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Investigating Artificial Intelligence and Modern Technologies Enhancement in Stone and Marble Cutting in Palestine

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Abstract

Stone and Marble sector in Palestine has a significant contribution to the GDP. There are some modern factories that use computerized and numerical controls for stone cutting employing modern tools and processes, but most of the marble cutting factories depend on manual and small machinery production lines. This paper examines integrating modern technologies; artificial intelligence (AI) and mechatronic systems like sensors, actuators and control systems, in these cutting factories in order to increase their efficiency, improve the added value and contribute in the occupational safety for human labor and cutting processes. In particular artificial intelligence, machine learning and image processing tools will be investigated as examples of modern technologies that can be implemented in marble and stone cutting processes in Palestine. Four Convolutional Natural Network (CNN) types were employed to classify marble slabs, comparing colored and gray-level databases. Gray-level yielded superior recognition rates due to marble's prevalent gray color. Texture, not color, drove classification; ResNet-152 achieved 100% Recognition Rate (RR) for gray-level and 98.6% for colored. In terms of efficiency, Inception CNN excelled. Ultimately, gray-level images best served marble classification, rendering color irrelevant.

Keywords: Artificial Intelligence; Image processing; Integrated modeling; Machine learning; Modern Technologies; Stone cutting; Palestine.

1. Introduction

Marble does not exist in Palestine, but imported as raw marble plates and then is shaped to fit the final application. Stones are extracted from Palestinian mountains as large limestone blocks and are used in the building industry. The stone and marble industry plays a pivotal role in the Palestinian economy, making substantial and invaluable contributions. From an economic standpoint, this industry holds immense importance. Firstly, it plays a crucial role in job creation, employing over 30,000 individuals and ranking among the largest employers in Palestine [1]. Secondly, the industry makes a substantial financial impact by contributing approximately $600 million each year to the Palestinian GDP. Moreover, its products find their way to markets in over 50 countries globally, serving as a significant source of foreign currency for Palestine [2]. Undoubtedly, this industry's significance is undeniable, and it is expected to make even more remarkable contributions to the Palestinian economy through its anticipated future growth [3].

On a social level, the cultural and historical significance of this industry plays a vital role. These materials have been utilized for centuries in the construction of important landmarks, preserving the region's cultural heritage and historical legacy. The presence of unique stone structures also enhances tourism potential, attracting visitors and supporting local businesses. Furthermore, the industry contributes to social development by providing employment, income, and skill-building opportunities for individuals, empowering them and improving their quality of life [4]. Overall, this industry has significant economic and social importance in Palestine. These natural resources contribute to economic growth, job creation, cultural preservation, tourism development, and social empowerment, while also requiring sustainable management practices for long-term benefits. Stone industry is over exploiting the natural resources and creating an environmental problem at the same time. Hilmi S. Salem in [5] presented results of two field studies concerning particulate matter emissions and pollution of this industry in West Bank. The study found that West Bank is greatly polluted, leading to adverse effect on people health, environment, and plants. Then the study recommends that the stone industry to confirm to World Health Organization’s (WHO) guidelines.

The stone industry in Palestine confronts several challenges, including the Israeli-imposed blockade, political instability, limited access to new markets,

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difficulty in importing raw materials and exporting finished products, lack of investment in technologies and infrastructure, and competition from countries with lower labor costs and advanced technologies. Despite the challenges faced, this industry in Palestine remains a significant contributor to the country's economy and society. There is immense potential for future growth if the government effectively addresses these challenges. Alongside the challenges, there are specific opportunities for the industry to capitalize on. Firstly, the demand for stone and marble is on the rise both domestically and internationally, presenting a favorable market environment. Secondly, new markets such as Africa and Asia can be explored to expand the industry's reach. Lastly, the government can play a crucial role by offering financial incentives and technical assistance to support the industry. The stone and marble sector holds great importance within the Palestinian economy and society, and with the right measures in place, it can flourish and maximize its potential in the future.

The supply chain of stone industry in Palestine encompasses various stages, each playing a crucial role in bringing these materials from extraction to the market. The process begins with the identification and licensing of stone quarries, followed by the extraction of raw blocks using modern machinery and techniques. These blocks are then transported to stone processing facilities, where they undergo cutting, shaping, and polishing to meet specific customer requirements. The processed stone and marble products are then distributed to local and international markets through wholesalers, exporters, and retailers. Throughout the supply chain, quality control measures ensure that only high-quality products reach the customers. Additionally, sustainable practices and environmental regulations are important considerations to minimize the impact on the environment. Collaboration among stakeholders, including quarry owners, processors, transporters, and regulators, is essential for an efficient and transparent supply chain. Marble and Stone Center as a community service is established at the Palestinian Polytechnic University with aim of providing training to people working in the sector as well as carry out laboratory testing of stone properties. Lab tests provided by the center include water absorption, specific gravity, compressive strength, and abrasion[1].

This industry in Palestine has the potential to achieve economic growth and development by embracing modern technologies and optimizing the supply chain. Through the integration of advanced technologies and artificial intelligence (AI), the industry can enhance value addition, ensuring the timely delivery of products and maximizing customer satisfaction. By leveraging these innovations, the supply chain's efficiency and productivity can be significantly improved, leading to an overall growth and success in the stone and marble sector. Advanced technologies like computerized and numerical controls, AI-driven image processing, and automated transport techniques can streamline the extraction and processing stages, leading to faster production and reduced waste [4]. For example, using smart crack detection facilitates taking decision in cutting defect stones. One the other hand, using sensors and actuators for water recycling reduces the amount of wasted water. Moreover, incorporating AI and machine learning can enhance the precision and quality of stone cutting, resulting in higher-value products. Using Computerized Numerical Control for the design and shaping of the cut stones allows producing products with more accurate dimensions and intricate artistic shapes that can be offered at better prices. Furthermore, the integration of modern technologies can contribute to occupational safety by minimizing human labor in hazardous processes and implementing active control of vibrations. By embracing these technological advancements, Palestine's stone and marble supply chain can further boost its economic significance, create more job opportunities, improve the added value of products, and ensure a safer and more efficient working environment for its workforce.

The role of AI in this industry in Palestine is increasingly becoming significant. Stone cutting factories in Hebron, Ramallah and Nablus started using computerized and numerical controlled machines besides to using waterjet cutting machines to increase the performance of their products and export competing stones worldwide. AI technology offers several advantages and opportunities for improving efficiency, productivity, and sustainability in various aspects of the industry. One area where AI is making an impact is in the extraction process. AI-powered algorithms can analyze geological data to identify optimal locations for quarrying, minimizing the need for exploratory drilling and reducing costs [5]. Additionally, AI can optimize the routing and scheduling of transportation, improving logistics and reducing fuel consumption. In terms of processing, AI can automate and enhance precision cutting, shaping, and polishing operations, leading to improved quality and reduced waste. AI-powered systems can also assist in quality control by analyzing and detecting defects or inconsistencies in products. Moreover, AI can aid in predictive maintenance, monitoring the health of machinery and equipment, thereby reducing downtime and maximizing operational efficiency. By leveraging AI technologies, this industry in Palestine can achieve higher productivity, better resource management, and overall operational excellence [6].

2. Literature review

AI in manufacturing is explained as the intelligence of machines to perform humanlike tasks autonomously. Tool wearing out or unexpected accidents can be detected and then machine can solve the problem. According to Andy Harris in [6],implementing AI in manufacturing will increase speed, precision, and quality control. In order to drive the digital transition in the natural stone industry Veronese Marble Consortium and big data analytics the AI solution developer Maxfone forged a partnership. Managing Director of Maxfone, says: "… three objectives: to have the costs of each process and job under control thanks to machines 4.0 analyzed in real-time; to use artificial intelligence (AI) to optimize processing routines based on electricity and water consumption and finally, to monitor through specific Internet of Things (IoT) sensors all other inefficiencies, such as compressed air leaks." [7].

Main tools for AI include machine learning, neural networks, self-learning systems, and deep learning. Such systems can find and discover the patterns in large volume of Big Data then they would take the necessary actions[6].

A Fuzzy Multiple Attribute Decision Making (FMADM) was developed by Yavuz in [8] for finding the best natural stone plant location in the mining industry. Analysis was performed by combining the FMADM and the analytic hierarchy process (AHP) technique. Author stated that the FMADM model can be applied to all natural stone types, and can perform the analysis for worldwide natural stone mining. Employing multi-objective and bi–level approach Jun Gang et al [9] optimized the stone park location problem, considering both the local government and stone enterprises positions. The local government objective is reducing environmental pollution and development cost while the enterprise is aiming to reduce the cost. Adaptive Chaotic Particle Swarm Optimization is used to reach the optimized location solution.

Huang et al in [10] proposed a surface texture and color recognition method for Chinese stones. The technique combines various visual recognition tools including Gobar feature, Grey-level Co-occurrence Matrices, and human visual color features. In addition, it uses non-overlapping images for the training samples.Karanam et al 2022 [11] developed granite classification process based on edge computing and machine learning, such that end users could distinguish different type of granites for their decoration purposes. Different machine learning algorithms were examined, they found that Random Forest classifier yields best accuracy followed by Support Vector Machine SVM then K-Nearest Neighbor KNN classifier.Employing deep learning models such as KNN and DenseNet Murat et al 2023 [12] built on Matlab environment; they were able to classify marbles with efficiency of 99.7%. Classification stone system for southern Italian regions as developed by Tropea et al 2019[13] is a two-stage system involving deep learning CNN models and machine learning Algorithms. This hybrid two-stage model is also based on Transfer Learning for pre-training on large available ImageNet data sets.Muhammad et al [14] developed a system to classify natural stones using Convolutional Natural Networks CNNs. They found that such system incorporating color and texture is extremely effective and reliable when compared to conventional visual methods.

De Luca et al in [15] presented a smart phone application called RecoStones that can determine stone materials and find their provenance origin using image recognition techniques. They explained that although the software was based and developed for Calabrian quarries it can be further expanded to other quarries nationally or internationally. Haoming Zhang et al in [16] based on deep learning techniques proposed for Chinese stone inscriptions a framework for image denoising and inpainting. They established a dataset for image denoising and inpainting by preprocessing of the gathered images of stone inscriptions. The denoising model is developed using multiscale feature fusion and a Charbonnier loss function. Testing of model showed the advantages of the methods over other de-noising methods; however more work is needed to improve its features. Classification system of ornamental rocks by using analysis and classification of images, based on machine learning algorithms was developed by Tereso et al 2020 [17]. This method will be used for quality control of different type of rocks in order to reduce material waste. Applying method to 2260 samples in Portugal showed improved results and reduced time.

Moghaddam et al 2018 in [18] proposed a two-step method for white marble classification. The first step uses image processing to segments impurities on marble surface, while in second step area of impurities is computed. Testing this method on 100 samples yielded an accuracy above 97% which is comparable with other human based and industrial methods.Fatih Akkoyun, et al in [19] developed an image-based classification technique for stone grading applications. The solution capture images at different angles to extract the visual stone parameters, then using machine learning algorithms stones are classified based on color and shape. The technique successfully classified mine stones up to 98% Recognition Rate (RR).

Medispec is a medical equipment manufacturer who developed the Stone vision X-ray machine which is an advanced after-image processing system provided with algorithms for best stone identification and lithotripsy applications. The software incorporates an enhanced contrast and brightness settings to the image [20].

Hosseini et al in [21] investigated the effect of cooling and lubricant fluid on the stone cutting performance using two methods; artificial neural networks (ANN), and the hybrid genetic algorithm – artificial neural network algorithm. Their model employs both operational and stone parameters. Their results showed that concerning efficiency of providingan accurate and stable model, the Multi-Layer Perceptron (MLP) Neural Network is better than the hybrid ANN-GA algorithm.

G.S. Sangeerani and Deepak in [22] investigated the effectiveness of Artificial intelligence in the Indian stone Industry. They found that using version 4 machine language in the stone processes would improve production efficiency, leading to less material defects, and faster production rates.

Sousa et al in [23]explained an example of Zero Defects Manufacturing (ZDM)in stone slab manufacturing industry. Automatization techniques such as image processing are used to detect voids, and cracks in the stone slabs.

Mikaeil et al in [24] used a combined experimental AI method to predict noise in stone drilling processes. Three AI methods were used including adaptive neuro-fuzzy inference system- SCM, neuro-fuzzy inference system-FCM, and radial function network –RBF. They concluded that Adaptive neuro-fuzzy inference system ANFIS-FCM is the efficient system in predicting drilling stone noise and that noise is mostly dependent on the type of stone and the drilling bits.

Kazem and Zangana in [25] discussed the implementation of Neural Network control strategy in turning process. The technique was able to reduce the vibration overshoot in the natural frequency vicinity to about 30% of its level. This can be used in the CNC milling and cutting machines of stone and marble to improve the surface finish of turned columns and sculptures.

Several publications talked about using cranes in industry, stone industry similarly, uses different types of cranes. Al-Refaie and Abdelqader in [26] tackle scheduling quay cranes between industrial vessels' pays.

The paper aims at showing the influence of using quay cranes to handle sequencing between pays by reducing time and maximizing number od operations. Lifting high-tonnage weights using hydraulic cranes is discussed by Nie and Fu in [27]. The article concentrates on using closed-loop hydraulic cranes for hoisting heavy weights which can be used in lifting rock blocks in stone cutting factories.

Detection of surface defects in metals was discussed by several research groups, once for casting by using CNN logic algorithm and another time for detecting cracks of spur gears by using Limit Line Method and Finite Element Method [28, 29]. Hybrid Fuzzy Logic with Genetic Algorithm detection system was used by Sahu and Jena in [30] to detect the crack of structural elements like beams and cantilevers. Neural Network has been implemented in controlling the energy efficiency in industrial sectors [31]. Although, these references use the foregoing AI techniques for metals and structures but the same algorithms can be adapted to be used for stone defect detection.

One of the important issues to depict in this study is the influence of energy and energy efficiency in stone cutting industry. Some researchers have studies energy and energy efficiency and the possibilities to implement renewable energy in both; residential and industrial applications in Jordan which has mosre or less a similar situation like Palestine [32, 33, 34].

The above reviewed literature showed the wide interest and numerous implementations of AI in natural stone industry both on research & development and by academia. Such opportunities are not explored for Palestine stone sector, this paper would serve as an attempt to introduce this AI and initiate research in this sector.

In this paper, implementation of modern technologies and AI in the stone cutting industries in Palestine will be investigated. The main objective of this study is to improve the general situation and performance of the stone industry in Palestine by enhancing the use of AI technologies. There is a high need for that to cope with international standards and compete in the regional and global markets. One of the main obstacles facing implementing these technologies is that customs and imports are controlled by the Israeli authority that imposes extreme restrictions on importing modern technologies to Palestine. Another obstacle is availability of technically skilled people for installation and maintenance of these technologies, thus external experts are brought along with technologies to install and commission the systems.

3. Stonecuttingmodel with AI technologies

Limestoneis extracted from Palestinian mountains using heavy duty equipment. Extracted rocks come usually in prismatic or cubic shapes to facilitate transportation and cutting later on. Cubic blocks are transported using trucks and moved to the cutting factories, where loaders are used to load them on trucks and heavy-duty cranes are used to download them from these trucks in cutting factories. The main focus of this section is to show the supply chain of the cutting process inside the cutting factories and to show how artificial intelligence techniques can improve the different tasks.

3.1. Integrated model for Stone cutting process

The general integrated definition model of the stonecutting process is depicted in Figure 1 while the detailed parameters of these models are shown in the following five figures from Figure 2 to Figure 6. Figure 1 gives the general structure of the cutting process where the inputs to the cutting process are transferred to outputs by the aid of external and internal dynamics influencing the process. Controls are the parameters that form restrictions and regulations to the cutting process.

In the Middle East and North Africa (MENA) region especially in Palestine, most of these processes are performed using traditional machines or hand working which increases the risk of injury and death between workers, on one hand. On the other hand, using traditional machines and hand works decreases the performance of the cutting process and reduces the added value as well.

The foregoing problem can be solved by implementing different artificial intelligence (AI) techniques in the different tasks and activities of the stonecutting process. AI technologies can be implemented in the dynamics and controls of the cutting process as well as in the process itself as can be seen in Figure 1.Examples of implementing AI in the process dynamics is usedfor accuracy and architecture, where in controls of the system AI are implemented in machinability and mechatronic systems.

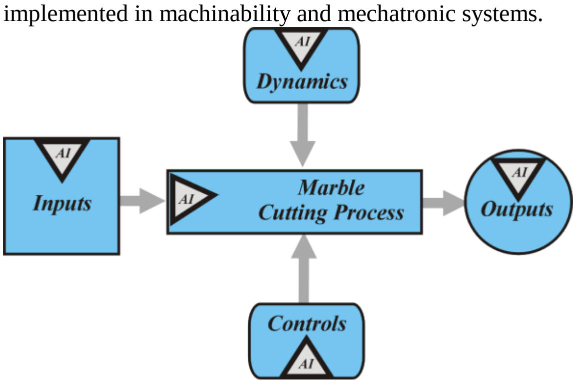


Figure 1. General integrated model for stonecutting.

More details about the inputs of the stonecutting process are shown in Figure 2. Rock blocks are the main input that have been transported from quarries then lifted using heavy-duty cranes and positioned on the cutting machine table to be cut or sliced using steel cutting saws. The cutting process is accompanied by high energy consumption (mainly electricity). Because of big weights, Gantry cranes requirehigh electricity power to hold up to 30 metric tons and more, while cutting saws require high power to overcome high hardness of limestone. Water is a very significant input to the process, where an average cutting workshop consumes more than 10 cubic meters of water per day. In most of stone cutting factories there is no treatment and recycling of waste water.Hence the employment of AI technologies to reduce the amount of generated wastewater is urgently needed [35].

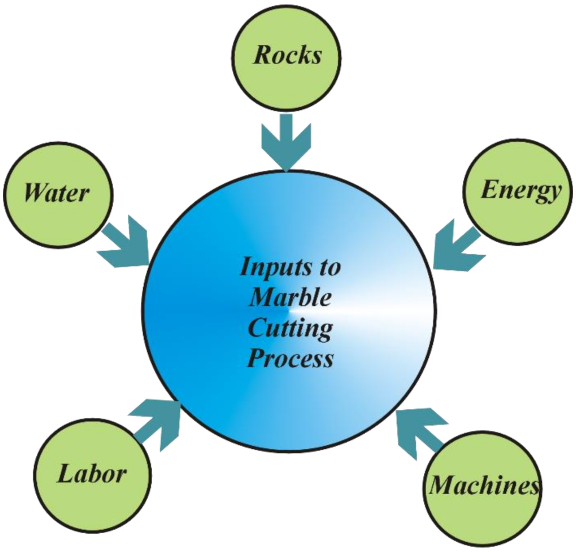


Figure 2. Input parameters to the stonecutting process.

The main stonecutting process is detailed in Figure 3. The process starts by lifting rock blocks using overhead heavy-duty cranes tied by steel cables positioned on cutting machine tables. This task encounters a very high risk on workers where most of the injuries and deaths occur here. The rocks are sliced using large-diameter circular saws driven by high-power electric motors. These saws runclose to workers and expose them to risk of injury as well. Sliced stones are transferred to other smaller cutting machines for square cutting to form the final up-to-size stonepieces. In most of the cases this process is done by hand. The final cut stonepieces are then moved to be either shaped, engraved or surface-finished depending on the application. If the product is to be used for inside tiles or decoration, it needs to pass under the surface finish process that needs another finishing machine. If these stones are tobe used for the outside building construction, they need to be engraved and shaped to specific shapes according to their place in the building façade. Finished products are sorted and packaged by hand-working to be transported to building sites or exportation. These tasks encounter internal movements in factory and external transportation using big trucks.

Stonecutting process is motivated by five dynamics that direct and justify its tasks as shown in Figure 4. Market needs specify the required shapes, colors, quantity and quality of stoneproducts, this market can be local, regional or international one depending to the commercial activities of the cutting factory. Accuracy of the produced stone is decided and restricted by the quality of the used cutting machines and skill of working labor. Architectural design also motivates most of the produced stonepieces, for example, using arches needs hand engraving of pieces included in the arch and using columns needs turning machines to turn stones to cylindrical shapes. Stonecutting factories produce huge amounts of dust and noise polluting the surrounding environment which adds another dynamic that restricts this kind of work[5]. A big cluster of people work in stone cutting factories and their level of life depend mainly on the income from this sector; this creates societal behaviors related to the working time in these factories and opened job opportunities to the society.

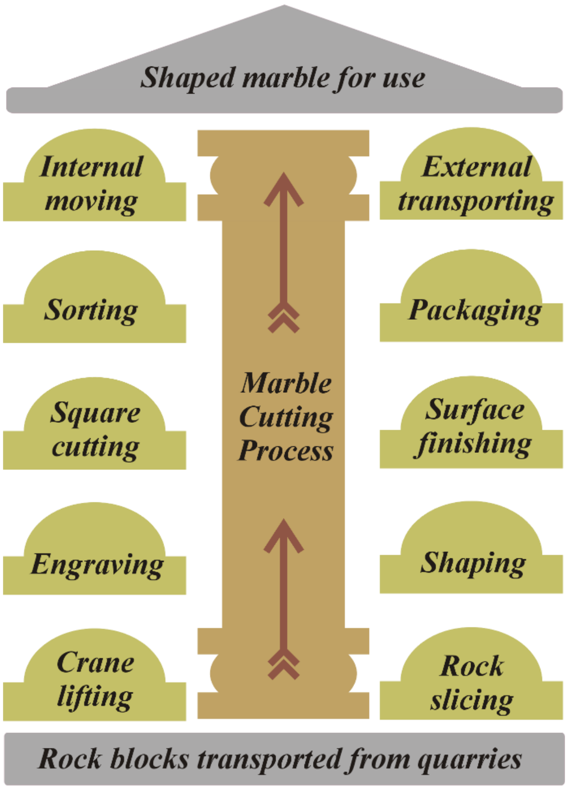


Figure 3. Process of stonecutting showing all phases and stages.

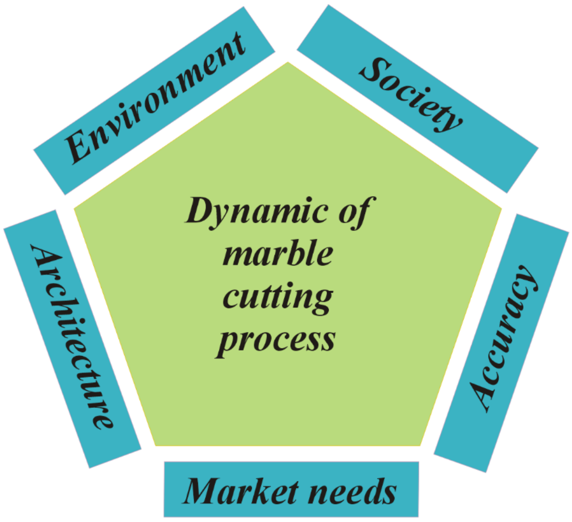


Figure 4. Dynamics influencing stonecutting process.

Figure 5 shows the main controls and regulators that sets restrictions and limits to the stonecutting process. Workers Occupational Health and Safety (OHS) make the main restrictions and controls that force cutting factories to adopt regulations related to labor safety. Safe overhead cranes and safe cutting saws are considered the main precautions need to be implemented in every stonecutting factory. Sustainability includes dust reduction, noise isolation, water and energy conservation are essential controls that make limits to the operations and cutting processes. Most of the cutting factories dispose the waste slurry in rural areas which deteriorate the landscape of the country[5]. On top of all controls there is a high need to implement Artificial Intelligence (AI) in stonecutting factories to solve most of its problems as will be seen in the next section. Other mechatronic systems and mechanisms can be used to control and regulate cutting processes where specific sensors and actuators are used for this purpose. The hardness of stones restricts the machinability of these stones and decides the type of cutting tools and edges used for this cutting process.

The foregoing model sections lead to the outputs shown in Figure 6. One of the main outputs is the normal stone used for building construction; these stones are usually the cheapest and easiest to produce as they don't need high accuracy or intricate shapes. Columns are used in modern construction for villas, palaces and even entrances of normal houses, they are produced using special turning machines to turn prismatic stones to cylindrical shapes. Arches are usually used for building holly places; mosques and churches, sometimes they are used for windows and doors of modern houses, and they are produced using hand or machine engraving process and need highly-skilled workers. Arches and columns are more expensive than normal stones because they need more complex processes. Stones and marbles used for decors and tiles usually pass through a specific surface finish process to have a brilliant smooth surface and considered the most expensive products.

3.2. AI solutions for stone cutting process

In previous section several problems envisaged by the stone cutting processes are discussed. Most of these problems can be solved by implementing AI technologies in keeping and conserving sustainable development goals SDGs. This idea copes with the principles of Society 5.0 that aims at creating the super human in the society by implementing the most recent and modern technologies like AI, big data, IoT and mechatronics in the frame of the international SDGs declared by the United Nations.

The required AI technologies to be integrated in the stonecutting factories which are summarized in Table 1 and shown in Figure 7 will be discussed further in next section.

Table 1. Stone cutting tasks and suggested mechatronics &AI technologies.

Item	Stonecutting task	AI technological solution
1	Overhead lifting	. Smart overhead gantry robot cranes operated remotely . Caged by steel fence
2	Rock slicing	. Laser measurement for better accuracy . safety shields for circular saws
3	Square cutting	. Accurate sleeve bearings . Active control of vibrations
4	Surface finishing	. Image processing . Active isolation of vibrations
5	Sorting	. Gantry or industrial arm robot . Automatic labeling
6	Internal moving	. Automatic guided vehicles . self-driving fork lifts
7	Engraving & shaping	. Automatic tools and machines . Hydraulic copy machines

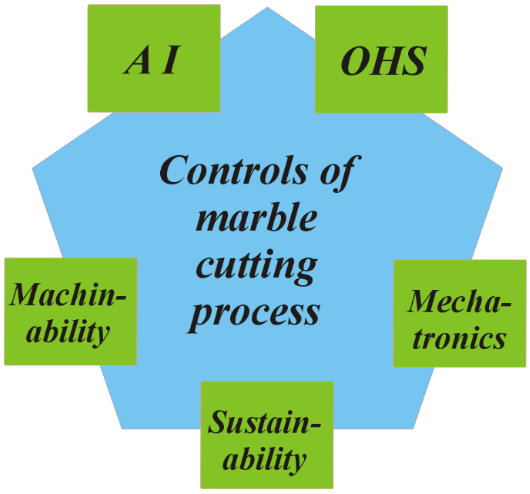


Figure 5. Controls and restriction that have impact on the limitations of stonecutting process.

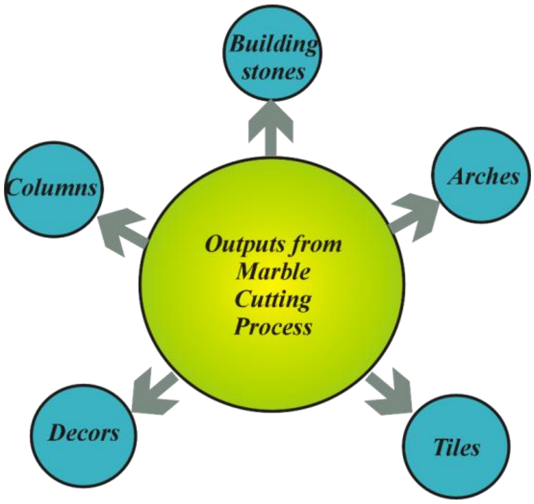


Figure 6. Outputs of stonecutting process.

Table 2 and Figure 8 show some solutions for the sustainability issues related to stone cutting factories. The main sustainability issues include the following: Electricity and fuel saving, water saving, wastewater treatment and reuse, rock waste circulation and air and sound pollution reduction.

Table 2. Stone cutting sustainability issues and suggested AI technologies.

Item	Stone cutting task	AI technological solution
1	Electricity and fuel saving	. PV solar panels . Automatic control of machines
2	Water saving	. Solenoid valves . Water flow rate control
3	Wastewater treatment	. Smart slurry presses . Water recycling
4	Rock waste circulation	. Crushing . Street tiles
5	Air and sound pollution	. Dust filters . Sound isolators

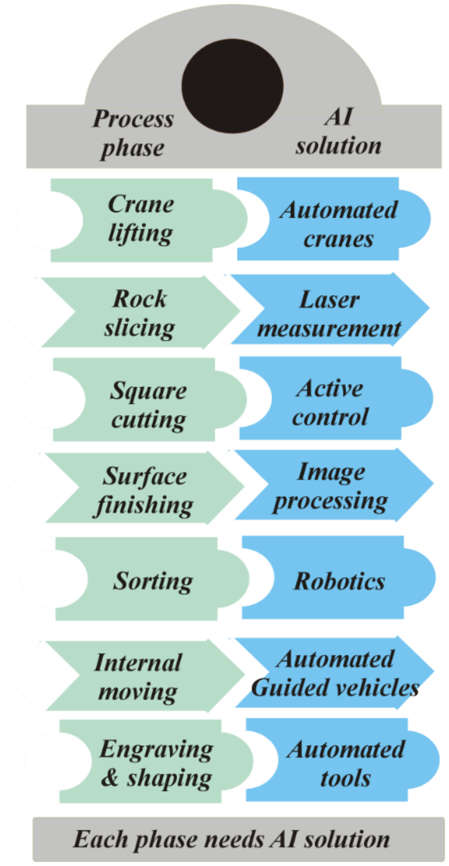


Figure 7. AI solutions for the different stages of stonecutting process.

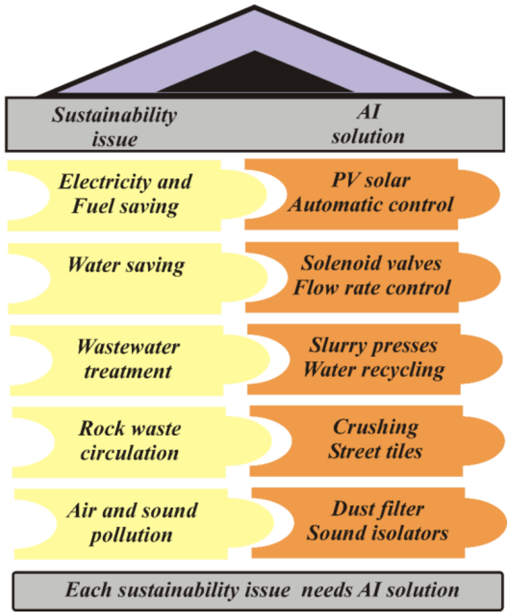


Figure 8. AI solutions for the different sustainability issues related tostone cutting process.

4. Implementing modern technologies and AI in stonecutting

Traditionally, most of the tasks related to stone cutting processes in Palestine are made by hand or by conventional techniques. To improve this important sector, it is necessary to automate it by implementing modern artificial intelligence technologies throughout the whole process. This automation technique is essential to increase the added value and quality of all products leading to increase in profit and in national income, as well as safety of workers and protection of environment.

4.1. Modern technologies for stone cutting

The modern technologies and artificial intelligence (AI) affect most industry fields.The field of stone cutting is one of fields highly influenced by modern technologies and AI to improve the quality, performance, and human safety while reducing the run time, energy and risk. In this section, the alternative technological solutions will be introduced for the different stages of stonecutting process.

4.1.1. Crane Lifting

There are different types of cranes which can be used in stone and marble cutting factories. Selection of a suitable crane depends on the factory size and produced amounts and types. There are three types that can be used for stone cutting process:

- Overhead crane

This type is used for large factories that work on large and heavy stone blocks. This type is built as fixed to cover most workspace area in factory and moving by remote control. It consists of two bridges at two opposite sides to carry orthogonal horizontally bridge with portable crane (Hoist).

- Gantry-Crane

This type is more flexible than the previous one and more suitable for middle and small factories. It depends mainly on two mobile holders that carry the main girder with hoist.This type moves either by four wheels or slipping into a duct on the floor.

- Jib Crane

This type depends on one pillar to carry the girder and hoist. Therefore, it is used in small workspace area. The pillar can be fixed on floor or built on mobile base.

Across various crane types, the remote control and dynamic control systems are used for accurate, effective, and efficient move of the crane.

4.1.2. Rock slicing

There are many types of machines used for stone cutting. It can be categorized into two types: the first one is the external machines used in open space and quarries, while the second one is the internal cutting machines. For the first type, still heavy machines are used to cut and transfer the heavy big stone blocks, that machines such as: double blade granite quarry machinery either as a mechanical or magnetic machine. To transfer the stoneblocks from quarry to cutting factories, the traditional huge wheel loaders, big dumper, excavators, Trucks, and bulldozers are needed at quarry sites. This type of cutting will not be studied intensively here because this research concentrates on internal cutting in factories.

4.1.3. Square Cutting

The second type of stonecutting is more important where more improvement can be implemented here by using automatic control and intelligent systems. This type is used for rectangular or square stonecutting as it is used inside factories; it is relatively small and must be more accurate and effective with precise performance. There are many modern technologies that can be used for stonecutting of slides with different thicknesses according to use. One of these technologies is the Multi-wire stone cutting machine.

This machine is employed to cut the big stone block to rectangular slices which are more suitable for shaping according to demand (marblefor walls, floor, countertops, furniture, sculptures, pillars, or bedrooms). The machine is used inside factory,it is computerized and enclosed completely during operation with external electronic control board to save employees live. Large amount of water is consumed by this machine, thus, it is necessary to implement a system to treat and reuse water.Hence cooling water is collected in a lower container, then filtered and pumped to be reused again.

4.1.4. Surface finishing

In this stage, the resulting slices from square cutting step need to be polished and smoothed. The resulting stones have to bein accurate and in precise shape.Furthermore, factories have to polish a large quantity of slices in a relatively short time.Automatic Line Polisher Machine with Multi-Heads is used to polish Marble Large Slab. This machine can work automatically by computer numerical control board and thus increasing safety level.

4.1.5. StoneSorting

Automated Tile Sorting Machine constitutes a global innovation and still is a hot research area. Some stonefactories use Artificial Intelligence and Deep Machine Learning expert systems to sort the tile. This process is used to accredit Palestinian Stonetile with precision and efficiency for potential exportation features. The proposed expert systems for sorting will be discussed in the next section.

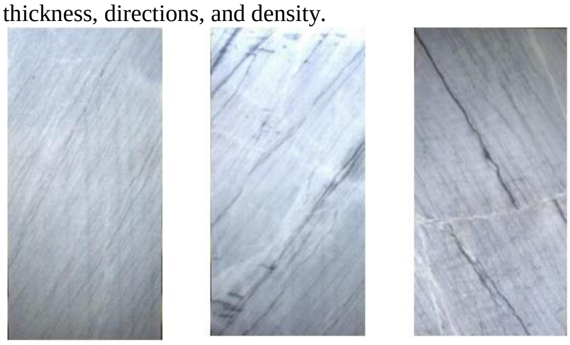
4.2. Expert systems for stonesorting

One of the most important stages for the natural stone tile production line is the sorting of the final product to different types.In pastime, this stage was used to beaccomplished manually by specialized human experts. The sorting criteria are not clear and very much dependent on the human expert. Automating this time-costly process by using expert systems is necessary and vital process in stoneindustry.

Machine learning (ML) is used in many fields of industry to solve classification problems in a wide variety of real-world problems. For this reason, in this research, many approaches of ML will be used to classify stonetiles and polished slabs.The first expert system is used for slab classification and uses texture analysis and classification. The second expert system is used to detect the defects in each tile.

4.2.1. Stone slab classification

The dataset used in this research is collectedby Marble Solakis Enterprisesin [36], the dataset contains 441 digital images for threeclasses of marble slabs based on texture analysis, 147 for each class and 400*700 pixels for each jpg image. Figure 9shows sample for each class, whereasthese classes are classified based on cracks thickness, directions, and density.



(a) (b) (c)

Figure 9. Marble classes (a, b, and c) as used in [20]

The marbles were manually extracted from the original images (2000*857) and resized to the above image size to be ready for use [36]. Few papers used some classification methods such as: support vector machine (SVM), K-Nearest Neighbor (KNN), Random Forest (RF), Multi-Layer Perceptron (MLP), Logistic Regression (LR), Stochastic Gradient Descent (SGD), Extreme Gradient Boosting (XGB) and others. However,all these methods need many preprocessing like transformation to gray level, brightness normalization, feature extraction, reduction of data dimensionality, filtering and denoising, and other data pre-preparation. To reduce all these steps, this research will use deep convolutional neural network (CNN) which contains a multi convolutional and Pooling layers without the need for pre-preparation steps.A Convolutional Neural Network (CNN, or ConvNet) is a special type of multi-layer forward neural networks to classify images and videos directly from original pixels with minimum level of preprocessing.

Currently there are many open-source platforms to apply different types of CNN algorithms, this is because CNN is very complicated and high level of computation. CNN needs advanced CPU and servers to achieve their tasks. Four CNN algorithms that are used in this study along with their features are shown in Table 3; a comparison will be made between results of these algorithms for marble classification [37].

Table 3. Four CNN algorithms used and their features.

CNN name	Year	Salient Feature	Trainable parameters	Floating Point Operations
AlexNet	2012	Deeper	62M	1.5B
Intception	2014	Wider-Parallel kernels	6.4M	2B
VGGNet	2014	Fixed-size kernels	138M	19.6B
ResNet-152	2015	Shortcut connections	60M	11B

4.2.2. Defects detection

After recognizing the marble type for sorting, the detection of defects in marble tile is very important to be achieved automatically. Table 4lists some types of defects that can be detected in tiles.

Table 4. Some types of Defects on Tiles.

Defect	Description
Blob	Water drop spot on the surface
Corner	Break down in the corner of tile
Crack	Break in tile
Edge	Break in edge
Glaze	Blurred surface on the tile
Pinhole	Isolated black-white pinpoint spot
Scratch	Scratch on surface
Spot	Discontinuity of color on the surface

Some of these defects can be detected by morphological operators such as: dilation, erosion, edge extraction, boundary extraction, etc. However it is not possible to depend on morphological operators completely because the marble contains lines that appear as cracks, therefore, this research will recategorize these defects to two types:Surface cracks, and Geometry defects. To overcome these defects, HD camera and flat light source are needed in a dark box. HD camera will capture the tile surface with reflected light and deliver the images for expert system to detect any surface cracks.

Reflection of smooth surfaces such as mirrors or a calm body of water leads to a type of reflection known as specular reflection. Reflection of rough surfaces such as clothing, paper, and the asphalt roadway leads to a type of reflection known as diffuse reflection. Whether the surface is microscopically rough or smooth has a tremendous impact upon the subsequent reflection of a beam of light. Figure 10depicts two beams of light incident upon a rough and a smooth surface.

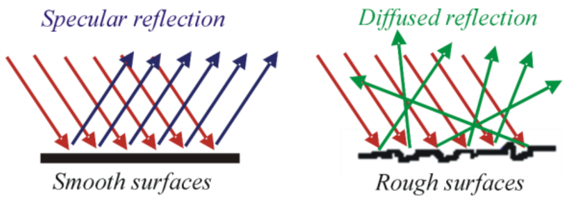


Figure 10. Specular reflection and diffuse reflection.

On the other hand, the color of production line belt represents the background for marble tile, and helps to detect on geometry of tile as shown in Figure 11

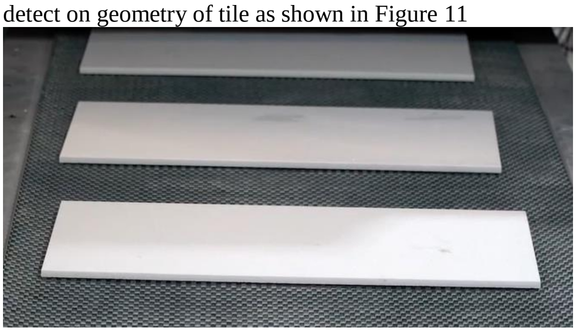


Figure 11. Marble tiles on belt.

5. Simulation results and Analysis*:*

To implement our codes and CNN algorithms, many python programming language libraries and tools (such as: Anaconda, Banda, jupyter) are installed on HP intel(R) Core (TM) i7-6500U CPU @ 2.59 GHz, 8 GB Ram. Furthermore, this research used TensorFlow, open-source AI software by Google, created for tasks with heavy numerical computations with support of CPUs and GPUs and distributed processing. TensorFlow is suitable for Deep Learning algorithms for many reasons as: it is extensive built-in support for deep learning, it has tools for assemble of Neural Networks (NN), and it has ability to achieve many of mathematical functions for NN, beside of the functions for auto-differentiation and first-rate optimizers, and versatility.

5.1. Classification expert system for colored Marble images

The first implemented system in this research is used to classify the colored images of marble. As shown before in Figure 9, the used dataset contains 441 digital images for three classes of marble slabs based on texture analysis, 147 for each class and 400*700 pixels for each jpg image. Four CNN classifiers are implemented to classify these three types of marble slabs, and their results are shown in Table 5.

Table 5. The recognition rate (RR) of Four CNN algorithms used for colored marble images.

CNN name	No. of samples	Corrected samples	RR%	Approx. Execution time (days)	No. of layers
AlexNet	147	139	94.5	5	8
Intception	147	141	95.9	4	22
VGGNet	147	145	98.6	14	16
ResNet-152	147	145	98.6	8	152

The dataset is separated to three balanced groups (49 samples from each class). These groups are: 147 samples for training, 147 samples for validation, and 147 for testing.

As shown in Table 5, ResNet-152 and VGGNet gave the best RR% but both take a lot of time to achieve training step comparing with both AlexNet and Intception CNN. Although ResNet-152 has more layers than VGGNet but it finished training step in less time than VGGNet, because time complexity for ResNet-152 algorithm is less than for VGGNet algorithm. Although the results of AlexNet and Intception CNN has good time for training step comparing with ResNet-152 and VGGNet but it has a worse recognition rate.

5.2. Classification expert system for Gray-level Marble images

As noted in Table 5, the best results need to spend a longer time to achieve the training step. Actually, for colored image, the used expert systems are treated with three images which are RGB components. To reduce the time for processing the three images, can be convertedto gray-level image and treat just one image. The results of the four CNN algorithms are shown in Table 6.

Table 6. The recognition rate (RR) of Four CNN algorithms used for Gray-level marble images.

CNN name	No. of samples	Corrected samples	RR%	Approx. Execution time (days)	No. of layers
AlexNet	147	145	98.6	2.5	8
Intception	147	147	100	2	22
VGGNet	147	146	99.3	6.5	16
ResNet-152	147	147	100	4	152

Table 6shows the training step time improvement, and emphasizes that ResNet-152 has the best RR% for both colored and gray-level marble images. Meanwhile according to training step time, Inception CNN gives the best RR% in less time and a smaller number of layers and complexity than ResNet-152. A comparison of the RR% in the different algorithms is presented in figure 12for color and in Figure 13for grey level.

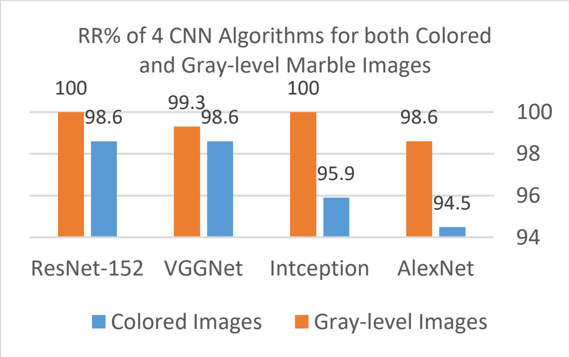


Figure 12. Comparison of Recognition Rate (RR%) for used Algorithms by both colored and gray-level marble images.

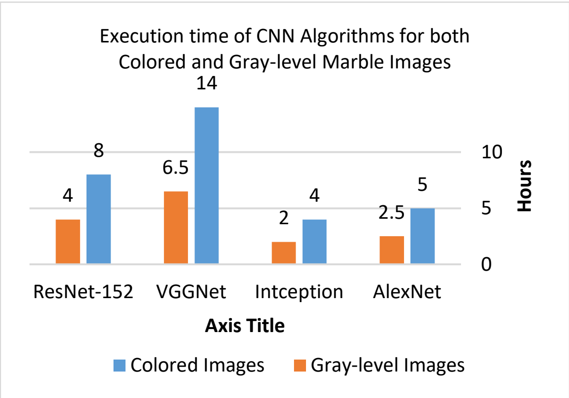


Figure 13. Comparison of execution time for used Algorithms by both colored and gray-level marble images.

6. Conclusions & recommendations

The stone and marble sectors are integral to Palestine's economy, blending artistic heritage with economic growth through skilled labor, cultural preservation, and global appeal. In essence, this work highlights the symbiotic relationship between Palestine's economy, its stone and marble stone sectors, and the infusion of AI and modern technology for enhanced productivity and precision in marble processing.

Investigating the stone cutting industry in view of advanced technologies and AI implementation in stone industry worldwide, as well as investigating Image Processing techniques for marble classification, the following conclusions can be pointed out;

1. To amplify productivity and ensure workplace safety, integrating modern technology across the entire stone and marble supply chain is imperative in Palestine.
2. Integrating modern technologies in stone industry will reduce water, energy, and natural stone consumption, as well as decrease pollution and improve sustainability of stone sector sustainability in Palestine.
3. Artificial Intelligence can play a crucial role in elevating cutting precision, stone categorization, and numerous applications across the entire stone and marble industry supply chain.
4. Employing deep learning to streamline image processing and utilizing four CNN variations to classify marble slabs, the following are found out;

- A comparison between colored and gray-level databases reveals the superiority of the latter in recognition rates. While colored images involve three color layers (Green, Blue and Red), gray-level images rely on one layer.
- With gray-level predominance in most marble and stone types, color proves less critical parameter compared with texture in classification.
- CNNs techniques excel at texture-based marble slab classification, exhibiting notably high recognition rates.
- Gray-level images emerge as optimal for CNN-based marble vein classification.
- Among CNN types, ResNet-152 achieves remarkable 100% recognition rate for gray-level images and 98.6% for colored images. Conversely, Inception CNN excels in both reduced processing time and gray-level image recognition rate, making it the preferred option for marble classification.

5. This research underscores that colored images offer minimal value in marble classification compared to gray-level counterparts.
6. The study shows that using these experts systems in marble testing reduces the time required for production and reduces the cost of transportation of defect products to the construction sites. Saving time and cost reduces the production cost and thus increases the benefits leading to a better efficiency of the industry.

The study recommends developing comprehensive datasets encompassing diverse marble defects for research purposes.In essence, this workhighlights the symbiotic relationship between Palestine's economy, its stone sectors, and the infusion of AI and modern technology for enhanced productivity and precision in marble processing

Statements and Declarations

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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