1 FINAL PUBLISHABLE SUMMARY REPORT

1.1 Executive Summary

In 2007 European countries provided about 40% of global natural stone production, bringing Europe to be one of the world's largest producers and exporters of natural stone with Italy, Greece, Portugal and Spain being major players within the sector. The European sector consisted of 60,000 companies in 2007, and employing a total of more than 500,000 workers, it was (and still is) strongly dominated by SMEs, being more than 90% and having less than 50 employees each. In spite of its leading role on the global market, Europe has however been losing power in the last years due to non-European aggressive trading competition. As a result, employment decreased of more than 15% in the last 5 years.

Additionally, only 20-25% of extracted stone blocks are accepted at extraction, having the requirements of standard-sized and regularly shaped blocks to be processed into cost-efficient products. This quantity constitutes a major environmental impact because the discarded blocks (75-80%) are considered unprofitable to process with the current equipment. Within the framework of reducing waste by valorising currently discarded stone blocks, new equipment is needed that can profitably process irregular and undersized stone blocks into products such as slabs and strips, resulting in additional yields, higher productivity, and lower waste material produced.

The XStone project addressed the development of a compact high-productivity sawing frame specifically designed to profitably saw irregular and undersized stone blocks into marketable products such as slabs or strips. The major novelty of the machine is a block-holding mechanism which is able to firmly hold in position irregular and undersized stone blocks during the cutting operation. The novel sawing frame, which has a very compact and versatile design as compared to state-of-the-art sawing frames for standard-sized natural stone blocks, has been conceptualised by stone machinery and cutting tools manufacturers with the support of RTD Performers following production and market requirements expressed by SME End-Users.

The prototype's validation activities brought a realistic assessment for the environmental impact in stone quarries and stone processing centres where a significant reduction of stone waste will be possible thanks to the novel sawing frame and block-holding mechanism. Bringing a more rationale use of stone quarry resources, this project will provide to SMEs a novel solution for processing actually discarded stone blocks and also the ability to bring an increase in yields by valorising and exploiting normally rejected stone blocks.

1.2 Project Context

Europe is one of the world's largest producers and exporters of natural stone, with European countries making up around 40% of global natural stone production in 2007. The sector is particularly important for the traditional stone-producing Southern European countries such as Italy, Greece, Portugal and Spain, which hold 81% of Europe's global production, but it also steadily gains in importance to Northern European countries, such as Belgium, Germany, Sweden and Norway as well as to other Countries such as Russia. Globally, Europe's natural stone sector is made up of 60,000 companies and employs more than 500,000 workers, which make up 2.3% of the global European labour force. The sector is strongly dominated by SMEs, with more than 90% of European companies being small enterprises with less than 50 employees.

In spite of its traditionally strong position on the global market, Europe has been losing power and leadership in the world natural stone trade in favour of non-European countries such as China, India, Brazil and Northern African countries. As a result, also employment has decreased of more than 15% in the last 5 years and the prediction for the near future is somehow uncertain.

One of the main issues that negatively affect the competitiveness of the European stone sector is the large quantities of high value stone blocks, which, despite meeting quality requirements, need to be discarded right after extraction because they do not meet dimensional and shape requirements towards profitable processing. Actually, only 20-25% of the extracted blocks can be further processed, as they satisfy the dimensional and shape requirements to enter the market of natural stone blocks, while the discarded stone blocks are generally devalued and sold out in lots at reduced cost due to their defective or irregular nature.

In contrast to marketable blocks, which are regular squared shaped blocks satisfying quality requirements and additionally conforming to specific dimensional standards, an irregular stone block can be defined as one having an undefined shape (usually far from being regularly squared, or parallelepiped) or in general being small sized in comparison to standard marketable blocks.

According to the desired final product, the first step in a traditional stone processing cycle includes sawing the blocks into slabs, which can be further cut into strips and subsequently into tiles. However, only standard sized and regularly shaped blocks (20-25% of quarry production) can be profitably worked out, the rest being undersized or irregularly shaped blocks being discarded, as it is unprofitable to try to obtain regular size slabs from these blocks with traditional stone processing equipment. On the other side, those blocks would be suitable to obtain non-standard slabs, with dimensions being limited to the dimensions of the block. Though, there is currently no available stone processing machine on the market, which allows cutting profitably non-commercial blocks into slabs.

1.3 The XStone project goal and objectives

The current state-of-the-art equipment is specifically designed to operate cost-efficiently solely with standard-sized regular shaped blocks. Smaller or irregular blocks would on the contrary lead to low productivity and higher rates of waste material and currently the further processing of such blocks would be unprofitable. The technical problem to deal with when sawing smaller, non-commercial blocks lies in their considerably lower weight with respect to standard commercial blocks. The approximate sizes and weights of small blocks may highly differ from large or commercial blocks. For small as well as undersized and irregular blocks, the weight is low in comparison with the horizontal components of the sawing forces applied. This means that while sawing a standard (heavyweight) stone block, its own weight can provide the necessary stability during the sawing operation. Instead, a small (lightweight) block would move during the cut, compromising any chance to achieve precise dimensions of the semi-finished product (if any regular cut is possible at all). The option of reducing the number of blades, as well as reducing the sawing forces by decreasing the sawing rates, should be discarded as being not viable, due to the strong reduction in productivity that would affect in a very negative way the cost of the operation, and even more the general flexibility of the sawing unit, that is, the capability to complete a sawing job in a reasonable time.

Nonetheless, these non-standard (undersized or irregular) stone blocks would result in additional yields, if only they could be profitably processed. Within this framework, the introduction of novel techniques enabling higher flexibility with respect to block shape and size would allow increasing yields and decreasing environmental impact at the same time, as they would allow recovering stone bocks which are currently rejected by the market despite meeting quality requirements.

Within this framework, the XStone project addressed the development of a compact high-productivity sawing frame specifically designed to profitably saw irregular and undersized stone blocks into marketable products such as slabs or strips. The major novelty of the machine is a block-holding mechanism which is able to firmly hold in position irregular and undersized stone blocks during the cutting operation. The novel sawing frame, which has a very compact and versatile design as compared to state-of-the-art sawing frames for standard-sized natural stone blocks, has been conceptualised by stone machinery and cutting tools manufacturers with the support of RTD Performers following production and market requirements expressed by SME End-Users.

1.4 Main results achieved

One of the main results achieved within the XStone project consist of a prototype of a compact high-productivity sawing frame specifically designed to profitably saw irregular and undersized stone blocks integrating a system of dynamically driven block-holders specifically designed to be integrated within the compact sawing frame in order to firmly hold in position irregular and undersized stone blocks during the sawing operation. The sawing frame design activities and integration activities between the new block-holding system and the compact sawing frame were addressed using 3D CAD software and virtual prototyping. Initial activities focused on designing the block-holding system, and then on evaluating how to integrate the block-holding system design with the compact sawing frame design. A first 3D CAD mechanical design of the components was elaborated to evaluate the interactions between the block-holding system and every mechanical component involved in the cutting process: sawing blades, chassis, driving system, etc. Then, given the target technical specifications, the boundary conditions and the technical constraints, the detailed design of the machine was elaborated. Detailed mechanical designs were developed for the machine components and for the system as a whole, along with a virtual prototype allowing for virtual simulations of the compact sawing frame. The virtual prototype allowed the evaluation for potential integration issues during the prototype machine development, thanks to the dynamic graphic representation of the different cutting operations and phases. In order to finalize the design of the compact sawing frame, furthermore, several FE analyses were carried out to evaluate the structural integrity of the components at different working conditions, thus verifying the adequateness of the selected materials and of mechanical design choices. Activities initially consisted in the identification of the most critical components of the sawing frame and in their subsequent verification by FE analyses. The blade holder was identified as being by far the most critical component since it must stand the sum of the stresses induced by the blades tension, plus the sawing loads and inertial loads.

A full scale physical prototype of the new compact sawing frame integrating the block-holding system along with all components composing the new prototype equipment was then realized by the stone cutting equipment manufacturer PEDRINI. Starting from the final mechanical as well as electrical designs for the block-holding system and the machine as a whole, procurement of components took place, which was followed by assembly. Assembly took place at PEDRINI's facilities and an extensive prototype validation campaign took then place at the Turkish company TUREKS, where the physical prototype developed and assembled within WP4 was tested extensively with the aim to validate it by comparing results of functional as well as production tests with attended technical targets. Moreover, optimization activities were conducted. In order to evaluate the actual performance of the new sawing machine prototype, in a first instance functional tests were conducted (without blocks being sawn) in order to check that the machine had in effect the same behaviour as attended in accordance to the virtual models. During this phase, also the response of the machine to the control was checked, and a debugging activity took place in order to resolve few control issues and prepare the machine prototype to actually operate as required by a further processing phase. At this stage, the actual performance evaluation during processing could start. To this purpose, series of processing tests were conducted onto stone blocks of various types and having various sizes. During processing tests, the behaviour of the machine prototype was studied under real circumstances. The operation of the machine was visually inspected by skilled technical personnel, and several measures were taken for monitoring the stone conditions and quality during and after the cut. The testing activities allowed to validate the design and the performance of the machine, as well as to identify areas for optimization.

Empirical numerical models, along with an adaptive control strategy for sawing machines capable to create a closed loop controller with parameters that can be updated to change the response of the system, thus achieving a higher quality cut, hence a higher quality end-product (slab or strip), and enhanced cutting tools, were also developed. The project involved the development of empirical models representing the relationship between cutting and control parameters. Hence, during activities, a number of tests were performed in order to understand the effect of mechanical properties of binders, size of diamonds, changes in the working parameters such as transversal speed, cutting speed and blade course in the sawing process. Overall, the parameters that influence the models are manifold including diamond size, diamond concentration, mechanical properties of the binders, transversal speed, cutting speed. Among these, the parameters that influence more directly the durability (life time) of the linear blades are binders properties, working parameters and material (stone) properties and abrasiveness. On the other hand, the parameters that influence more directly the efficacy (capacity of cut) of the linear blades are vertical and horizontal forces, electric energy consumption, vibrations of the cutting process, diamonds quality, concentration and size. It is clear that changing several of the above parameters influences the durability of the cutting tools on the one side and the resulting quality of the cut on the other side. The optimal result is obtained as a trade off. By applying the developed empirical models it is hence possible to understand and predict the best tool as well as the forces involved in the sawing process. This means, that these models represent a way to process optimization. Furthermore, the models allow evaluating the performance and the efficacy of the linear diamond tools for a specific process. Consequently, it is possible to develop a method to put the diamond tools in a performance ranking to assess the more appropriate tool for a specific process towards tool optimization.

An adaptive control strategy was also developed, with the aim to create a closed loop controller with parameters that can be updated to change the response of the system. The output of the system is compared to a desired response from a reference model (tests in laboratory). The control parameters are updated based on this error. In order to be able to develop such an adaptive control strategy, it was necessary to validate the empirical models derived from previous tasks in a first instance, taking into account the tests done in laboratory, the tests done in standard machines and the experiments carried out with the XStone machine. Moreover, the models were employed in order to perform an optimum tool selection, and the results were analyzed to establish the adaptive control. An important conclusion of this activity is that with certain important output parameters controlled in real time such as, energy consumption, resultant forces, and vibrations and with the capacity of giving the correct feedback of the machines (sensor – actuator) it is possible to optimize a gangsawing system. Moreover, the method to perform the adaptive control is simple and effective, but must be necessarily tuned with the machines where the system is installed.

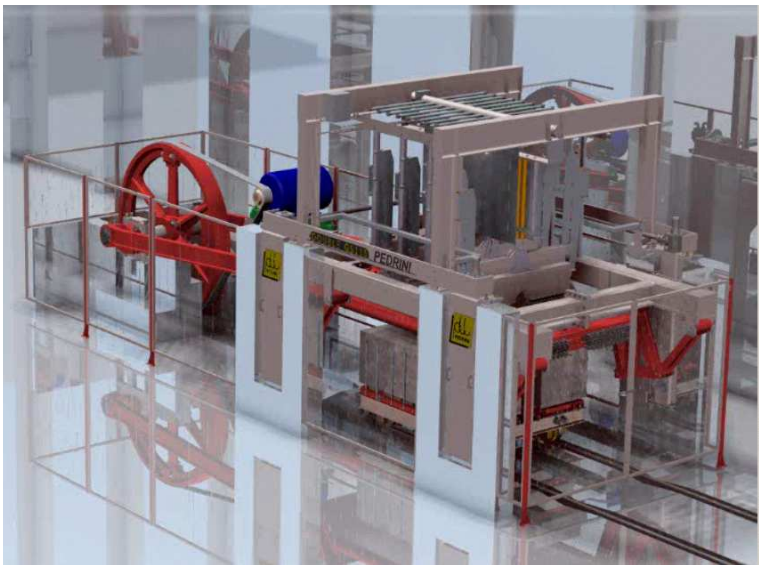

Figure 1: Compact sawing frame model with integrated block-holding system

1.5 Potential impact of results

The prototype's validation activities brought a realistic assessment for the environmental impact in stone quarries and stone processing centres where a significant reduction of stone waste will be possible thanks to the novel sawing frame and block-holding mechanism. Bringing a more rationale use of stone quarry resources, this project will provide to SMEs a novel solution for processing actually discarded stone blocks and also the ability to bring an increase in yields by valorising and exploiting normally rejected stone blocks.

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