THE CONCEPTUAL DESIGN FOR ENHANCING CONSTRUCTION EFFICIENCY AND PRODUCTIVITY THROUGH THE USE OF AN AUTOMATIC FLOOR LEVELLINGMACHINE

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***Abstract*— In today's fast-paced society, efficiency and speed are highly valued, especially in the construction industry. To address the challenges of irregularities and slowness in the construction process, various tools and machines have been developed to improve productivity and streamline workflows. One such innovative machine is designed to automate the manual leveling task, which is known to be both tedious and complex. By automating this process, the construction industry can achieve higher precision and ease of use, improving efficiency. The proposed machine utilizes the Arduino method for its programming, offering several benefits. It allows for better control of mechanical parts, efficient time management, ease of programming, increased profitability, and space efficiency. These features enhance productivity and make the machine an attractive investment for the construction industry. The construction industry can save time and money by replacing traditional manual methods, which are time- consuming and require skilled labor, with automated floor leveling technology. The automation reduces labor costs, increases precision, and improves overall workflow efficiency, leading to higher-quality work and timely project completion. In summary, the development of machines designed for automated floor leveling represents a significant advancement in improving the efficiency and productivity of the constructionindustry. Using sensitive, high-tech devices and Arduinoprogramming provides several advantages over traditional manual methods. These advantages include increased precision,reduced labor costs, and improved workflow efficiency. As the construction industry continually embraces new technological advancements, this technology represents a valuable investment to enhance construction processes further.**

Keywords—Flow levelling, Robotics, Efficiency, Productivity, Arduino

I. INTRODUCTION

The construction industry faces numerous challenges, including the impact of COVID-19, an ageing workforce, and the ever-increasing pace of life [1]. The construction industry is undergoing rapid advancements and technological innovations to meet the demands of the modern world. Among the essential materials, cement and its related applications have gained significant prominence due to their versatility and ease of use. As a result, there is an increasing demand for efficient tools and methods to handle cement-related tasks. Traditional approaches have become time-consuming and physically demanding, leading to side effects and worker discomfort. Moreover, precise levelling in construction processes, such as road building, yard development, tile laying, slab construction, and landscaping, cannot be overstated. The application of concreteconstruction robots in the construction industry can be tracedback to the 1970s and 1980s, with a growing focus on enhancing productivity in the sector since the late 1980s [2].

To address these challenges and optimize construction efficiency and productivity, this research paper proposes the conceptual design of an automatic floor levelling machine. The primary objective is to develop a multifunctional device that simplifies and accelerates the levelling process while considering the specific requirements of different construction activities. By integrating advanced technologies [3] and customizable components, this machine aims to streamline construction processes, improve worker comfort, and enhance overall productivity.

The significance of this research lies in the potential for the automatic floor levelling machine to revolutionize construction practices. By offering a comprehensive solution for various cement-related activities within a single device, it has the potential to minimize manual labor, reduce construction time, and increase the quality of work. Additionally, the incorporation of ergonomic design principles aims to address the physical strain experienced by workers, ultimately improving their well-being and job satisfaction.

In the subsequent sections of this research paper, we will explore the detailed design, functionality, and potential benefits of the automatic floor levelling machine. Through prototyping, testing, and analysis, we seek to validate the feasibility and effectiveness of this innovative solution. By doing so, we hope to contribute to the advancement of the construction industry by enhancing efficiency, productivity, and the overall construction experience.

II. Literature Review

The literature review focuses on the evolution and application of various concrete levelling and compactiontechnologies. In the 1950s, the first autonomous concrete floor screeds were invented, allowing operators to adjust thelevelling mechanism for smooth pavement [4]. Caterpillar's M series [5] screeds became renowned for their versatility inoperation, adapting to different concrete consistencies.

Floor Master Corporation [6] developed crawler-based levelling equipment and devices with a spiral mechanism for dispersing excess concrete and a motor-driven compacting plate for vertical compaction. Laser receivers and photoelectric sensors accurately controlled the compacting height and self-running position, reducing labour intensity and making it suitable for levelling and compacting ground surfaces.

Guangdong Bojiatuo Construction Technology Co., Ltd. [7] introduced a ground-levelling robot with a two-degree-of-freedom adaptive system, laser identification, and real-time control. It maintained millimetre-level accuracy, autonomously planning concrete levelling paths using a self-developed GNSS navigation system. This robot found applications in smaller industrial, commercial, and residential projects.

Fortepiso Corporation [8] developed large-scale concrete levelling robots that travelled over paved areas, employing a unique paving system and patented molds for vibration, consolidation, and smooth surface creation. Laser technology ensured precise ground smoothness in large areas, reducing errors and improving construction efficiency and cost-effectiveness.

Additionally, Abhishek [9] presented a concrete compaction robot featuring two rolling barrels, that compact the ground concrete through forward and backward movements. While it required manual direction changes by workers, it proved suitable for ground compaction.

Overall, the literature highlights the advancement of concrete levelling and compaction technologies, their adaptability to different construction scenarios, and the potential benefits of enhanced construction efficiency and productivity. However, there is a need for further research to explore the integration of advanced technologies into the design of an automatic floor levelling machine and address any existing gaps in the literature.

III. Methodology

This section outlines the approach and steps to designing the automatic floor levelling machine's mechanical components and control system.

The Control of the machine is designed to perform all its functions electromechanically. Once the initial levelling is manually set to the required size, the machine operates autonomously without human intervention. Only one operator is needed to operate the machine.

The power relies on electrical components to power its movement wheels and the two front screws driven by

Motors. Therefore, a dedicated DC power supply is provided for the machine. This machine is specifically designed for levelling small land areas, ranging from a minimum of 5m x 5m to a maximum of 10m x 10m. It achieves maximum efficiency of up to 100m² per hour and utilizes a 12V batteryas its power source.

The machine requires no specialized knowledge or training. The operator needs to level the ground to the desired size and initiate the machine at that location. The machine performs its tasks based on predefined commands and programming, making it user-friendly and easy to operate.

Considering the compact size of the machine and its minimal use of materials (battery, razor, motor, Arduino board, level board, sensor, screws, etc.), the cost isdetermined primarily by design. The aim is to bring the machine to the market at an affordable price while ensuring its effectiveness [10]. The selection of components has focused on simplicity, ensuring that the machine can bemanufactured and delivered to the market reasonably. Quality, durability, utility, and safety have been key considerations in selecting materials. Great attention has been given to utilizing the best techniques and suitable materials for connecting all the machine's parts, including moving and rotating components, to maintain accuracy and meet customer expectations.

Accordingly, the machine's components can be primarily categorized into mechanical and electrical/electronic parts, ensuring the seamless integration of both aspects in the design.

A. Machanical Design

The mechanical design involves the design and specification of various parts, including the screw shaft, screw connecting arm, screw adjusting arm, wheel bearings, front and second level boards, spring pairs, machine body, lid, roller, roller adjusting arm, belt, gear wheels, and gear chains.

a) Total Machine Force

m = 60 kg
g = 9.8

$$F = mg \tag{1}$$

$$F = 60 \text{ x } 9.8$$

$$F = 58\text{N}$$

b) Wheel Motor Calculation

Machine Force	=	588N
Friction for Roller	=	0.5N
Friction for Screw	=	0.5N
Friction for		
1 Level Board	=	0.5N
2 Level Board	=	0.5N

Note: - Friction Values Assuming

c) Wheel Belt Pull

Total Force = Machine + Friction Coefficient (2)

$T_F = 588 + (0.5 \times 4)$

$T_F = 590N$

Wheel Belt Pull = 590N

d) Required Power

Required Power = Belt Speed x Wheel Belt Pull (3)

Note: - Assume wheel Belt Moving Speed 0.02 ms^{-1}

$0.02\ ms^{-1} \times 590N = 11.8\ Nms^{-1}$

Required power = 11.8 W

e) Helix Screw Shaft Diameter

Pitch (P) - 100mm
Blade Diameter (D) - 80mm
Shaft Diameter (d) - 40mm

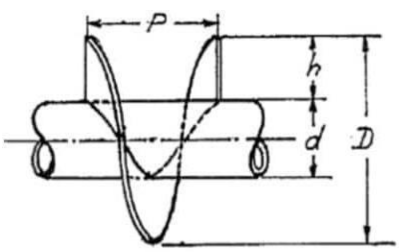

Figure 1. Dimensions of screw shaft

$$l^2 = (d \times \pi)^2 + p^2 \quad (4)$$

$$l^2 = (40 \times \pi)^2 + 100^2$$
$$l^2 = 25775.36mm$$
$$l = \sqrt{25775.36} = 160.54mm$$

$$L = (D \times \pi)^2 + p^2 \quad (5)$$
$$L^2 = (80 \times \pi)^2 + 100^2$$
$$L^2 = 73101.44mm$$
$$L = \sqrt{73101.44} = 270.37mm$$

$$Formula\ 1 = \frac{270.37}{160.54} = 1.68$$
$$Formula\ 2 = 1.68 - 1 = 0.68$$
$$D - d = 80 - 40 = 40$$
$$d' = \frac{40}{1.68} = 23.80mm$$
$$D' = 40mm$$

Development Helix Screw Shaft
ID = Ø 23.80 mm
OD = Ø 40.00 mm

B. Electrical Design

Figure 2 shows the flow diagram of the levelling machine's operation. The machine functions based on the travel diagram. Firstly, the machine is started using the power switch, and the initial position is set in the concrete flow. Next, the distance between the starting and ending positions is measured and inputted into the encoder. If the encoder value equals the given value, the machine stops and moves to the next position. If the encoder value does not equal the given value, the machine continues levelling until itreaches the specified value.

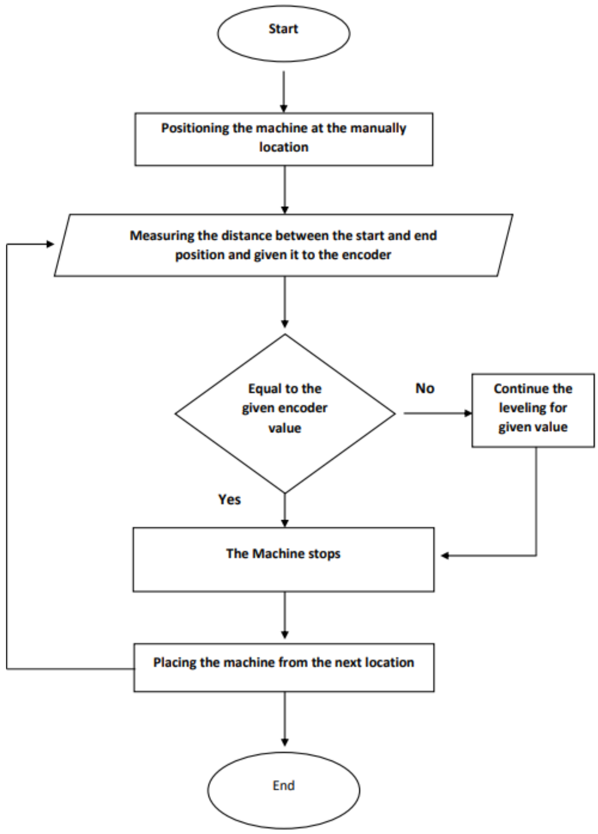

Figure 3. Flow diagram of levelling machine

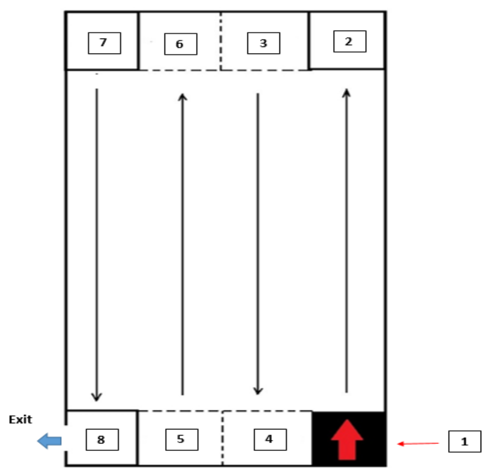

Figure 2. Machine travel diagram

Figure 3 show the travel diagram concept of the flow levelling process.

The system is powered by a Lipo (Lithium Polymer) battery, the primary energy source. The Lipo battery provides the electrical energy required to operate the levelling machine. This type of battery is known for its high energy density, lightweight design, and ability to deliver consistent power output.

Scientifically, the Lipo battery functions through a reversible electrochemical reaction between the anode and cathode materials within the battery [11]. During the discharge process, lithium ions flow from the anode to the cathode, generating a flow of electrons that can be harnessed to power the machine's electrical components. The Lipo battery's voltage and capacity ensure a sufficient power supply to drive the machine's motors and other electrical devices.

Moreover, using a Lipo battery offers advantages in terms of energy efficiency, long cycle life, and high power- to-weight ratio. These characteristics make it suitable for portable and compact systems, such as the levelling machine, the battery calculation as following.

a) Battery Discharge Time

$$Battery_{(h)} = Capacity_{(Ah)} / I_{(Ah)} \quad (6)$$

Note: - Assume machine total current is 2A

Capacity of Batter = 1200mAh

$$1Ah = 1000mAh$$

$$\therefore\ C = \frac{12000}{1000} Ah = 12Ah$$

So here,

$$Battery\ (h) = \frac{12Ah}{2A} = 6h$$

Machine Work continuously 6 Hour.

b) Battery Charging Time

Note: - Using Charge for 1.5A Source

$$Battery\ (h) = \frac{12Ah}{1.5A} = 8h$$

Battery Charging time is 8 Hour

c) Encoder Calculations

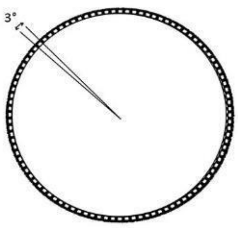

Figure 4. Wheel hole angle from

Pulse Per Revolution (PPR)

Degree of Wheel - 360^0
Wheel Hole Angle From center -3^0

$$PPR = 360^0 \text{ x Wheel hole angle from centre} \quad (7)$$

$PPR = 360^0$ x 3PPR = 120
Revolution = 120 PPR

The machine algorithm operates on an Arduino microcontroller, the central processing unit. The microcontroller receives input data from encoders and sensors, which provide information about the machine's position and environmental conditions. These values are processed using the algorithm programmed into the microcontroller.

The output data from the algorithm is then sent to the speed controller, a component responsible for regulating the speed of the DC motor. The speed controller adjusts the motor's rotational speed based on the program instructions provided by the algorithm. This allows for precise control and coordination of the machine's movements during the levelling process.

In addition to the DC motor, a vibrator motor is utilized for the levelling sequence. This motor applies vibration to the concrete surface, aiding the levelling and compaction processes. A battery supplies the DC motors' power, and the relay module facilitates the electrical connection.

The machine operates systematically and automatically by utilizing an Arduino microcontroller and integrating various components such as encoders, sensors, speed controllers, and motors. The algorithmic control ensures accurate levelling and compaction of the concrete surface, enhancing the efficiency and effectiveness of the construction process. Figure 5 shows the sensor architecture of the levelling machine.

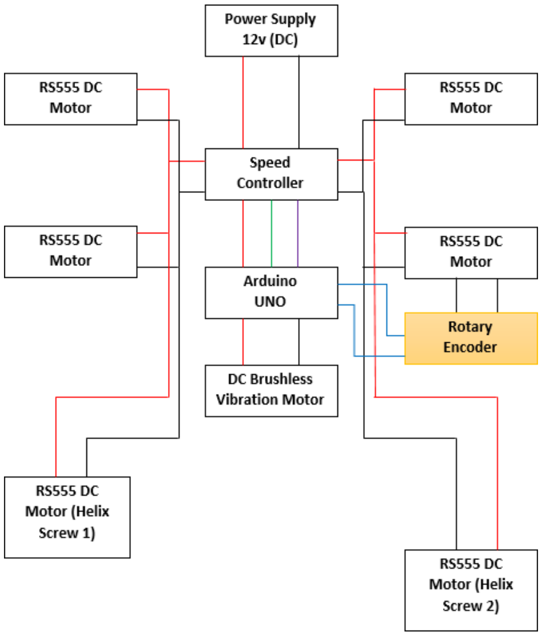

Figure 5. Sensor architecture

C. Mechanical assembly of levelling machine

The chassis design is a critical component of the overall system architecture, providing a sturdy foundation for key elements such as the sensor, controller, batteries, and locomotion parts. The design process involved meticulous development using Solidworks CAD software, ensuringprecise specifications.

The chassis is rectangular, with 1141 mm in length and 555 mm in width, tailored to meet specific operational requirements. These calculated dimensions enable efficient accommodation of various machine components compactly. Integrating the sensor, controller, and batteries onto the chassis allows optimal placement and organization. The sensor is strategically positioned to capture and transmit environmental data effectively. The controller, functioning as the central processing unit, is securely mounted to ensure stability and reliable operation. The batteries are efficiently housed on the chassis, facilitating convenient accessibility and maintenance.

Solidworks CAD software offers several advantages, including accurate modelling, precise measurements, and visualizing the final product before manufacturing [12]. This advanced design approach ensures that the chassis meets the necessary specifications, maintains structural integrity, and optimizes overall functionality.

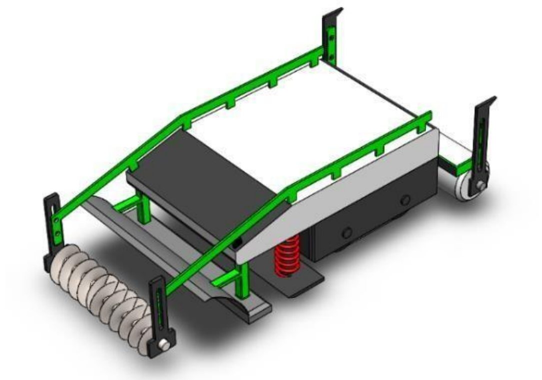

Figure 6. Overview design of Automatic flow levelling machine

Figure 7 shows the screw design and the front view of the levelling machine.

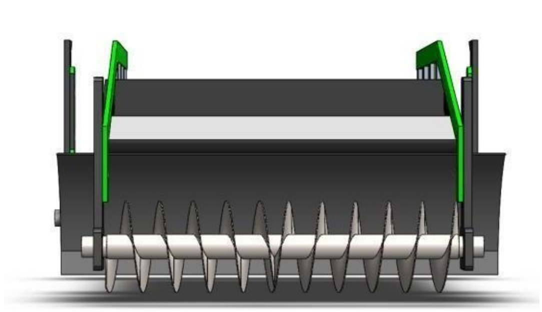

Figure 7. Front view and screw design

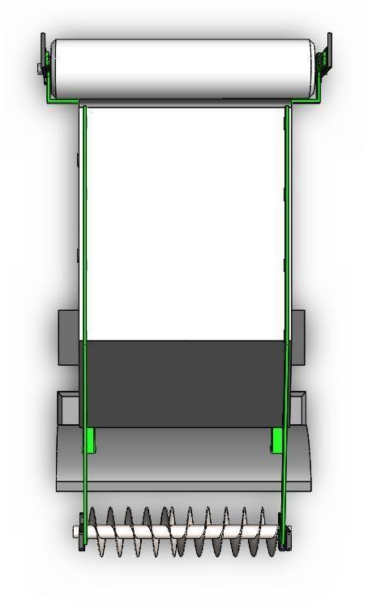

Figure 8. Plan view

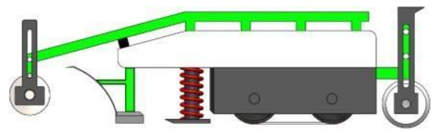

Figure 9. Side view

IV. RESULTS AND ANALASYS

To evaluate the performance and efficiency of the machine, a comparative study was conducted between human effort and machine effort in completing a designated area of 100 square meters. The objective was to assess the time required and the level of effort involved in manual levelling compared to the machine's automated capabilities.

A team of experienced workers, following standard manual levelling procedures, was assigned to level the designated area. The time taken and the collective effort expended by the workers were recorded and analysed. The results showed that, on average, it took approximately 200min (3 hours) of human effort to complete the task.

In contrast, the machine, operated following its designed algorithms and control system, was tested in the same area. The machine autonomously executed the levelling process, with its sensors and actuators efficiently adjusting the concrete flow and ensuring accurate levelling. Remarkably, the machine completed the 100 square meters in just 24 min (0.5 hours), showcasing its rapid and efficient performance.

The stark contrast in time and effort required between human and machine efforts highlights the significant advantage offered by the automated levelling machine. Based on the design specifications, the machine can achieve this efficiency level by leveraging its autonomous operation advanced sensor capabilities, and optimized mechanical components. The algorithm, programmed into the Arduino microcontroller, enables efficient coordination and control of various subsystems, ensuring seamless and rapid operation.

The machine's capability to accomplish the task in a fraction of the time required by manual labor improves productivity and reduces the physical strain on workers.

In this way, the machine completed a 900 cm2 (1 Square Feet).

Speed of Machine = 0.02ms-1 (minimum)

Time is taken to travel a distance of 30cm,

$$v = \frac{d}{t} \tag{8}$$

$$t = \frac{d}{v} = \frac{30cm}{2cms^{-1}}$$

$$t = 15\ Second$$

(Note: - Don't think about the width of the machine here)

Figure 10. Comparison result of manual operation and the machine operation

The figure 10 shows the comparison result of manual operation and machine operation 1 square feet and 100 square feet, respectively. These results demonstrate the potential of the machine to revolutionize levelling processes and enhance construction efficiency. The machine offers a promising solution for optimizing construction operations andincreasing overall productivity by minimizing human effort and reducing the time required.

V. Conclusion

In this study, we have successfully designed an automatic concrete levelling machine with advanced technologies and mechanisms to enhance efficiency and productivity in the construction industry. The key findings from our research demonstrate the significant advantages of utilizing this machine over traditional manual levelling methods.

Firstly, the comparative analysis between human effort and the machine's performance revealed a remarkable reduction in time and labor. While human workers took an average of 3 hours to complete a 100 square meter area, the automatic levelling machine accomplished the same task in just 0.5 hours. This substantial improvement in efficiency highlights the machine's ability to expedite construction processes and increase overall productivity.

Secondly, the machine's precision and accuracy in levelling concrete surfaces were consistently demonstrated. The machine achieved millimeter-level accuracy by integrating sensors, controllers, and algorithms, ensuring the creation of high-quality, even surfaces. Eliminating human errors and inconsistencies further enhances the reliability and efficiency of the levelling process.

Additionally, the utilization of the automatic levelling machine significantly minimizes labor intensity. Automating the levelling process relieves workers from physically demanding tasks, promoting their safety and well-being. Moreover, this allows human resources to be allocated more effectively to other construction activities, optimizing overall project timelines and resource utilization.

However, several limitations and challenges must be considered for successful implementation in real-world scenarios. These include the initial investment and cost associated with acquiring and maintaining the machine and potential adaptability issues when dealing with irregular or complex surfaces. Technical complexity, maintenance requirements, and proper integration with existing workflows also pose challenges. Safety considerations and regulatory compliance must be addressed to ensure worker protection and adherence to industry standards. Despite these challenges, further research and development efforts can optimize the machine's performance and address these limitations.

Furthermore, the cost-effectiveness of the machine is another significant advantage. Construction costs can be optimized by reducing the time required for levelling and minimizing manual labor. The efficient operation of the machine contributes to shorter project timelines, resulting in potential cost savings.

Overall, our research demonstrates the immense potential of the automatic concrete levelling machine in revolutionizing construction practices. The combination of enhanced efficiency, precision, labor reduction, and cost-effectiveness position this technology as a transformative solution for the industry. These findings underscore the need for further research and development to explore additional features and address existing literature gaps.

References

[1] X. W. V. R. K. C. C. M. Ci-Jyun Liang, "Human–Robot Collaboration in Construction: Classification and Research Trends," *Journal of Construction Engineering and Management* , pp. 147, 03121006., 2021.

[2] A. C.-R. R. Z. M. Gharbiaa, "Robotic Technologies in Concrete Building Construction: A Systematic Review," in *The International Association for Automation and Robotics in Construction*, Banff, Canada, 2019.

[3] M. A. Carlos Balaguer, "Trends in Robotics and Automation in Construction," in *Robotics and Automation in Construction*, Norderstedt, Germany, InTech, 2008, pp. 1-22.

[4] R. Navon, "Conceptual design of a flooring robot: development methodology and results," *Automation in Construction ISSN 0926-5805*, vol. 4, no. 3, pp. 225-238, 1995.

[5] E. C. Orlemann, " Motorbooks International," in *Caterpillar*

Chronicle: History of the Greatest Earthmovers , Saint Paul, MN, USA, ISBN 0760336733, 2000, p. 168.

[6] Admin, "Floormaster," CLAPA FLOOR MASTER, [Online]. Available: https://www.floormaster.eu/index.php/en/. [Accessed 05 05 2023].

[7] B. D. Robotics, "IF design," Basement Concrete Troweling and Leveling Robot, 2021. [Online]. Available: https://ifdesign.com/en/winner-ranking/project/basement-concrete-troweling-and-leveling-robot/314447. [Accessed 05 05 2023].

[8] "Fortepiso," Laser-screed, [Online]. Available: https://fortepiso.com.br/laser-screed. [Accessed 05 2023].

[9] P. Mehta, "Advancements in concrete technology.," *Concrete International*, vol. 21, no. 6, pp. 69-79, 1999.

[10] E. M. A. d. M. F. G. J. P. Marti, "A Review of Sensor Technologiesfor Perception in Automated Driving," IEEE INTELLIGENT TRANSPORTATION SYSTEMS MAGAZINE, 2019.

[11] S. Luong, "Hydrothermal Growth of Co3O4 Nanoparticles Hydrothermal Growth of Co3O4 Nanoparticles," Clean Energy Institute, University of Washington, Washington, 2020

[12] A. D. W. Bonsa Regassa Hunde, "Future prospects of computer-aided design (CAD) – A review from the perspective of artificial intelligence (AI), extended reality, and 3D printing," *Results in Engineering ISSN 2590-1230,* vol. 14, 2022.