LIFE CYCLE ASSESSMENT OF ITALIAN ORNAMENTAL STONES. ANALYSIS OF PROCESSES AND DEVELOPMENT OF AN ADAPTABLE MODEL

Original
LIFE CYCLE ASSESSMENT OF ITALIAN ORNAMENTAL STONES. ANALYSIS OF PROCESSES AND DEVELOPMENT OF AN ADAPTABLE MODEL / Bianco, Isabella; Blengini, Gian Andrea. - In: ITALIAN JOURNAL OF ENGINEERING GEOLOGY AND ENVIRONMENT. - ISSN 1825-6635. - Special Issue 2:(2017), pp. 17-23. [10.4408/IJEGE.2017-02.S-02]

Availability:
This version is available at: 11583/2707710 since: 2018-05-18T17:01:35Z

Publisher:
Sapienza Università Editrice

Published
DOI:10.4408/IJEGE.2017-02.S-02

DOI: 10.4408/IJEGE.2017-02.S-02

LIFE CYCLE ASSESSMENT OF ITALIAN ORNAMENTAL STONES. ANALYSIS OF PROCESSES AND DEVELOPMENT OF AN ADAPTABLE MODEL

Isabella BIANCO & Gian Andrea BLENGINI

Politecnico di Torino - Corso Duca degli Abruzzi, 24 - 10129 Turin, Italy
Corresponding author: isabella.bianco@polito.it

EXTENDED ABSTRACT

La filiera della pietra ornamentale è un settore tradizionale dell'economia italiana, le cui tecniche produttive sono sostanzialmente rimaste invariate negli ultimi decenni. Recentemente, tuttavia, sta crescendo la consapevolezza che il contenimento degli impatti sia condizione sempre più necessaria per confermare la pietra ornamentale come risorsa economica, sociale e occupazionale. L'attenzione alla sostenibilità è inoltre incentivata dai recenti regolamenti europei sull'ambiente e sulle materie prime, che stanno incoraggiando il passaggio da un'economia lineare a un'economia circolare, in cui il valore dei prodotti, dei materiali e delle risorse sia mantenuto nell'economia il più a lungo possibile (Commissione Europea, 2015).

Tra gli aspetti complementari che contribuiscono al miglioramento della sostenibilità dell'industria lapidea, il progetto di ricerca presentato in questo articolo verte sull'analisi di tipo ambientale. La metodologia seguita è quella del *Life Cycle Thinking*, ovvero un approccio complessivo che considera i fattori di impatto in riferimento a tutte le fasi del ciclo produttivo. Lo strumento utilizzato a tal fine è il *Life Cycle Assessment* (LCA), secondo la procedura standardizzata dalle norme ISO 14040-44 e dalle linee guida ILCD pubblicate dalla Commissione Europea. I confini del sistema preso in esame sono *from-cradle-to-gate*, termine che indica l'analisi della filiera a partire dall'estrazione delle materie prime fino alla completa realizzazione del prodotto lapideo. In letteratura è possibile trovare alcuni studi LCA volti a quantificare gli impatti del ciclo di vita della pietra, tuttavia essi risultano sovente parziali o non del tutto significativi a causa dell'alta percentuale di approssimazioni e assunzioni presenti nei calcoli. Ciò è dovuto essenzialmente alla mancanza, nelle banche dati LCA, di informazioni che facciano riferimento agli specifici processi del settore lapideo. A titolo di esempio, i database non contengono, attualmente, informazioni su alcuni materiali propri del settore lapideo (quali, per esempio, il filo diamantato o i diversi tipi di esplosivo), carenze che vanno inevitabilmente a inficiare e uniformare i risultati di calcolo degli impatti ambientali. Scopo del progetto di ricerca è dunque innanzitutto quello di definire, dal punto di vista LCA, i processi e i materiali non ancora disponibili nelle banche dati. A tal fine sono stati raccolti dati primari circa i materiali utilizzati, il consumo di risorse e di energia presso cave, impianti di trasformazione e industrie annesse al settore. I bacini estrattivi selezionati come riferimento sono quelli delle Alpi Apuane (marmo di Carrara) e della provincia del Verbano Cusio Ossola (granito).

Le informazioni ricavate sul campo hanno permesso di identificare le tecniche di estrazione e lavorazione superficiale più diffuse e rappresentative della filiera lapidea italiana, e di considerare come queste variano in base alla natura del materiale lapideo lavorato. Tramite il confronto diretto con le aziende è stato possibile strutturare e sviluppare un modello di calcolo LCA con uno specifico software. La realizzazione di tale modello nasce al fine di fornire alle compagnie del settore lapideo uno strumento che permetta di calcolare con soddisfacente accuratezza gli impatti ambientali relativi specifiche realtà produttive. Tale adattabilità è raggiunta creando il modello LCA secondo alcuni accorgimenti: da un lato la struttura verticale, che rende il modello più dinamico e facilita l'analisi dei contributi ambientali in relazione alle diverse fasi del processo, e, dall'altro lato, l'inserimento di una serie di parametri. Questi ultimi definiscono le più frequenti variabili che influenzano la produzione e i consumi della filiera della pietra; essi sono campi inseriti nel modello con valori medi rappresentativi della filiera lapidea italiana, ma predisposti in modo da essere facilmente modificabili. Di conseguenza, le aziende interessate avranno la possibilità di adattare facilmente il modello inserendo le quantità di consumo relative al proprio caso specifico. Il progetto di ricerca, ancora in itinere, prevede nel prossimo futuro l'analisi ambientale di alcuni materiali i cui dati non sono ancora attualmente disponibili. Con questo progetto si auspica infatti di promuovere la diffusione dell'approccio del ciclo di vita nella filiera lapidea e di incoraggiare la chiusura di alcuni cicli produttivi secondo i principi dell'economia circolare.

ABSTRACT

The Italian traditional field of dimension stone is currently experiencing a growing interest toward the application of the sustainability principles. In this framework, the main aim of this ongoing PhD project is to create a flexible tool able to support the environmental assessments of Italian stone companies. The methodology is aligned with the Life Cycle Approach and it analyses the *cradle-to-gate* production chain of both soft stones (marbles) and hard stones (granites). Because of the lack, in LCA databases, of quarry specific and process specific data, it has been necessary to collect information directly on the field. This allowed to investigate more accurately the resources, energy and emissions involved in the most widespread techniques of extraction and transformation. The inventory phase is then followed by the realization of an LCA model able to be adapted according to the specific firms productions. This aim is reached by choosing a flexible structure for the model and by setting customizable parameters. Final goal of this study is to allow stone companies to employ the model for improving their processes, for better marketing the products or for developing further researches.

Key words*: Life Cycle Assessment, Italian dimension stones, parametric LCA model, stone production chain, stone environmental sustainability*

INTRODUCTION

The geology of Italy allowed the country to develop, during the centuries, an important tradition of ornamental stone production. Still nowadays, the Italian stone (such as marble and granite) is known for its good quality and its production play a big role in the economy of the country. As described by Bertolazzi (2015), the quarrying techniques deeply changed from the XX century with the mechanisation of the extraction process, which improved the production and guaranteed better conditions for quarrymen. During the last decades, the techniques remained quite unchanged, but a recent interest toward the sustainability of the stone sector is growing, boosted by European regulations and by the increase of competition coming from other countries or other construction products.

Currently, for example, an issue of big concern is the waste production: slurry wastes coming from the cutting processes usually contain heavy metals that hinder the reemployment of muds as second raw material and force their disposal as special waste with high economical and environmental burdens (Dino & Fornaro, 2005). Other hot points are, from one side, the risk of turbid aquifer in case of processes using water (Bellini, 1992; Doveri, 2008) and, from the other side, the concentration in atmospheric particulate matter in case of dry processes (Cuccia *et alii*, 2011). Atmospheric aerosols are, in any case, source of concern if the lorry transportation of blocks pass near built-up areas. Other complementary constraints related to the dimension stone sector are for example the lack of standardised techniques or tools, the worker safety, the market dynamics, the efficiency of the production chain, etc. Firms, public administrations and universities are looking for and testing solutions to the different problems. Some solutions have been found, for example, by different research groups that are making experimentations in order to reemploy the wastes and give them a new value (e.g. Marras *et alii*, 2010; Dino & Fornaro, 2005, Vola *et alii*, 2011; Carraro & Castelli, 2005); in the Carrara context the aerosol problem has been limited through the construction of a road that avoid the passage of lorries in inhabited areas and by a system of lorry washing. On the other hand, through experimentation with spores they have been identified the quarries that majorly contribute to the aquifer contamination (Baldi, 2004), and taken some measures to minimise the amount of water employed by those quarries. It is therefore clear that there are several aspects to take into account, and that the choice of solutions is not obvious because the variables that influence them are sometimes in contrast one each other. It is nowadays accepted that the stone production chain needs a forward-thinking environmental protection able to confirm the stone as an economic, social and occupational resource for the society and not as a burden. For this reason, a lot of efforts are currently made in the direction of the circular economy, in order to close the chain of the production system and analyse how by-products and wastes can be reemployed or restored in the same or other production systems.

In this context, this paper shows the first results of an ongoing PhD research project concerning the environmental sustainability related to the stone production. This project focuses on the environmental problem with the global and comprehensive approach of the so called Life-Cycle Thinking, taking into account all the processes of the production chain, from the extraction of raw materials to the finished product (*from-cradle-to-gate* approach).

Other studies have been carried out for evaluating the environmental consequences of the stone production chain (Traverso *et alii*, 2009; Capitano *et alii*, 2011, Gadioli *et alii*, 2012). Nevertheless, the calculation of environmental burdens often resulted to be over-simplistic and presented a high percentage of assumptions and approximations. This was mainly due to the lack, in LCA databases, of quarry specific and process specific data. As a consequence, a big aim of the project is to provide LCA data for the most significant processes of the stone production chain. On the other hand, aim of the study is to build an LCA model able to be employed by firms as a practical tool to assess their specific environmental impacts.

METHODOLOGY

As stated in the previous paragraph, the attention to the production sustainability is considered as more and more necessary for guaranteeing a good perspective and stability to the stone sector. Among the different and complementary aspects of the sustainability, this project focuses on the environmental issue. Since the impact of the stone production is the result of many interconnected variables, it appears important to analyse the problem with a global and comprehensive approach, in order to avoid the shifting of burdens from a phase of the process to another one. To this aim, the methodology of the current PhD project is aligned within the principles of the Life Cycle Thinking, that considers the implications of the whole life cycle of products, from their real beginning to their End of Life. In particular, this study follows the standardised methodology of the Life Cycle Assessment (LCA), whose working steps are defined by the ISO 14040-44 regulations and by the technical guidance of the ILCD Handbook published by the European Commission. The LCA methodology is composed by the four iterative phases of Goal and Scope definition, Inventory, Life Cycle Impact Assessment and Interpretation, through which are identified and quantified energy and materials used, as well as releases to the environment and their potential impacts throughout the whole life cycle. As far as concern the stone sector, the available LCA databases (such as Ecoinvent, Thinkstep, ELCD) do not contain datasets about the most common and widespread processes that take place in quarries and transformation plants. As a consequence, in order to obtain an accurate estimation of the environmental burdens, it has been necessary to investigate the production chain by collecting most of the data directly on the field. The boundaries of the studied system are *from-cradle-to-gate*, meaning that are included all the processes and flows till the realization of the finished product (stone slabs or tiles). To reach this goal, it was firstly necessary, for both soft stones (such as marbles) and hard stones (such as granites), to describe the current techniques and to collect data about the materials and energy employed during the processes. To this aim, in addition to the available literature (Primavori, 1999; Primavori, 2011), the dialog with stone firms and visits to quarries and transformation plants were of primary importance. The investigations have been carried out in two relevant Italian stone basins: in the Apuan Alps (for marble deposits, Fig. 1), and in the Verbano Cusio Ossola province (for granite deposits). The level of hardness of the stone influences the production technique and, as a consequence, the use of tools and raw materials.

Fig. 1 - Marble quarry of the Colonnata basin (Carrara, Italy)

As it can be seen in the scheme of Fig. 2, soft stones are preferably extracted and cut with tools exploiting inserts made of hard materials such as synthetic diamonds (employed for diamond wires, disks and saws) or widia (used for chain cuttings). On the other hand (Fig. 3) the granite extraction is more often made with different kinds of explosive (slurries, water gel explosives, etc.), while the cutting is generally realized through the friction with a mixture of metallic grids, water and lime. Moreover, since the stone is a natural material, within the same technique, different variables can influence the efficiency of the process,

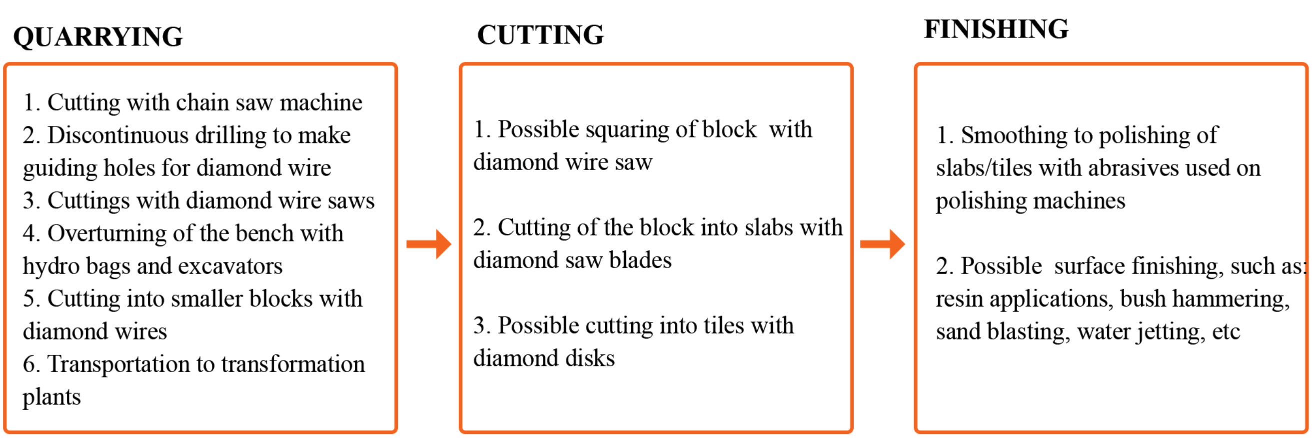

Fig. 2 - Scheme summarizing the techniques most commonly used in the Italian production chain of soft stone products (such as marble slabs and tiles)

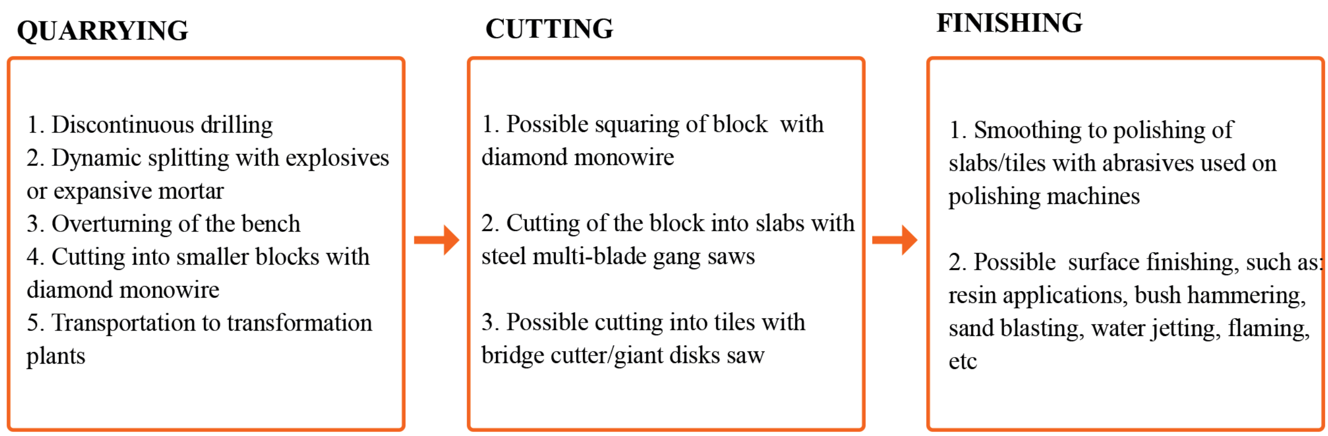

Fig. 3 - Scheme summarizing the techniques most commonly used in the Italian production chain of hard stone products (such as granite slabs and tiles)

the consumption of resources and energy and the emissions into soil, water and air. Investigations on field were, as a consequence, necessary to understand the range of materials generally employed and their average use according to the variables affecting them. Every technique is currently analysed with an LCA approach, meaning from its real beginning to the final steps, considering also possible loops coming from the recycle or reuse of materials. Therefore, for each technique of cutting or transformation are taken into account:

- The burdens coming from the production of the materials and tools employed. Some general data are already available in the databases (such as the electricity, the fuel burned into machines, the steel employed for some tools, etc.). Nevertheless, for most of the specific materials usually employed in the stone sector there is no availability of data. In these cases the collection of information has to include the impacts that are behind those tools, investigating the relative production chain. For example, as far as concern the marble cutting, the widely used diamond wire is not available in LCA databases. As a consequence, different kinds of diamond wire are currently under investigation. More details are given in the results section.
- The burdens coming from the execution of the cutting or transformation technique. Considering again the example of the diamond wire cutting it is evaluated the consumption of wire, water, electric energy, vulcanized rubber and protection nets necessary for cutting 1 m^2 of stone.
- The burdens (or credits) given by the final phase of the process. Besides the stone block, other outputs of the process are the wastes or by-products. For the cutting with diamond wires, some outputs are, for example, the slurry mud (*marmettola*) and the exhausted diamond wires. In phase it is important to take into account the end of life of products. The impact of the diamond wire and of the slurry waste will therefore change if they are recycled/reused or if they are sent to disposals.

The data collected are then organised and analysed through the LCA software Gabi. A model is built making use of parameters in order to create a flexible tool for the evaluation of specific stone productions. This model is indeed created with the goal of supporting firms to elaborate environmental assessments.

RESULTS

The main purpose of this work is to give a practical support to stone companies that are interested in improving or certifying the sustainability of their production chain. As outlined before, this study follows the methodology of the Life Cycle Thinking, analyzing the stone production with a comprehensive approach, which take into account processes and flows *from-cradle-to-gate*. In earlier studies attempts were made to estimate the environmental impact caused by stone tiles or slabs, but they resulted to have a lot of approximations due to the lack, in LCA databases, of specific data.

As a consequence, with this PhD project, the biggest challenge is to provide to firms an easy and customizable model allowing them to calculate more accurately the environmental consequences of their specific production. As described in the previous section, collecting data about the techniques and resources employed in marble and granite quarries is a time consuming process and requires the collaboration of companies and firms.

In this section is presented the current realization of the LCA model that will be made available to stone firms in the nearest future. The model is built with Gabi, a commercial LCA software developed by the German company Thinkstep. The main elements of the software are "processes" (the manufacture or treatment of products), "flows" (that quantify the input and outputs of processes) and "plans" (which can contain processes, flows and other plans). The model has been organized with a vertical structure of plans, that can be conceptually assimilated to a Chinese boxes' structure. This means that each plan is a step of the production chain and it contains, inside, the processes that

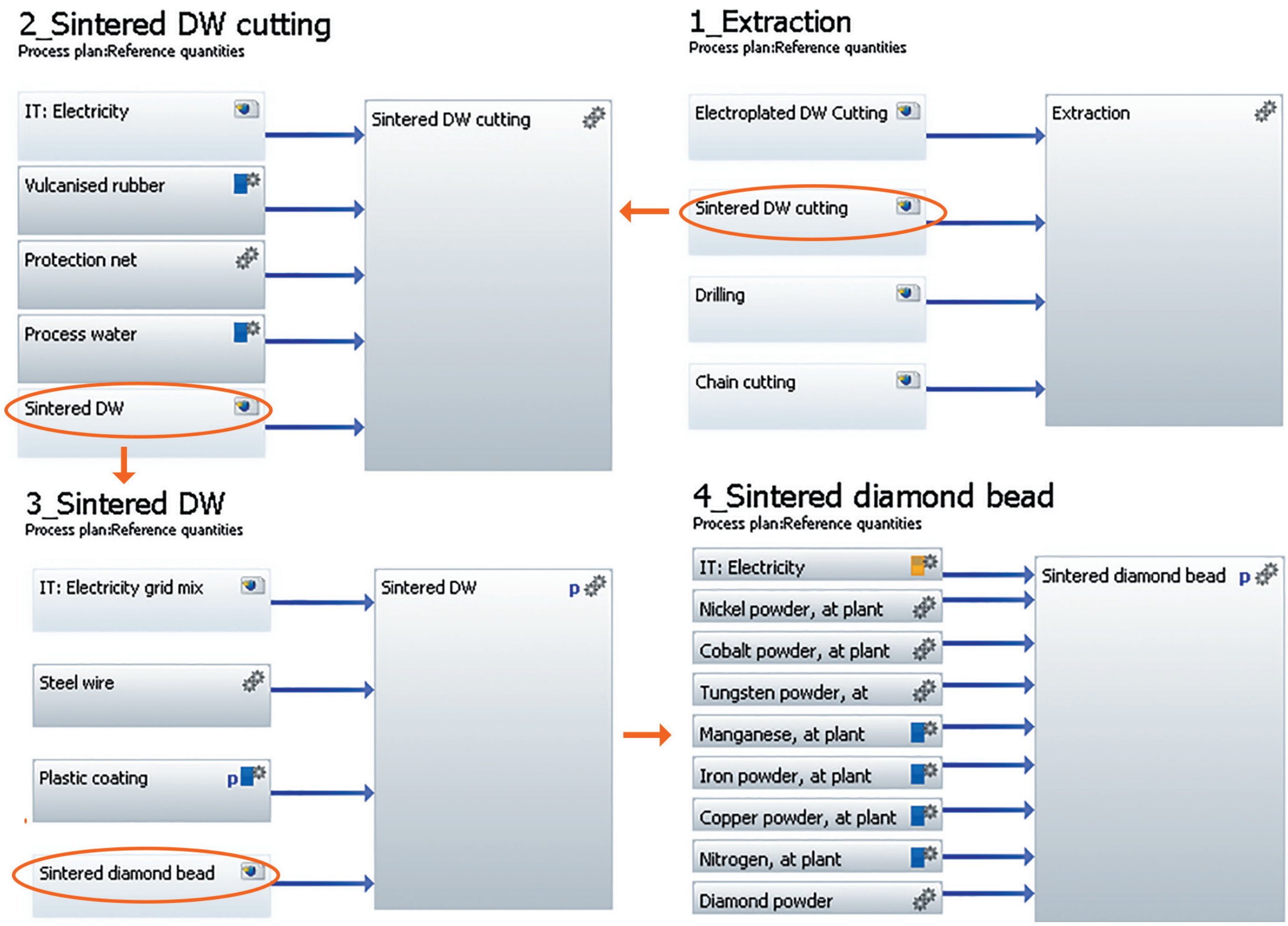

Fig. 4 - Exploded view of part of the LCA model created for the stone sector environmental assessment (developed with Gabi software).

were previously necessary for its realization. Figure 4 shows the exploded view of the plans realized for modeling the cutting of marble blocks with diamond wires. As it can be noticed, the cutting requires the resources water, electric energy, vulcanized rubber, protection net and diamond wire; this latter, however, has been produced through a process that required the assembly of a steel wire, a plastic (or rubber or spring) coating and diamond beads; the same analysis have therefore to be done for these three elements, and so on. The investigation toward the "cradle" of the process stops when the process is reduced to elementary flows or in case of negligible weight of some processes (cut-off criteria, ILCD Handbook, 2010). The choice of structuring in this way the model has been taken in order to make it more dynamic and because the analysis of the impacts contribution of the processes is made easier and clearer. Moreover, the dynamicity of the model is given also by the setting of parameters. Average values are inserted in the model, but parameters allow stone companies to modify quantities and materials according to their specific production. As it can be seen in Fig. 5, firms have the chance of customizing the model by choosing, for example, the characteristics of the diamond beads employed for the cutting or, in the granite context, the resources employed for during the extraction processes. Therefore, this tool is a structured model which can be easily customized to different level of detail according to the company availability of data and to the goal of the assessment.

Nevertheless the model still needs to be implemented with data concerning some processes. As outlined previously, indeed, the collection of data is one of the most complex and time consuming phase of the LCA, usually because the secrecy of some industrial processes makes difficult the estimation of some impacts.

Future work is therefore planned to investigate in depth these missing materials and variables and in order to provide the firms with a model as much accurate as possible.

The flexibility and customizability of the model suggest indeed to stone companies a way for approaching the environmental sustainability with a recognized and standardized method.

Parameter

Parameter	Formula	Value	Minimum	Maximum	Standar	Comment, units, defaults
Tungsten	Tungsten_rate*Met_powder	3,5E-005				kg
Electricity_mat	0,36	0,36				MJ for each bead
Synth_diamond	0,02*Matrix_mass	2E-005				kg
Copper	Copper_rate*Met_powder	0,00021				kg
Iron	Iron_rate*Met_powder	0,00035				kg
Phosphorus	Phosphorus_rate*Met_powder	1,4E-005				kg
Cobalt	Cobalt_rate*Met_powder	7E-005				kg
Met_powder	Matrix_mass*0,7	0,0007				kg - weight of the metal powder in 1 bea
Matrix_mass	Bead_mass-Sleeve_mass	0,001				kg
Tungsten_rate		0,05			0 %	-
Tin		1			0 %	-
Sleeve_mass		0,003			0 %	kg
Phosphorus_rate		0,02			0 %	-
Oxygen		1			0 %	

Parameter

Parameter	Fo	Value	Minimum	Maximum	Standar	Comment, units, defaults
Black_powder		0,063	0,006	0,176	75 %	kg/m3 - kg of black powder necessary for quarrying 1 m3 of hard stone.
Co_products		0,53			0 %	mc/m3 - Volume ofco-products for 1 m3 of quarried stone
Debris		0,11			0 %	m3/m3 - m3 of debris for 1 m3 of quarried stone
Det_cord		5,16	1,26	16,9	76 %	m/m3 - m of detonation cord necessary for quarrying 1 m3 of hard stone.
Detonator		0,069	0,029	0,129	54 %	n/m3 - number of detonators necessary for quarrying 1 m3 of hard stone.
Diesel		289	116	472	42 %	MJ/m3 - Tot diesel necessary for quarrying 1 m3 of hard stone.
Drilling_beam		0,034	0,011	0,068	68 %	m/m3 - m of steel beam necessary for quarrying 1 m3 of hard stone.
Electricity		0,123	0,06	0,301	81 %	MJ/m3 - electricity necessary for quarrying 1 m3 of hard stone.
Land_transfor		1			0 %	m2/m3 - area transformed to quarry 1 m3 of hard stone.
Natural_stone		1			0 %	kg/m3 - Weight of 1 m3 of hard stone.
Regular_block		0,35			0 %	mc/m3 - mc of regular block for 1 m3 of quarried stone
Slow_fuse		0,156	0,094	0,218	56 %	m/m3 - m of slow fuse necessary for quarrying 1 m3 of hard stone.
Water		2			104 %	kg/m3 - kg of water necessary for quarrying 1 m3 of hard stone.
Parameter						

Fig. 5 - Some parameters of the LCA model allowing the adaptability to specific stone production chains

CONCLUSIONS

The sustainability of the dimension stone supply chain is currently an important issue in order to confirm the Italian dimension stone as an economic and social resource. Different kinds of problem emerged during the last years (the disposal of wastes, the production of particulate matters, the aquifer contamination, etc.) and many studies investigated possible solutions. This paper proposes to face the problem through a more global approach, following the principles of the Life Cycle Thinking and taking into account all the processes involved in the extraction and transformation of both soft stones (marbles) and hard stones (granites). Previous attempt of using this approach in the field of dimension stones were mostly qualitative or revealed to be over simplistic because of the lack of specific datasets in the LCA databases. Therefore, first goal of this ongoing Ph.D project is to provide LCA data of the specific processes by collecting information directly on field. Moreover, this study aims to provide a flexible tool allowing the stone sector to act toward a more environmentally sustainable management of the production chain. This tool is a parametric LCA model which can be customized by the stone companies according to their specific consumption of resources.

The LCA approach is here proposed as a comprehensive methodology for understanding which processes mostly influence the environmental burdens and, as a consequence, it could be used as a decisional tool for improving the production chain and going toward the closure of some cycles, in a perspective of circular economy. In addition, the environmental assessment could be exploited by firms for marketing, in order to enhance the stone products.

Further work is planned to implement the model with processes that are still under investigation. Moreover, it is planned to create the model also with an open source LCA software (OpenLCA, developed by GreenDelta) in order to boost the environmental assessment among the stone companies.

ACKNOWLEDGEMENTS

The authors are pleased to thank people who contributed to the realization of this paper. We thank in particular: Marilena Cardu, Stefano Bianchini and Raimondo Cossu for their useful aid in organizing visits to marble quarry and transformation plants in Carrara; Carlo Dell'Amico for his enthusiastic sharing of knowledge about the quarrying techniques in marble basins; Lorenzo Cupini and Roberto Bertolini for their availability to show me the Campolonghi transformation plant; Massimo Franchi for explaining me the cutting techniques of his transformation plant; Marco Bartoli for the information he shared about the production of diamond wires; Antonino Criscuolo for his explanation about aquifer problems related to the marble quarries; Marco Cerutti and Massimo Marian for their aid in organizing visits at VCO quarries and transformation plants; Carlo Briganti for the information he shared about his granite quarry; Massimo Peretti and Mariateresa Moro for showing me granite transformation plants.

REFERENCES

Baldi B. (2004) - *Studio idrogeologico dei bacini marmiferi carraresi mediante l'utilizzo di spore di Lycopodium clavatum. Rapporto Finale.* Università degli studi di Pisa, Italy.

Bellini A. (1992) - *Inquinamento da idrocarburi delle sorgenti del gruppo di Torano (Acquedotto di Carrara)*.

Bertolazzi A. (2015) - *Modernismi litici 1920-1940. Il rivestimento in pietra nell'Architettura Moderna*. Franco Angeli Ed., Milan, Italy.

Capitano C., Traverso M., Rizzo, G. & Finkbeiner M. (2011) - *Life Cycle Sustainability Assessment: an implementation to marble products*. Proceedings of the LCM 2011 Conference, Berlin, Germany.

Carraro G. & Castelli S. (2005) - *Il limo di segagione quale risorsa: biorisanamento e potenzialità di impiego nel settore verde*. Interreg IIIA - project report, Locarno, Italy.

Castoldi M., Fernández N., De Andrade A., Ribeiro C. E., Fernandes P. & Pimentel D. (2012) - *Life-cycle inventory of dimension stones, Brazil.* Proc. of Global Stone Congress 2012, Borba, Portugal.

Cuccia E., Piazzalunga A., Bernardoni V., Brambilla L., Fermo P., Massabò D., Molteni U., Prati P., Valli G. & Vecchi R. (2011) - *Carbonate* *measurements in PM10 near the marble quarries of Carrara (Italy) by infrared spectroscopy (FT-IR) and source apportionment by positive matrix factorization (PMF)*. Atmospheric Environment, **45**: 6481-6487.

Dino G.A. & Fornaro M. (2005) - *L'utilizzo integrale delle risorse lapidee negli aspetti estrattivi, di lavorazione e di recupero ambientale dei siti.* Giornale di Geologia Applicata, **2**: 320-327.

Doveri M. (2008) - *Studio idrogeologico e idrogeochimico dei sistemi acquiferi carbonatici nel bacino del Torrente Carrione (Alpi Apuane nord-occidentali).* Proceedings Simposio stato del territorio e delle risorse naturali in Toscana, 167-176, Florence, Italy.

EU Commission - Joint Research Centre (2010) -. *International reference Life Cycle Data system (ILCD) handbook: general guide for Life Cycle Assessment - Detailed guidance.* 1st Edition 2010.

ISO 14040:2006 (EN) - *Environmental management - Life cycle assessment - Principles and framework.*

ISO 14044:2006 (EN) - *Environmental management - Life cycle assessment - Requirements and guidelines.*

Marras G., Careddu N., Internicola C. & Siotto G. (2010) - *Recovery and reuse of marble powder by-product*. Proc. of Global Stone Congress 2010, Valencia, Spain.

Primavori P. (1999) - *Pianeta Pietra*. Giorgio Zusi Ed., Verona, Italy.

Primavori P. (2011) - *I materiali lapidei della Sardegna.* Sardegna Ricerche Ed., Pula, Italy.

Traverso M., Rizzo G., Finkbeiner M. (2009) - *Environmental performance of building materials: life cycle assessment of a typical Sicilian marble.* The International Journal of Life Cycle Assessment, **15**: 104-114.

Turchetta S. (2003) - *Tecnologie di lavorazione delle pietre naturali*. Ph.D thesis, Università degli Studi di Cassino, Italy.

Vola G., Lovera E., Sandrone R., Allevi S. & Piazza E. (2011) - *Riutilizzo di residui di "Pietra di Luserna" come risorsa nel settore delle costruzioni: tecnologia, sostenibilità ambientale ed economica*. Geoingegneria Ambientale e Mineraria, **2**: 5-16.

Received August 2016 - Accepted May 2017