by implementing innovative and more efficient machinery were realized through the "FlexStone" and "Manufacturing the Future". Furthermore, was stone waste eliminated within the "FlexStone" project and all residuals in form of stones, fragments and dust were seen as secondary products and collected and introduced into other industries that can use the material as filler for construction material for example. Through this lean thinking approach cost for transportation of the incurring material can be avoided.

In regards of the future development Solancis also invested in a projects which are called "InStone" and "InovStone 4.0" and drove the innovation for the company and kept it competitive.

Figure 20: Solancis' innovative smart home product from the "INstone" project ("INStone", 2017)

New product development, connecting stone material with smart home infrastructures (as seen in figure 20) as well as revolutionary procurement strategies with building information modelling are measures to keep Solancis relevant on the market and financially profitable in the long term.

Environmental sustainability measures

Measures that favour the environment can also be found in the projects Solancis participates in but also in the ISO standards the company follows. The ISO standard 14001 for environmental management systems is implemented in order to enhance the environmental performance ("Sustainability | SOLANCIS", 2015; ISO - International Organization for Standardization, 2018).

The company's biggest environmental impact lies in the quarrying activities. In order to countermeasure the adverse effects on the environment by extracting natural resources an "Environmental and Landscape Recovery Plan" has to be developed by each licensed quarry. It covers the topics of operational measures during extraction activities in the quarry, recovery plans for the touched landscapes as well as options to close the quarry after termination of activity. For operations in quarries which are located in the Natural Park Serras de Aire and Candeeiros, Solancis follows the regulation which were set up to protect the area. Depending on the degree of protection of the declared area up to twice the amount of the extraction is being recovered by Solancis in order to be allowed to run the quarry (“Sustainability | SOLANCIS”, 2015).

“FlexStone” and “Manufacturing the Future” embody also environmental measures as new machinery, the sophisticated secondary material transport system, the rainwater catching and filtering system (as seen in figure 21) for the cooling water in the factory helped to reduce energy and resource consumption.

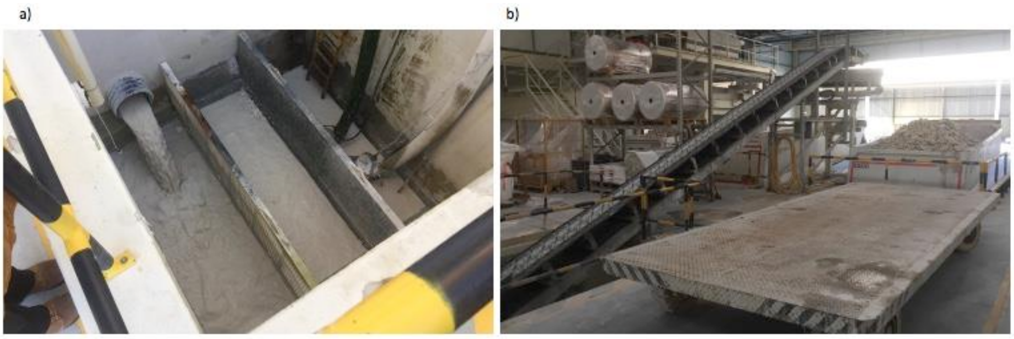

Figure 21: a) Filtersystem which recycles the water at Solancis. b) Conceyor belt transporting collected secondary material from the production site to a truck.

In addition to this solar energy panels were installed on the roof to further lower the environmental impact of the company (Henriques, 2018).

1.5 RESTATEMENT OF THE INVESTIGATION

Main issue of this research is the implementation of circular economy based on Solancis, a company that has a high sustainability awareness and translates it well to their operations. The interview with Patrícia Henriques at Solancis as well as the review of the company’s website in connection with the literature review in the field of sustainability and circular economy suggest that high standards are set in the operations when comparing to the sector’s average processes.

Still are we witnessing a climate that is slipping out of balance and change has to be driven on a deeper level than currently in order to turn fully sustainable. As we saw is the production of natural stone an energy and resource intensive series of processes. With new and innovative technology, it was already possible to turn more efficient but nevertheless are we facing a depletion of unrenewable resources in the long term. Changing the operations strategy from linear economy to circular economy has very much potential to reduce the environmental footprint of the natural stone production. The result of this research should help to guide the implementation of the transition to circular economy, underline the benefits and suggest an operational model.

Chapter 2: **Pedagogical note**

2.1 AUDIENCE

The case study research targets the following audience: stakeholders of the natural stone sector, stakeholders of the construction sector, undergraduate students in the fields of sustainability, economy or management, researchers and the local governmental entities to give an deeper understanding of sustainable resource usage and to raise awareness for modern solutions like circular economy in order to change the paradigm. The educational objectives for the research are outlined below.

2.2 LEARNING GOALS

This case study aims to fulfill the following educational goals:

- To undertake an analytic and descriptive analysis of the natural stone sector in Portugal.
- Investigate the natural stone production and its contribution to the Portuguese economy.
- To evaluate the degree of corporate sustainable action.
- Get an understanding of sustainability and its elements at the example of Solancis.
- Developing a sustainable operational strategy for the natural stone industry.

2.3 LITERATURE REVIEW

The literature review describes the research done around the natural stone sector in the fields of procurement models with building information modelling, environmental impact with lifecycle analysis and sustainable strategies with circular economy model implementation. Reviewing the bibliography provided new insights on the benefits and translation to circular economy.

2.3.1.1 Building information modelling

In the construction sector building information modelling (as seen in figure 22) is used to plan buildings prior to their construction. Computer software helps to design a virtual model which assists in controlling the whole project from planning the structure, procuring building material, assessing environmental impacts, calculate costs, accompanying construction processes and deconstructing or demolishing buildings (Alvarez Antón & Díaz, 2014).

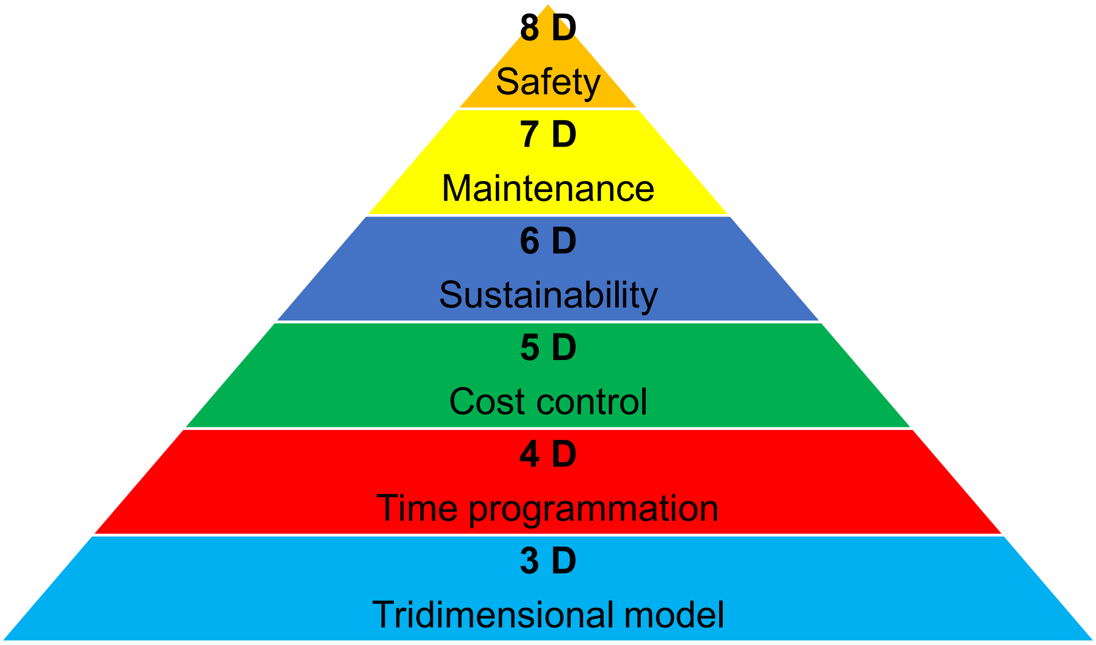

Figure 22: Concept of the 8 dimensions of Building Information Modelling (Smith, 2014).

The software can be understood as a database to optimise construction by improving communication between the collaborators though increased information transparency (Barazzeti, Banfi, Brumana, Gusmeroli, Previtali & Schiantarelli, 2015). All items in the database need to contain information about each product's life-cycle. When all parties work together building information modelling has great potential to contribute to lower the environmental impact by avoiding waste and improving efficiency ("Digital Built Britain. Level 3 Building Information Modelling - Strategic Plan.", 2015). Essential steps in this case study are therefore mainly the design phase as well as the demolishing phase of the lifecycle of every project as they might have potential to help the implementation of circular economy.

As the modeler or designer uses virtual objects in the software to set up a scheme of the building which are provided by third parties namely the material suppliers. In this first step (standing for the first three dimensions) the measurements and design of the building material is used in order to virtually construct the model (Marinho, 2014). At this point natural stone manufacturer can shape their products and innovate their mounting since the reversibility of construction processes is one of the biggest challenges in reusing reclaimed stone ("CASE STUDY: THE USE OF RECLAIMED STONE IN BUILDING CONSTRUCTION", 2009). Modular applications of stone material similar to Solancis' project "INOVwall" could facilitate the deconstruction of buildings and reclaim of building material after the lifecycle of the building is exhausted.

Dimensions four and five of building information modelling process data regarding time and cost planning of the whole process from initial planning till demolition of the building in order to supervise and control the procedures ("What is 5D BIM", 2015).

The sixth dimension of building information modelling is addressing the items ecological footprint (Wong & Zhou, 2015). If natural stone producers conduct life cycle analysis of their products and their retrieved products after the lifetime of a building has passed, they can feed the database with the necessary information. Especially the reused material will benefit in the material selection process through the decreased environmental impact.

Demolishing or deconstructing buildings is the subject of the seventh dimension of building information modelling (Barazzeti et al., 2015). As explained earlier covers this dimension the information regarding the finalization of a building after it's lifetime. Information like maintenance, reuse and recycling possibilities as well as planned deconstruction or demolition are collected and organized. Natural stone material which was used in the building should at this point be recovered since the lifetime under the correct maintenance stone should exceed the temporal use of the building.

2.3.1.2 Life cycle analysis studies in the natural stone sector

Life cycle analysis (as seen in figure 23) have the purpose to evaluate possible environmental impacts of a produced good throughout its whole life (Castoldi, Gadioli, Fernández, Tecnologista, Abiliane de Andrade, Bolista, … Bolista, 2012).

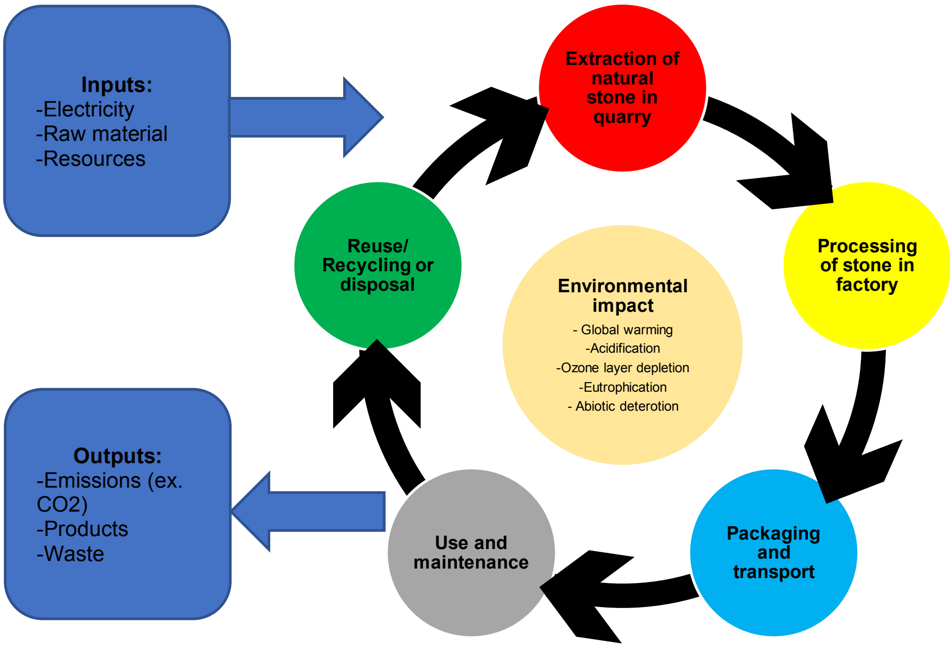

Figure 23: Life cycle analysis model cradle to cradle for the natural stone production (own figure based on: (Castoldi et al. 2012).

The procedure is standardized by regulations of the International Organization for Standardization as well as the European commission under ISO 14040 and the International Reference Life-cycle Data System Handbook guidelines (Bianco & Belengini, 2017). The investigated frame reaches from the raw material extraction (also named cradle) till its point of sale (also named gate) or disposal (also named grave). If the material is looping in cyles, the spectrum is called cradle to cradle (Castoldi et al. 2012). Life cycle assessments consist of four stages: defining scope and goal with their system boundaries and assumptions, life-cycle inventory analysis, life- cycle impact assessment as well as the interpretation of the results (Traverso, Rizzo & Finkbeiner, 2009). Whereas the first steps set the frame of the assessment and define what is being observed the second step compiles all inputs (for example energy and raw materials) and outputs (for example emissions and wastes) throughout every stage of the product's life-cycle are calculated (Castoldi et al. 2012). This stage is followed by the impact analysis where effects on air, soil, water, health of humans and animals as well as the environment in general are captured. Lastly in the interpretation of the results either aims at improving the Life Cycle Inventory to match the needs which were set in the study goal or it aims at comparing results with each other to draw conclusions (European Comission, 2010).

Bianco and Belengini investigated life-cycle data sets from cradle to gate in the natural stone sector of Italy in 2017. The production of soft and hard stones was analysed from quarrying over processing and finishing it. Primary data was collected in selected production sites of Italian marble. Only the processes of the cutting was evaluated in the end since the aim of the study was it to create first datasets for the natural stone production. Secondary data was used to complete the information around the consumption of electric energy, lime and steel elements in the form of blades and grit. The researchers discovered that high amounts of material are required for the multi-blade cutting processes. This is to explain with the amount of blades and multiple cuts that are being performed simultaneously. Concluding it must be said that life-cycle databases are not complete when it comes to processes of the natural stone production and therefore a lot of assumptions were made in the study, which limits the inductiveness of this study due to unmet significance.

In Brazil we can find life-cycle inventory studies of dimension stones. Castoldi et al. concluded research similar to Bianco & Belengini's in 2012 and aimed at creating data for the databases for the stone production in Brazil. The results underlined the challenges the mostly medium sized enterprises are facing in the implementation of life cycle assessments. Operational processes are not always well documented, since measuring the environmental impacts can be a complex, time and money intensive procedure. Tracking in- and outputs of the different production stages are common burdens for the companies and complicate the interpretation of results.

In 2013 Mendoza, Feced, Feijoo, Josa, Gabarell & Rieradevall were researching on life cycle inventory analysis of the Spanish granite production from cradle to gate. Per defined unit of 1 m^2 finished granite tiles the products embodied 28 kWh of electric energy, 23 MJ of diesel, 103 l of water and 7 kg ancillary materials reaching a resource efficiency of 31%. While a granite tile of 1 m^2 weighs 53 kg, 117 kg of stone waste is accumulated which consists of 74 % merchantable scrap material. Regarding the composition of the energy demand it was found out that for the production of finished tile when started from an entire excavated granite block it takes 4 % of the total electric and consumption 94 % of the total fuel (diesel) consumption for the quarrying. During the processing of the stone material sawing consumes 54 % of total electric and 2 % of total fuel consumption. For further illustration of the relative energy consumption of processing granite blocks consult figure 6.

Energy demand	**Quarrying**	**Processing**		
		Sawing	Finishing (polishing)	Cutting
Electricity	4,5 %	54,5 %	6 %	35 %
Diesel	95 %	2 %	2 %	2 %

Table 2: Relative energy consumption of processing granite blocks into tiles (Mendoza et al., 2013).

Traverso, Rizzo and Finkbeiner studied the environmental performance of marble from Sicily in 2009 and used the ISO 14040/44 Life-cycle assessment. Comparing to the research of Mendoza et al. 2013, in this study the emission on the used fuel was also observed. Per MJ of consumed electric energy 200,5 g of CO^2 are emitted and regarding the fuel (diesel) consumption 74 g/MJ are released into the atmosphere.

2.3.1.3 Circular economy implementation at Solancis

Based on the results from the just reviewed fields of building information modelling and life-cycle assessments this work is now applying this knowledge on the topic of circular economy and aiming at recommending on how to close the loop of the natural stone production.

Vötsch 2014 investigated the CO^2 footprints of reused natural stone applied in the construction of walls. He compared the footprints of natural stone from the wall construction sector from conventional Chinese linear economy production with locally reused natural stone material. Summing up it was discovered that the Chinese material has a 69 times higher global warming potential with 300,44 kg CO^2-e/t than the local reused stone material with a emission of 4,34 kg CO^2-e/t. Non reused local stone material was also taken into consideration and compared to reused material. Also here the non-reused material had higher global warming potential with a emission of 20,40 kg CO^2-e/t, exceeding the reused material by 14 times.

Life-cycle assessments already high lightened the potential savings in global warming potential if the quarrying would turn obsolete and Vötsch's analysis strengthened this idea as well. With the help of the already presented building information modelling dimensions a model for circular economy in the Portuguese stone production will be developed.

By turning the linear economy of the Portuguese stone production to circular economy, the idea is to diminish the extraction activities until in the long term no extrication at all will be needed anymore. As already explained is natural stone a scarce and non-renewable resource which will be completely depleted within the next couple generations. In order to keep the business sustainable in the long-term the environment with its mineral resources must be conserved by changing the strategy drastically so that future generations find themselves in a at least comparable surrounding. Ending extraction would mean a serious raw material sourcing problem for the natural stone businesses. If no new material is being extracted the only solution would be to follow the concept of circular economy where stone is reclaimed from buildings that reached the end of their lifetime and introduced back into the supply chain.

Stones would then be processed again in the existing processing facilities to refurbish the material for new custom use of their clients. This process would be limited to applications where the customer either demands identical or smaller dimension of products as the material can only be reduced an no new material can be added without gluing at this point of time. Shifting from custom sizing to standardized building units or three-dimensional printers may be a promising technology to fix this problem in the future.

With the help of building information modelling the biggest barrier of implementing circular economy can be overcome namely the organisation of information. In order to make construction material reusable and circle in tight and numerous loops a lot of communication as well as adaption between the entities is needed in the fields of design and cocreation.

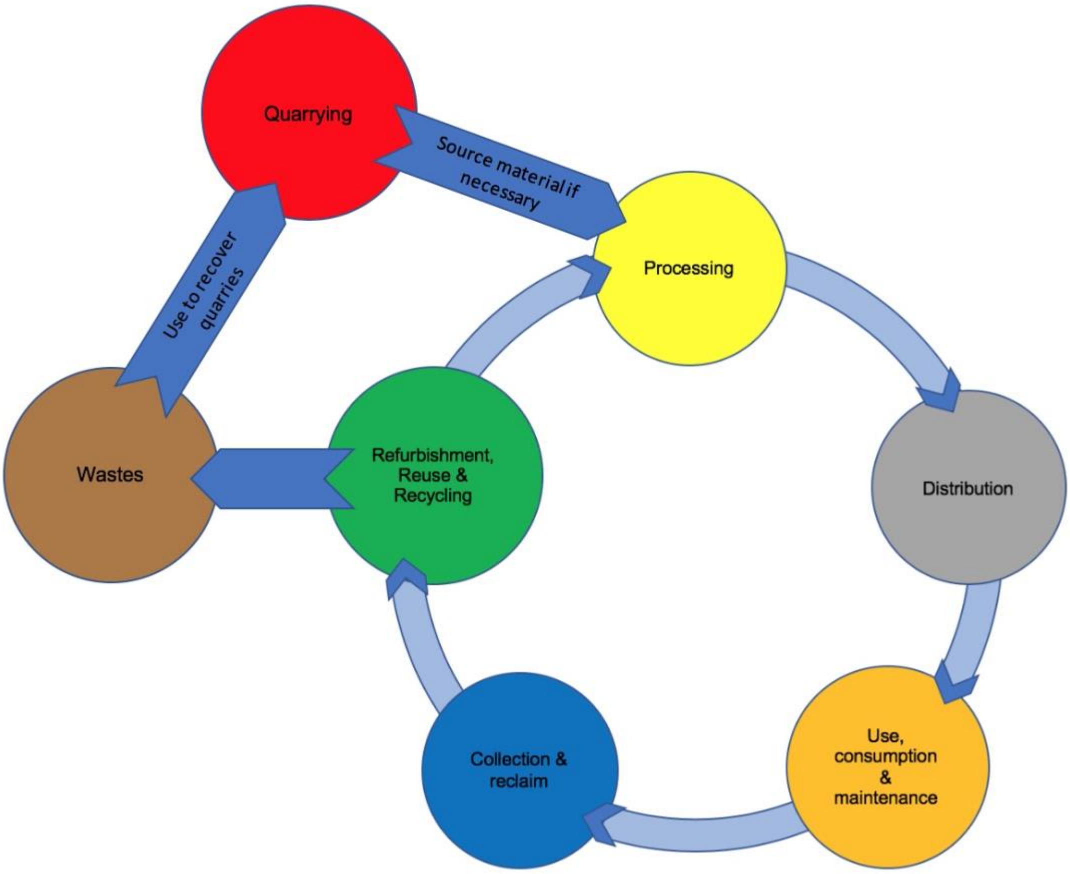

Figure 24: Circular economy model for the Portuguese natural stone production (own figure).

First a transparent database needs to be built to include all natural stone products into an inventory with detailed information about the application of the stone, probable duration of use, size, appearance etc in order to find a matching stone for refurbishment or reuse that will be reclaimed, processed and resold. Furthermore, it will take a new design that facilitates the mounting and demounting of the stones as a whole piece since reclaiming construction material in buildings would be hardly possible if the mounting is not reversible. Especially the economic feasibility will be mostly defined through the effort it takes to reclaim the material and ideally it should not be more cost intensive than quarrying stone. At the example of building information modellings fourth and fifth model time and costs should also be scheduled and calculated across the involved entities in the most efficient way possible. Lastly are the sixth and seventh dimension which deal with sustainability and maintenance. Also, in the circular economy model this can be integrated since data around the environmental impact of construction material as well as maintenance and deconstruction manuals will be necessary to run the model.

Chapter 3: **Methodology**

The research for this pedagogical case study involved a descriptive literature review (of Building information modelling, Life-cycle Assessments and Circular economy) as well as an interview with Henrique Patrícia the head of marketing at Solancis in order to lay out the status quo of the production of natural stone, it's application and it's overall impact in the dimensions of sustainability.

The adopted methodology was held basic as different fields such as resource scarcity, industrial production, sustainability analysis and business strategy were drawn together in this study. Facts are being exposed and contents collected to give a broad overview of the most relevant topics. Portuguese sources were investigated and cross-checked with material from international organizations, which were relevant to the theme of this study. A hybrid approach was chosen, correlating positive and interpretive judgement as most of the research to this current problem is still very young and little correlated in an inter-disciplinary point of view. The work is supported by content from private companies of the natural stone industry, empirical knowledge, as well as governmental regulations to cover a balanced perspective on this topic.

The systematic search enables an accurate expression of the needed information. Firstly, an extensive research of the various areas contributing to the implementation of circular economy was conducted. That was completed by reviewing cases, contextual studies and literature.

An investigation in this area is difficult to perform due to the recentness and the absence of in-depth follow-up studies.

A qualitative approach was adopted in data collection, and the main sources of information were; Solancis, UN-reports, European Commission, websites of natural stone producers, the observatory of economic complexity and the Natural stone council. In particular, the leading authors were Bianco & Belengini (2012), Castoldi et al. (2012) and Traverso, Rizzo & Finkbeiner (2009), as they are the leading authors in the research of natural stone production and it's environmental impacts, recycling and reuse. Second tier literature that was reviewed were political reports by the German government, the EU Comission as well as authors like McDonough & Braungart (2002) to extrapolate sustainable models, regulations and recommendations that were then applied on the natural stone sector.

Chapter 4: **Analytical tools**

Circular economy in the Portuguese natural stone production SWOT Analysis

Strengths

With the implementation of circular economy, the communities around Solancis would benefit through an improved quality of life. Less or even no excavation will avoid disturbances for the surrounding areas of the quarries. There would be less noise from the machinery, less dust particles in the air and less traffic as less raw material is moved around in the logistics.

Another strength of the proposed model in figure 24 is that the product's environmental impact would decrease comparing to the current operational approach. Eliminating the quarrying activities would significantly lower the impact despite the emerging production steps of the deconstruction and backwards logistics which are essential for the model's viability.

As natural stone is considered a scarce (because of its unequal distribution) and non-renewable resource the biggest benefit of circular economy in the natural stone sector would be the independence from finite natural resource deposits. Since the material circulates in loops the need to introduce new stone material will decrease and in the long term, best case scenario become completely obsolete. The economy would therefore never run out of raw material.

The last strength lies within the change from a one-time sale to the consumer to offering a long-term service. Maintaining as well as disposing the construction raw material for the customer will lead to higher proximity and retainment of customers as they are standing in a more committed and long-term relationship.

Weaknesses

The most challenging points of the realization of circular economy are the backwards logistics as well as the cooperation between the involved entities. In order to build up the backwards logistics for this strategy a high financial investment and a high degree of collaboration between the construction sector and the raw material manufacturers will be necessary. Processes will need to be aligned regarding the timing and the know how in regards of the construction/deconstruction. Furthermore, a lot of changes in the operation of Solancis were already realized which first needs to bring a return on investment before another major investment will be applied in order to keep the financial reserves and the risk of insolvency low.

Stone is a natural product and varies in it's appearance of color, grain size and the courses of veiny patterns which makes it complicated to reapply a stone in another use. A stone is initially adapted to its application and can therefore only be used in similar uses in order to keep most of the material in circulation without the creation of big amount of wastes. A lot of cut would arise if for example a big slab would have to be processed to a single tile. In addition it can be challenging to find matching stones for the new construction purpose as the patterns of the natural stone should ideally align with each other when reapplied in a new building.

If the demand for natural stone exceeds the deconstruction rates of buildings which contain the desired material, the model of circular economy will reach its limit. By excluding the introduction of new raw material only products which were already processed can be used. When the deconstruction of houses falls out there is no material available to be reused and operations will stop.

Opportunities

Currently there is no market for reused natural stone material. That means if the idea is carried out there will be no competitors on the market. This gives the opportunity to solely serve the market as well as acting as the role model for the entire industry by showing the viability of simultaneous economic, social and environmental sustainability without compromises between the dimensions.

Politically and societally we are currently living in a time of ecologic and sustainable spirit and awareness. Implementing circular economy might therefore create the opportunity to run a green image for the company Solancis in order to retain and acquire new customers through the improved image of the company.

The European Commission is very likely to make their recommendations of sustainable action lawful as the economy is being driven to many green goals. If sustainability reports become compulsory the implementation of circular economy will set Solancis even further apart from its competitors and also prevent the company from violating laws which might be passed in the future.

Threats

When it comes to the threats of implementing circular economy one of the probably least predictable behavior is the one of the consumers. In a financially driven capitalistic system, the price might be the most important decision driver. Since the alteration of the company's strategy will most likely consequent in a rise in the price of the produced marble due to the needed investment other competitors might be able to underbid. Depending on the importance the customer gives to the environmental impact of the purchased product in relation to its price there is a valid threat of him opting for other products on the market.

The model of circular economy depends on a sophisticated bidirectional distribution system. Natural stone material is very heavy and therefore costly to transport. Changes in fuel prices can affect the viability tremendously but current developments like hydrogen and electric engines might help to face this challenge in order to lower the risk.

In table 3 the summary of the just performed SWAT analysis can be consulted.

Strengths	**Weaknesses**	**Opportunities**	**Threats**
Improved quality of living for communities	Hard to implement due to costly backwards logistics	Gap in the market	Consumer might opt for cheaper alternatives
Product has lower environmental impact	Stone is unique and hard to standardize	Capture the spirit of modern times	High sensitivity to transport costs
Sustainable long-term operation	Cooperation between involved entities is very challenging	European Commission plans to make their recommendations/ goals lawful	
Service instead of one-time sale	Resource shortage If demand higher than deconstruction rate	Role model position for the industry	

Table 3: SWOT analysis summary for the implementation of circular economy in natural stone industrial sector.

Chapter 5: **Lecture plan and issues to be resolved**

After having presented the natural stone industry with it's characteristics, the concept of sustainability with circular economy as well as Solancis the object of this investigation was the possible implementation of circular economy from existing tools and knowledge.

Besides the direct effects on the extraction industry the task now is to get an understanding how complex the effects of sustainable action are and who is becoming in what degree and form of subject of those.

The following issues and situations emerged from this case study and should be worked on by the students:

1. A stakeholder in a business setting is responsible for the outcomes (positive or negative) of the business. In the present case, they define the enhancements and future orientations for the sector.
    1.1. Identify the stakeholders of the natural stone industry in Portugal. Present your findings in a stakeholder map.
    1.2. Describe the demands of these stakeholders.
2. Explain the characteristics of natural stones that make it a suitable good for the implementation of circular economy.
3. Sustainability is seen as an integration of, or a win-win-win situation between, ecological, economic and social dimensions and nowadays more and more companies integrate sustainability in their business strategy.
    3.1. Identify and describe the dimensions of sustainability that are touched by the implementation of circular economy in the natural stone sector.
    3.2 Analyze the importance of sustainability indicators in the natural stone sector.

4. The built environment offers a huge opportunity for businesses, governments and cities to play a leading role in realizing circular economy without having to wait for the transformation of the whole system. New tools and platforms will support the change; the construction industry is already using Building Information Modelling or BIM, which combines people, processes and technology, to drive efficiency and improve performance.

- Considering this, evaluate how the concepts of Circular Economy and BIM will help the natural stone sector to make a new business strategy formulation.

Chapter 6: **Resolution**

1. *Who are the stakeholders of the natural stone industry in Portugal? Present your findings in a stakeholder map.*

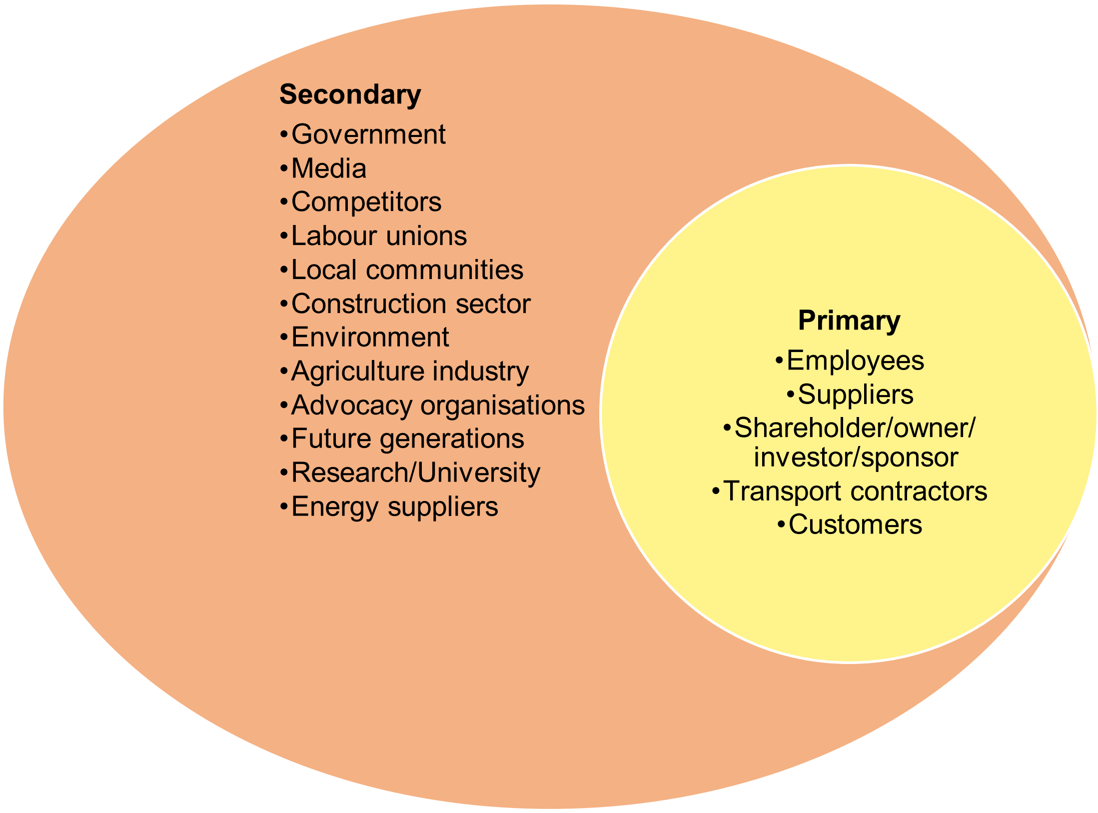

Figure 25: Stakeholder map of the Portuguese natural stone industry (own illustration).

1.1. *What are the demands of these stakeholders?*

Primary Stakeholders

- Employees → secure job, appropriate working conditions, fulfillment, self-development, group belonging
- Suppliers → punctual payment, long term cooperation, feedback and cooperation on product improvement
- Shareholder/owner/ investor/sponsor → return on investment, word in decision making, transparency and information by company

- Transport contractors → consistent and punctual operations, aligned processes, commitment
- Customers → quality products, good customer service, fair prices and products, good corporate responsibility

Secondary Stakeholders

- Government → taxes, following laws and regulations, good social environmental and economic performance
- Media → information, transparent communication
- Competitors → fair competition, co-competition, supporting common interests against other parties like the state for example
- Labour unions → fair working conditions, long term jobs, fair salaries
- Local communities → jobs, social support, no irresponsible disturbance in regards of environment (emission into air, soil, nature and noise)
- Construction sector → constant and reliable supply, aligned working processes, development and improvement of construction material
- Environment → compliance of environmental regulations, restoration of old quarries and surrounding nature
- Agriculture industry → secondary products, no to reasonable pollution of surrounding areas to not interfere with their activities
- Advocacy organisations → compliance of laws and regulations, open and transparent communication, no green washing
- Future generations → sustainable action, reasonable use of resources
- Research/University → cooperation in order to generate new knowledge, practical expertise
- Energy suppliers → constant demand, long term commitment and contracts

2. *Which characteristics of natural stones make it a suitable good for the implementation of circular economy?*

- Very long lifetime of stone products
- Products can be broken down into smaller pieces
- Variety of uses
- Contains no to very little toxic substances depending on way of processing
- Product will always be in demand as construction will always be needed
- Low maintenance material
- Little need of refurbishment for reuse

3. *Which dimensions of sustainability are touched by the implementation of circular economy in the natural stone production sector?*

3.1. *Which effects and measures are imaginable in the different dimensions through the implementation of circular economy?*

3.2 *Analyze the importance of sustainability indicators in the natural stone sector.*

The implementation of circular economy would touch all three dimensions of sustainability but especially the environmental dimension in the first place. Socially and economically effects would also be observable but rather in an indirect way or in the long-term and not instantly.

Environmentally the most profound impact would be stopping the depletion of natural resources and the resulting preservation of for future uses of the following generations. Moreover, would emissions decrease in the form of acidification and de-mineralization of the ground water through missing filtration of the excavated stone material as well as the created fine dust. Wildlife would not be disturbed by the noise in the quarries anymore and their habitat would not have to be transferred anymore when new land is being excavated. Air pollution would as well decrease as less dust and greenhouse gases will be emitted to the air through lower energy demand.

Socially the transformation of the business strategy would create a lot of jobs since the backwards logistics would need to be introduced. A lower environmental impact of the production could also lead to higher job satisfaction and fulfillment for the employees since they are seeing their profession less in conflict with the preservation of nature. Local communities could benefit from less disturbances in regards of noise, pollution, traffic, degradation of infrastructure as well as interference with other industries as agriculture. When thinking of future generations, the probably most elementary social effect is highlighted by the conservation of nature and resources and therefore also the possible continuity of operation in the sector and livelihood in general.

Economically speaking the implementation of circular economy would first of all secure a long-term operation which in theory sustains forever since the natural resource of stone would never run out. After the initial investment which will be very costly a decrease in operational cost would be imaginable due to lower energy demand and the redundancy of the quarrying machinery as well as the need for restoration of the nature.

4. The built environment offers a huge opportunity for businesses, governments and cities to play a leading role in realizing circular economy without having to wait for the transformation of the whole system. New tools and platforms will support the change; the construction industry is already using Building Information Modelling or BIM, which combines people, processes and technology, to drive efficiency and improve performance.

- Considering this, evaluate how the concepts of Circular Economy and BIM will help the natural stone sector to make a new business strategy formulation.

The two concepts of Circular Economy and BIM together offer a complementary effect which gives the opportunity to decrease the environmental impact starting from the creation of building material till the application of the material throughout its whole lifecycle by joining the industries of raw material production and construction.

Implementing Circular Economy aims at lowering overall environmental impact by reducing the use of resources in product creation and expanding the useful life of the product to its actual life cycle. The concept of BIM creates great possibilities in planning the use of building materials throughout its actual life span and this means even beyond the useful life of a building.

A symbiosis of the two concepts in question may offer an innovative perspective on how to revolutionize the way we use resources and how we plan their use. For the natural stone sector this means in particular the opportunity of creating a business strategy which can help the industry to sustainably operate in the long-term, without running risk of completely depleting it’s scarce and finite natural resource. The industry will have to shift from its co-dependent relation with the construction sector to an integrated relation – changing from supplying the construction sector to providing a service of material management. Since ideally all material will find itself being circularly reused the quarrying and production of new natural stone products would become obsolete and the industry would move towards refurbishing old material and preparing it for its re-entry in the circular economy.

Chapter 7: **Conclusion**

Natural stone can turn into a very scarce resource within the next generations as concluded earlier based on the great increase of our population we are facing till 2100. Construction of needed housing and infrastructure for the additional population in the next years, runs fear to become very challenging as we can see at construction delays due to missing raw material in the present. It is our responsibility to leave the planet as we found it and not to exploit all resources which might be one of the biggest threats for the future economy.

In order to turn our action fully sustainable in all of its dimensions and to satisfy all relevant stakeholders in their varying needs we are still facing lots of challenges. The status quo needs to be changed and the environment is doing its best to open our eyes through rising temperatures, ozone layer depletion, droughts, floods and in many more ways. Climate change is not evitable and this work is tackling one of the many industries that show great potential for revolutionary strategic models. Especially in industries which work with non-renewable resources the concept of circular economy solves many of the described burdens that are ahead and should be implemented better sooner than late. The described properties of natural stone show the suitability of the material for the implementation of circular economy. The implementation in this case promises to improve all three dimensions of sustainability by reducing the environmental pollution, socially by creating new job opportunities and improving quality of life for local communities as well as economically by raising efficiency and viability of the business strategy in the long-term when comparing to current practices.

A final remark about this study and the approached issues is the opportunity to use it as a reference for future research and for decision making in the strategic management of the Portuguese natural stone sector. Business models are being constantly improved and turned green in increasing measures. It is possible to witness great improvements on the environmental impact as we can at Solancis projects for example. The company can be understood as a role model for the whole natural stone production sector and their degree of sustainability should turn standard for the whole industry which mostly still id lacking the desired mindset until today. Still, the long-term viability of Solancis business model as well as their operational processes remain questionable when looking towards the future.

Production process in the natural stone production are very energy consuming and waste intensive. At the same time does the material have a very long lifetime and often exceeds the lifetime of its construction application. Taking into consideration that stone will be a scarce and non-renewable resource it is obvious that the implementation of circular economy could bring great benefits. This underlines the feasibility of the application in the natural stone production and could help to stop the quarrying, which has the biggest environmental impact of the operational processes. Even after the implementation of circular economy the industry will not be free from emission, waste and high energy consumption but it would decrease drastically through the tighter circles that stone products will loop in. Goal should be to further improve process efficiency of the remaining activities in order to possibly develop to an emission free industry one day.

While the preservation of nature is not yet fully regulated by the state a trend towards this goal is clearly to see, especially in the European Union. Today sustainability reports are published by companies on a voluntary basis since most of the environmental guidelines are still just recommendations. In the near future the economy is likely to change and recommendations will be turned into lawful legislations that will need to be followed by the companies. Building information modeling as well as life cycle analysis are tools that are being currently developed, which will also enable the industries to track and manage their use of resources om order to attain possible limiting values that might be formulated in the near future.

Since this change is coming and foreseeable it is probably that the recommended application of circular economy in the natural stone production is a profitable gap in the market. What looks like a revolution of the industry based on major financial investment today could be the unique selling proposition of the future and the only way to operate fully sustainable without compensating on the needs of future generations.

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