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A Model Adaptation Innovation For Mechanized Tunneling: Subsoil Uncertainty Consideration

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Abstract*— This research paper focuses on modeling a technology that will be useful in the mechanization tunneling of subsoil. Tunneling has evolved from cave creation to water management, underground transit, mineral extraction, and warfare throughout history. During the 1950s, cutting and blasting methods were replaced by the most modern and complex automated digging using tunnel boring machines. Tunnel drilling machines are significant in boring through various soil and rock types, including clays, granular soils, severely fractured or monolithic rock layers, partially saturated or saturated ground, escarpments with high loads, and sensitive metropolitan areas with little overburden [1]. Tunnel boring equipment is now common in a wider range of geotechnical situations. An overview of tunneling using tunnel boring machines and their applicability for soft ground conditions is provided in this review study.

***Keywords*—*Tunneling, Artificial Intelligence, Laser Beams, Subsurface soil, Geological Investigation, Excavation, Civil Engineering*

I. Introduction

Throughout human history, tunneling has been a very important contributor to our species' development and continuation. Tunneling technology has reached its zenith due to the ever-increasing demands of the contemporary human race. Geological and hydrogeological advances, tunnel design and capacity, building techniques, and speed and maintenance throughout operations contribute to its realization. Several tunnel-building techniques are pitted against one another in a competition, each with its pros and downsides. Tunnel Boring Machines have steadily improved since their inception, and they are now being used on more and more difficult tasks. Tunnel boring machines (TBMs) are gaining popularity as civil engineers and tunnel builders alike become more confident in the technology and the increased capacity [1]. Cut and cover for shallow excavations, cut and blast for hard rocks, and tunneling using Tunnel Boring Machines for different soil layers are examples of the advances in tunneling technology. Immersed tunneling, for example, may be used to bridge aquatic bodies, whereas jacked box tunneling can traverse busy roadways or railways.

According to the kind of rock or soil they travel through, tunnels may be divided into four major categories: soft soil, hard rock, soft rock, and subaqueous. Although these four kinds of soils need various excavation and ground support technologies, practically all tunneling projects entail similar fundamental processes: assessment, excavation, materials transfer, ground support, and environmental management [2]. Owing to their unique functions, tunnels for miners and civil works have conventional approaches but vary substantially in their development model to permanency. There are a lot of mining tunnels, but most of them have a design that is minimally expensive for brief usage during the process of ore extraction. However, the rising need of surface landowners for procedural safeguards against eventual tunnel collapse could force this to shift.

In contrast, the majority of tunnels that result from civil engineering or infrastructure maintenance entail continuing human occupation and complete protection for nearby building owners and thus are built to be considerably more moderately feasible over time [2,3]. Additionally, these tunnels are constructed to ensure permanent safety far more conservatively. Geology conditions in all tunnels largely determine the suitability of building techniques and the viability of various designs. Many examples have been cited throughout tunneling history when unexpected situations necessitated extensive delays in building new technologies or designs, which resulted in a significant rise in both time and expense [3,4.5]. This paper will look at developing a high-energy laser beam technology boring machine that will cut through an underground or raised surface to create a tunnel. The Machine will consist of several laser heads and purging gas integrated with artificial intelligence to cut through a surface based on the desired design shape of the tunnel. Laser technology may minimize boring time, eliminate the need to collect and dispose of cuttings and increase well performance via better perforation.

II. Research Problem

The main problem that this research paper will address is to develop a technology that will improve mechanized tunneling while minimizing the risks of collapse in the subsoil. The industry's international reputation for on-time, on-budget delivery is at risk because of difficulties with Crossrail. Tunnel building involves a lot of rock damage and removal. The removal of billions of cubic meters of rock throughout the years has required a significant cash commitment. Improved technological innovation is essential. The relative riks in various excavation sites require a thorough inspection and development of innovative technology that will minimize the level of risks. A thorough geologic analysis is essential to assess the relative risks of different locations and reduce the uncertainties of ground and water conditions at the chosen location. In addition to soil and rock types, key factors include the initial defects controlling the behavior of the rock mass; the size of rock block between joints; soft beds, and zones, including faults, shear zones, and altered areas weakened by weathering or thermal action; groundwater, including flow pattern and pressure; plus, several special hazards, such as heat, gas, and risk of cutting tremors [6]. The large cost and long time required for deep borings generally limit their number for mountain regions. Still, much can be learned from thorough aerial and surface surveys, plus well-logging and geophysical techniques developed in the oil industry. Often the problem is approached with flexibility toward changes in design and construction methods and with continuous exploration ahead of the tunnel face, done in older tunnels by mining a pilot bore and now by boring [7,8].

III. LITERATURE REVIEW

A. *Exploration of the earth's crust*

A geological analysis is needed to analyze the potential dangers at multiple spots and minimize uncertainty in subsurface and groundwater conditions. Also critical are rock types and their original flaws affecting their activity; block size within joints; unstable beds and zones, like faults, shears, and changed regions degraded by weathering or thermal activity; groundwater movement patterns; and various other unique risks [7]. Deep borings are difficult in mountainous areas because of the high cost and lengthy time needed; nevertheless, detailed aerial and surface surveys and well-logging and geophysical methods pioneered in the oil sector may provide a wealth of information [9]. As with previous tunnels, which used to use mining a pilot bore ahead of time, the issue is often tackled with a flexible approach to changes in design and construction techniques and ongoing investigation ahead of the tunnel face. Japanese engineers have pioneered the relocation of hard rock and water situations. Adverse geology may render a project unfeasible or at the very least prohibitively expensive for projects involving big rock chambers or tunnels [1]. A series of tiny exploratory tunnels called drifts are typically used to study their concentrated opening regions during the design stage of these projects.

B. *Material handling and excavation*

Boring and blasting techniques for hard rock may be semicontinuous, such as using handheld power tools or mining machines or cyclic. Boring, loading explosives, blasting, venting gases, and extracting the blasted rock are all part of the process—each cycle (called mucking). If you're looking for an efficient way to transport the shattered rock, a front-end loader called a mucker is your best bet. There is a lot of inventiveness involved in creating equipment that can operate in a tiny area since everything is focused at the top[11]. The ground inside the tunnel can be dug out in a semicontinuous way, like with hand tools or a quarrying machine, or cyclically, like with boring and blasting for harder rock. In this case, each cycle includes boring, stacking explosives, ventilating fumes, and digging up the blasted rock (called mucking) [11]. Muckers are front-end loaders that transport broken rock onto a conveyor belt into vehicles or trucks. As all activities occur at the heading, crowding is continuous, and equipment is designed to function in a tiny area. To expedite work, opening up intermediate headings using shafts or adits dug to give more access points for lengthier tunnels helps speed up the pace at which the heading advance is being made.

Borings are more viable for shallow tunnels in soft ground. Most subways need borings every 100–500 feet to assess soil strength, permeability, and other engineering qualities. Weathering typically weakens rock tunnel portals. Portal issues are easily explored via borings, although they're often overlooked. Consequently, many tunnels, notably in the US, suffer portal failures. Undiscovered hidden valleys have often brought expensive shocks—for example, New Mexico's 5-mile Oso Tunnel. In 1967, a mole made good progress in hard shale until it encountered a hidden valley of water-bearing sand and gravel, burying it. After being delayed by hand mining for six months, the mole was eventually rebuilt and shortly after broke new world records for progress rate, with an average of 240 feet per day and a high of 420 feet per day [11,12].

If the rock can sustain itself via a sturdy ground arch with the addition of just a little amount of artificial support, then large rock chambers are a viable option. It is very expensive to provide massive structural support for a wide hole in brittle rock. For example, a 45-by-60-foot granite grid supported by rock bolts was used in the Norad project, except in one region. The junction of two curved shear zones of fractured rock in this region necessitated an additional $3.5 million in construction costs for a 100-foot-diameter perforated concrete dome [12]. Due to unstable rock regions, the costly lining has been required in several Italian and Portuguese subterranean powerhouses. It's very uncommon for a 10- to 20-foot rock tunnel to handle severe rock flaws, but a large-chamber project may quickly become uneconomical if there is widespread weak rock present. Several borings and exploratory drifts are used to find rock flaws in rock-chamber projects, and a three-dimensional geologic model to help in visualizing conditions. A chamber placement is chosen carefully to minimize the possibility of support issues. At Churchill Falls, the granite gneiss, the position, and the chamber layout had to be adjusted multiple times to prevent rock flaws from achieving this goal. Exploratory drifts play a critical role in providing access for in-place field testing in rock-chamber projects, which relies significantly on the relatively young subject of rock physics to assess the engineering attributes of the rock mass[13].

C. *An examination into the mechanics of rocks*

Early in the 1970s, the emerging discipline of rock mechanics began to build a logical foundation for project design in rock; much has previously been produced for soil mechanics. Engineers were first inspired by difficult projects like dam structures that had to be built in various ways, such as tunnels, rock slopes, and foundations. Many approaches, like theoretical study, test procedures, on-site evaluation, and equipment, are used by the science of rock mechanics when considering rock mass[13]. For a rock chamber project, just the most typical field tests are described below to explain the importance of rock mechanics in the design process[13].

D. Bending Laser beams

According to physics researchers, high-energy lasers may bend slightly if some components are asymmetrical, creating what is known as an Airy beam. According to a new study, plasma trails may now be left by pulsed, high-intensity versions. When fired out in a stack, each pulse is one centimeter broad and lasts 35 femtoseconds before passing through a glass plate and taking on the appearance of a sharp peak on one side of numerous lesser ones [14]. There is a distinct difference between the brightest and darkest parts of the image. (The whole pulse's motion, on the other hand, stays straight.) A curving plasma stream is left in their wake because the bright spots ionize the air behind them and are so strong. Physicists may use the self-bending beam, disclosed in Science on April 10, to better understand the structure of laser pulses, even if the beam does not bend more than its diameter.

E. Artificial Intelligence and high-energy laser beam technology

Artificial intelligence in industrial production has been rising over the last several years. In only a few seconds, laser operations with nanosecond or even femtosecond pulse cycles create a large quantity of data, which can only be analyzed and appraised in a high-quality big-data assessment when powerful computers and algorithms interact effectively. Neural networks are important in laser machining in three steps, in general. When experimenting, the first step is to gather data in the form of input and outcome variables. Laser fluence and repetition rate might be inputs, while the depth of the laser-machined features could be the output. Backpropagation is used to automatically alter the internal weights of the neural network during the training stage [14,15]. Neural network accuracy is frequently monitored during the training phase to optimize development. Finally, in the third step, a new set of data are fed into the neural network, and the neural network produces a forecast for the corresponding outcomes. After it has been trained, a neural network may be used as a 'black box' modeling unit, which means that it can convert one set of data into another set of data linked with it [15]. However, training data formats significantly impact how the data are transformed from one format to another. the neural network can predict the level of the features for any laser intensity and repetition rate, even if those parameters are not measured during the experiments.

IV. Proposed Innovation

My proposed innovation is a high-power boring machine that employs lasers with artificial intelligence control to develop road and railway tunnels. Carving tunnels for roads and trains by using high-power lasers would enable drilling to the required depth without halting or having to draw out of the tunnel, creating a protective tunnel lining (casing), and completing and stimulating the well as an element of the drilling process, rather than as a separate process as is now done. For the boring business, a shorter time-on-site means less downtime for rigs that can cut, casing, and finish a well in a single pass using a quicker cutting method. Using lasers to cut through a material necessitates a fundamental rethinking process. There are no moving elements in the tunnel, and no weight is supplied to the bit. Because the down-tunnel assembly is built entirely of composite material, the surface equipment will be far lighter than it is now. Because the cut string rotates, there is no mechanical wear on the down-tunnel component. Since the bottom tunnel unit often consists of one or more portions of thicker-walled pipe that assist in applying a downward force to the cutting blade, the overall mass supported by the surface facilities might surpass one million pounds. Boring methods of the present-day need the use of specific bits for various kinds of rock. The bit must be swapped out whenever a different sort of rock is encountered. For example, bits designed for soft shale can't cut tougher ledges of sandstone or limestone. The pipe and bit are removed from the tunnel, and a new bit must be connected. The whole procedure may have to be redone more than once.

Rotating boring has been substantially improved throughout the previous century. Due to new bit designs, it can now cut through all sorts of rock at a much faster pace. Rotary boring is still a time-consuming and inefficient procedure. Well-creation requires a lot less time than previously thought since 1993 research found that the most time-consuming part of drilling is moving the drill bit rightward. Aside from cutting and raising the cut string, additional non-boring tasks like deploying equipment into the tunnel take up the remainder of the time. There is less potential for technical innovation in the boring, rotary sector because of declining profit margins in the boring industry. As a result of these previously groundbreaking innovations, such as diamond-impregnated bit teeth, gradual improvements are all that is feasible. The energy sector is forced to dig additional tunnels every year. The boring business is facing the potential of having to construct additional rigs and educate more people to run them due to a quiet period over the previous decade.

A. Design of the Machine

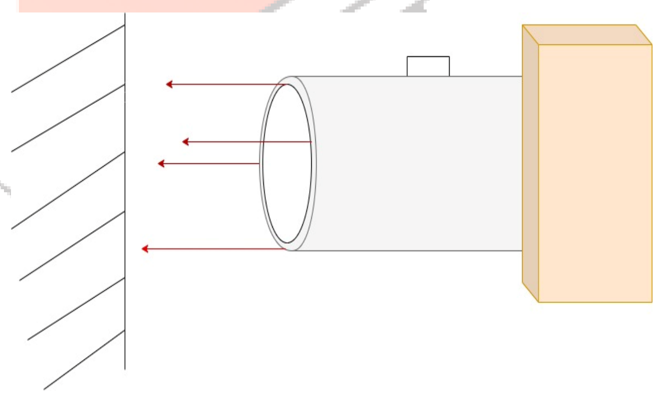

Fig i: Initial Design of the main Laser Beam Head

B. How the Machine works

For a closed system, there is no such thing as the creation or destruction of energy; only transformations from one form to another are possible. This rule holds for large groups as well. As a result, theoretically, a strong laser capable of destroying the mountain's solid materials would be able to melt it down into a tunnel. Extreme temperatures would be needed to break down solid minerals in the mountains. The energy required to cut through boulders with a high-powered laser beam is enormous. Marble can be vaporized at one cubic millimeter per second with an 80-watt laser. This gadget will need 80 Gigawatt seconds of laser power to vaporize one cubic meter of rock. We've put high-energy laser beam technology at the Machine's primary head to help regulate how much heat it generates, and that technology will gradually disperse that firepower.

However, working with it will take an eternity. The answer is that it may be launched simultaneously, allowing for the evaporation of up to 1000 mm3 of water every second, or around 0.001 liters of rock per second. If the tunnel's diameter is 2.7 meters, the area is 23 square meters or 230 square centimeters. If we fire 1.000.000 lasers simultaneously, the working area of each Laser will be 0.23 sqm. A fire will not be started as a result of this. So, every second, a liter of rock was vaporized using an 80MW laser. It can pulverize 3.6 cubic meters of the earth in an hour. That's a good pace. A lot of gas, particularly carbon dioxide, will be required for the Machine. Massive amounts of CO_2 will control the lasing process. As a result, the laser optics will be cleansed, and the fire will extinguish even further. Five bars and a powerful exhaust would be ideal for this task. Several megawatts of more electricity will be needed as a result of this.

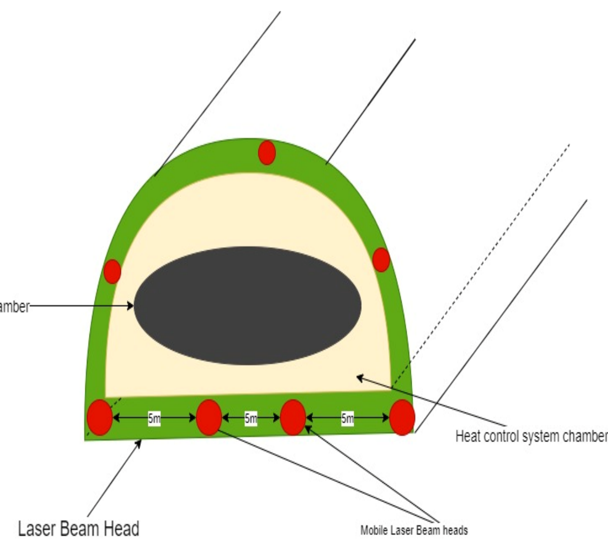

Fig ii: The main Laser head that will be

Fig ii shows how the Machine will curve the tunnel in a smooth shape that can make it easy to construct plat roads and rails. The laser heads can move toward each other as it cuts through the hard rock. This movement of laser heads is where artificial intelligence trains the head lasers to move at specific distances and frequencies. The high-energy laser beam-melted material should not be released into the environment. The main laser beam head is controlled to cut through the hard rock in a curve shape. This Machine has a suction tube that will collect all melted materials. Uniform material is ideal for using the Laser. Increasing the power and lasing time will be necessary if the laser drilling encounters hard soil that cannot immediately vaporize. There are virtually as many laser parameters to investigate throughout the testing procedure as surface factors a cut must penetrate. The first step in the tunneling process is to set up the Machine's calibration and scan the terrain to be dug. The power, duration, and wavelength of the Laser are required to get started. A continuous wave of iodine laser, which has a wavelength of 1.32m, will be set to determine the feasibility of this tunnel-making technology. The process will result in a sheath-like melt after portions of the surface have been fully penetrated. For subterranean highways and trains, the tunnel should be curvy and deep. A high-powered laser with a long pulse duration and rapid pulse repetition rate is needed to cut through the sub soil particles.

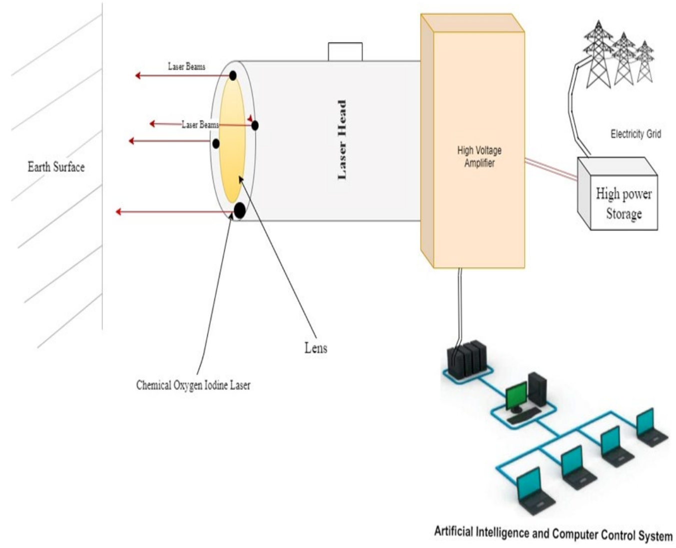

Fig iii: A combination of the Machine with a power grid and artificial intelligence control system

C. *Tests*

To determine the minimum amount of resources (the Specific Energy, or SE) required to cut the three primary lithologies drilling rigs tackle, sandstone, shale, and limestone. In addition to the three initial characteristics, we've included power density and an examination of the possible advantages of pulsed lasers over CW beams.

A 2kW Nd: YAG laser provides the pulse characteristics required to test ideas with roughly 1 ms pulse length. Laser pulse schedules with a range of values are utilized to retain the average programmed power. Between around 250 W and 1.4 kW of power are measured as the mean value. Even at average powers of just over 500W, it is intriguing how laser beam technology can cut the hard rock. As long as the average power remained high, higher repetition rates allowed quicker cutting. The challenge was to imagine how a conventional oil or gas well would be constructed and how the drilling assembly would appear. Using a single beam from a single lens to construct a one-inch diameter tunnel would be impossible. The idea was to build a bigger hole by adding beams together. As a result, the Machine performs best when lenses are used to ensure successful tunnel drilling. The Laser Beam heads will move up and sideways based on their set distance of 5 meters from each other. Up to 10 laser beam heads on the main head, each moving a maximum of 5 m. These motions will be programmed using artificial intelligence (AI) to guarantee that the procedure is automated once tunneling begins.

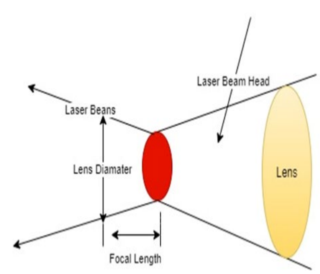

Fig iv: An overview of how the laser beams are focused on producing strong energy for cutting through a hard rock

V. Contributions

The contribution I am making with this innovation is developing a technology that can drill tunnels using high-energy laser beam technology while employing artificial intelligence. I am developing an innovation that increases safety while also increasing the efficiency of tunnel drilling. This technology does not cause risks to buildings on the surface which is a common trend of boring machines. Additionally, the subsoil and rocks will not destabilize since this technology does not cause cracks or quakes on the underground rocks. Tunnels throughout the globe are constantly developing in a race for safety, speed, and performance, driven by tremendous demand. As most tunnel drillers are boring machines, this is a new technology. The capacity of engineers and infrastructure professionals to quickly adapt to new technologies, processes, and applications substantially influences their job.

Additionally, this technology builds on using artificial intelligence in tunnel drillers to increase productivity and accuracy. Additionally, this new technology in civil engineering has the potential to reduce construction time and personnel costs. New challenges regarding economic models and funding have emerged due to increased tunnel constructions due to global urbanization. This new technology reduces construction time and labor costs by ensuring and improving construction quality as it is being used. The application of this new technology helps in reducing the labor quantity and labor costs and a significant reduction in labor intensity.

High-energy laser beam technology, virtual reality (VR), and artificial intelligence (AI) are some of the major elements integrated in this innovative technology. The minimal surface disturbance is critical when operating close to sensitive locations. Rather than constructing a cutting, tunneling beneath old woods might be considered.

This new technology builds on the growing use of AI in civil engineering. The construction industry is being pushed by automation and artificial intelligence to develop a growing number of standards that simplify, speed up, and unify the assessment of various elements. As a consequence of this progress, the more visible outcomes are already being clarified, and the flow of information among all parties involved in the maintenance process has been greatly accelerated. Beyond the fact that automation is driving standardization, a significant acceleration occurs at each stage of the inspection process. For example, one can use this information to create working data for the maintenance project. Even though the software is developed to assist judgments based on the combination of most of these criteria, the human control aspect is a challenge. Individual cases may be caused by, for example, the complexity of geology or the lack of information. Even though many steps in value preservation can be standardized, digitalized, supported, optimized, and finally accelerated by artificial intelligence, data collection, processing, and analysis are needed to integrate tunnel maintenance workflows with BIM, which will become more popular in underground construction.

The innovation of new technologies saves time and money by reducing time spent on-site and requiring less staff. The pre-inspections will be easier and more precise because of the increased level of detail in the data capture. On-site inspections will be faster and more accurate as a result. The inspection data itself can generate much of the documentation for the inspection. The tunnel owner will be able to view the inspection results online and in real-time due to the cloud solution, which will make all data available.

VI. Significance to the US

The implementation of this technology will see a major boost to the United States infrastructural projects, which will contribute to the economy of the United States. In the United States, contractors and consultants increasingly trust this high-energy laser beam technological breakthrough because it gives a practical option that might fulfill their infrastructure demands as the number of successful projects rises. Large bore tunnel construction presents many logistical and design issues to the designer. In developing the portal area, considerations like access to the site, material supply, power needs, muck processing, and transportation requirements are considered. Aside from these additional difficulties, the tunnel face pressure varies greatly. The cutting tool wears out, and the annular gap between the tunnel's dug diameter and its liner extrados is enormous. The final two challenges are properly addressed to reduce the possibility of settlement implications. When deploying big-bore TBMs, engineers in the United States face many issues, including addressing the buoyancy effect at the portal and managing settlement impact risk beneath existing infrastructures, which may be mitigated by adopting high-intensity laser beam tunneling technology. Although this could be an opportunity, optimizing the large bore's space utilization is another challenge. This challenge is because void spaces may necessitate additional ventilation and attention to matters of fire and life safety.

Tunnel construction in the United States will benefit greatly from this new technology.: Tunnel construction prices for big bores are higher than for twin bores because of the increased costs of TBMs, tunnel liners, and muck treatment and disposal. However, tunneling is not the only main cost issue for many projects. By reducing station and crossover construction and right-of-way acquisition, and surface disturbance mitigation costs in urban mass transit systems, for example, the additional costs from big-bore tunneling may be compensated. Although it's impossible to draw broad conclusions since every project is different, HNTB has found that a big bore may be as cost-competitive as a twin bore in some situations [16].

Construction, routine operation, and emergencies all need more ventilation due to the greater cross-section of big cross-section area tunnels. Fall protection, ladders and stairways, scaffolding, hoisting, and conveyors, among other things, must get more attention when massive interior structures are built within enormous bores [17,18]. Ground movement and settlement risk management become even more critical when using a large-bore because of the increased significance of face pressure control, shield gap grouting, muck volume balancing, and annular gap grouting.

VII. Its Future

Construction and civil engineering will be affected by how data boosts efficiency and minimizes project completion time. A growing need for subsurface infrastructure is driven by urbanization and population growth. The construction industry is experiencing a new wave of innovation due to new materials and energy, design approaches, and advancements in digital technology and big data. I'm utilizing artificial intelligence and high-powered laser beams for this technology as part of my new invention. It's quite effective, and the associated labor expenses are significantly lowered. It shifts the focus of tunnel drilling from labor-intensive approaches to methods that are both rapid and efficient. Hyperloop tunnels can be built using current construction and design methods. If tunnel building procedures can be mechanized, standardized, and automated to reduce costs, additional projects that were previously thought uneconomical may become feasible. Many metropolitan authorities are taking a deeper look at the financial, socio-economic, and environmental advantages that subterranean tunnels provide. Adopting a more direct path than is feasible with surface construction, cutting costs for the building projects, and decreasing future operating expenses.

VIII. CONCLUSION

This research analysis focused on developing technology for tunneling of subsoil. The innovation developed is a drilling machine that integrates artificial intelligence and high-energy laser beam technology. This technology's major contributions to the industry are efficiency and a time reduction in infrastructural operations. In principle, if such a strong laser existed, it would be possible to cut through hard materials like rocks to pave the way for the construction tunnels. This technology combines gases like CO_2 and laser beams to increase the energy in cutting through hard rocks. The laser beam efficiency will be increased with massive amounts of CO2. As a result, the laser melt remains will be cleansed, and high energy production will be extinguished easily. Existing tunneling technologies may benefit greatly from the concept's increased dependability and safety and other aspects of engineering. A large scale would need the use of an elevator, long loading and unloading periods, and a large number of designated locations across the city. This technology is significant and requires a lot of consideration, especially for large engineering operations like tunnel construction. Engineers need this equipment to create tunnel solutions that match the project's specifications while keeping expenses in check.

REFERENCES

[1] Bakhtiyari, Z. Wang, L. Wang and H. Zheng, "A review on applications of artificial intelligence in modeling and optimization of laser beam machining", *Optics & Laser Technology*, vol. 135, p. 106721, 2021.

[2] Belitzki, C. Stadter and M. Zaeh, "Distortion minimization of laser beam welded components by the use of finite element simulation and Artificial Intelligence", *CIRP Journal of Manufacturing Science and Technology*, vol. 27, pp. 11-20, 2019.

[3] M. Horn, G. Raidl and C. Blum, "Job sequencing with one common and multiple secondary resources: An A∗/Beam Search based anytime algorithm", *Artificial Intelligence*, vol. 277, p. 103173, 2019.

[4] C. Laughton, "The Characterization of Rock Masses Excavated by Tunnel Boring Machine (TBM): ABSTRACT", *AAPG Bulletin*, vol. 79, 1995.

[5] M. Zeinali and A. Khajepour, "Development of an adaptive fuzzy logic-based inverse dynamic model for laser cladding process", *Engineering Applications of Artificial Intelligence*, vol. 23, no. 8, pp. 1408-1419, 2010.

[6] T. Shan and Z. Qingwen, "Discussion on Hydrogeological Problems in Engineering Geological Survey", *Advance in Civil Engineering*, vol. 2, no. 3, pp. 80-84, 2020.

[7] S. Nagendran, M. Mohamad Ismail and Y. Wen, "Photogrammetry approach on geological plane extraction using CloudCompare FACET plugin and scanline survey", *Bulletin of the Geological Society of Malaysia*, vol. 68, pp. 151-158, 2019.

[8] X. Shen, M. Lu and W. Chen, "Tunnel-Boring Machine Positioning during Microtunneling Operations through Integrating Automated Data Collection with Real-Time Computing", Journal of Construction Engineering and Management, vol. 137, no. 1, pp. 72-85, 2011.

[9] M. Bowen and D. Knowles, "Excimer-Laser-Based, Thin Beam Directional 'Xtallization (TDX) and Thin Beam Based LTPS Technology for Processing Large Area Poly-Silicon", *The Review of Laser Engineering*, vol. 34, no. 10, pp. 689-692, 2006.

[10] S. Leng, J. Lin, Z. Hu and X. Shen, "A Hybrid Data Mining Method for Tunnel Engineering Based on Real-Time Monitoring Data From Tunnel Boring Machines", *IEEE Access*, vol. 8, pp. 90430-90449, 2020.

[11] H. Ma, J. Wang, K. Man, L. Chen, Q. Gong and X. Zhao, "Excavation of underground research laboratory ramp in granite using tunnel boring machine: Feasibility study", *Journal of Rock Mechanics and Geotechnical Engineering*, vol. 12, no. 6, pp. 1201-1213, 2020.

[12] H. Peng, "Tunnel Boring Machine Proportional Flow Control Valve Selection Method", *Journal of Mechanical Engineering*, vol. 50, no. 21, p. 92, 2014.

[13] B. Sheil, S. Suryasentana, M. Mooney and H. Zhu, "Machine learning to inform tunnelling operations: recent advances and future trends", *Proceedings of the Institution of Civil Engineers - Smart Infrastructure and Construction*, vol. 173, no. 4, pp. 74-95, 2020.

[14] K. Yu, J. Ren and Y. Zhao, "Principles, developments and applications of laser-induced breakdown spectroscopy in agriculture: A review", Artificial Intelligence in Agriculture, vol. 4, pp. 127-139, 2020.

[15] A. Schlaefer and S. Dieterich, "Feasibility of case-based beam generation for robotic radiosurgery", Artificial Intelligence in Medicine, vol. 52, no. 2, pp. 67-75, 2011.

[16] J. She, A. Mabi, Z. Liu, M. Sheng, X. Dong, F. Liu and S. Wang, "Analysis Using High-Precision Airborne LiDAR Data to Survey Potential Collapse Geological Hazards", *Advances in Civil Engineering*, vol. 2021, pp. 1-10, 2021.

[17] X. Shen, M. Lu, S. Fernando and S. AbouRizk, "Tunnel boring machine positioning automation in tunnel construction", *Gerontechnology*, vol. 11, no. 2, 2012.

[18] J. Wang, W. Zhu, L. Jiang, J. Jiang and T. Liu, "A multi-channel real-time detection method for tunnel boring machine cutter wear based on Chirped Fiber Bragg Gratings", *AIP Advances*, vol. 9, no. 1, p. 015312, 2019.