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Original Article

An Innovated Arduino-based Computer Numerical Control Plotter Machine: A Technology Model Diffusion

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Abstract - *The study evaluated the effectiveness of an innovative Arduino-based Computer Numeric Control Plotter Machine for higher-level students, faculty, and industry experts, focusing on its design, function, ergonomics, safety, and cost and its acceptability, which centered on quality, reliability, durability, functionality, conformance, and aesthetics. This research adopted a quasi-experimental approach, specifically using survey research. To evaluate the innovation, questionnaires were distributed to 80 advanced students, 10 faculty members, and 10 industry professionals. The collected data were analyzed using total weighted points and the weighted mean. From the results, supported by thorough analysis and interpretation, it is concluded that the technology diffusion of the Arduino-based Computer Numerical Control Plotter Machine meets established standards and serves as an effective tool for both campus maintenance operations and technology education. It was found that the technology diffusion of an innovative Arduino-based Computer Numerical Control Plotter Machine was "highly acceptable" in terms of its quality, reliability, durability, functionality, conformance, and aesthetics. It is recommended that the technology diffusion of an innovative Arduino-based Computer Numeric Control Plotter Machine be diffused and practiced for higher-level students, faculty, and industry experts' laboratories.*

Keywords - *Inkscape, Computer Numerical Control, Arduino UNO R3, 2D and 3D plot, Grbl controller.*

1. Introduction

Technology has profoundly reshaped modern society, streamlining everyday activities and driving economic progress. Tasks once labor-intensive and time-consuming have been significantly simplified through automation and digital innovations. One of the most impactful outcomes of this transformation is the emergence of new industries and job opportunities, particularly in the technology and engineering sectors. Despite these technological strides, ongoing environmental problems-particularly the production and mismanagement of electronic and plastic waste-remain significant obstacles. A critical and often overlooked contributor to this problem is the improper disposal of ink and toner cartridges.

According to recent estimates, over 375 million cartridges are discarded globally each year, with more than 6.9 billion tons of plastic waste classified as non-recyclable (Kalali et al., 2023; Qasim et al., 2019). Alarmingly, a single cartridge can take up to 1,000 years to decompose in a landfill. Furthermore, the toner's carbon black content is recognized by the International Agency for Research on Cancer as a possible human carcinogen, amplifying the health risks of improper disposal (World Health Organization, 2018). In addition, electronic waste is now among the most rapidly increasing types of waste worldwide. Research indicates that hazardous elements such as lead, mercury, and cadmium-often found in electronic parts-can seep into the ground and water sources, posing serious risks to both the environment and human well-being (Kumar et al., 2017; Quinto et al., 2025; Saha et al., 2021). Incineration, another common method of disposal, emits toxic fumes that contribute to air pollution and respiratory illnesses. Research further indicates that improper e-waste management disrupts biodiversity and exacerbates climate-related issues due to the release of greenhouse gases and pollutants (Forti et al., 2020). This issue is seen in the mounting plastic waste problem and brings harmful chemicals into the environment (Louise, 2024; Liu et al., 2025). While various waste management strategies, such as recycling programs and Extended Producer Responsibility (EPR) frameworks, have been implemented globally, these have not sufficiently addressed the growing volume of printer-related plastic and electronic waste (Liu et al., 2023). A noticeable research gap exists in the repurposing and re-engineering of used ink cartridges into new functional devices, particularly using low-cost, scalable technologies suitable for both educational and environmental applications. Most existing studies and waste management initiatives have emphasized the importance of recycling materials, particularly the proper disposal of cartridges (Ding et al., 2020; Wüthrich, 2022), but have overlooked the potential for reusing them in new, purposeful, and technological applications (Sarkhoshkalat et al., 2024). Furthermore, some research concentrated on e-waste upcycling but centered largely on electronic components, leaving out smaller but common items like ink cartridges that still possess a lot of potential (Shahib et al., 2025; Wüthrich, 2022). With these issues and research gaps, the study proposes a novel solution through the design and development of a low-cost Computer Numerical Control (CNC) plotter machine, which will serve a dual purpose: (1) demonstrate the educational potential of automation and microcontroller systems, and (2) promote sustainable practices by reusing ink cartridges as part of the machine's ink delivery system. While CNC machines have been widely studied and used for manufacturing, cutting, and 3D printing applications (Brown, 2017), limited research has focused on their adaptation for environmentally conscious reuse of e-waste materials like printer cartridges. The proposed CNC plotter machine will be powered by a microcontroller-based system-specifically the Arduino Uno R3-integrated with NEMA 17 stepper motors, GT2 timing belts, and other cost-efficient hardware. Prior studies have explored similar technologies for affordable automation (Mohsen Soori et al., 2024), but none have investigated their potential in integrating recycled components into the actual design and function of the machine. This research, therefore, introduced a sustainable and innovative approach to e-waste mitigation by transforming discarded ink cartridges into active components within a functional CNC plotter. The machine could draw text and images on various surfaces, making it suitable for educational demonstrations, design prototyping, and eco-friendly production. By connecting automation, sustainable practices, and waste management, this study explores the often-overlooked possibilities of repurposing e-waste, while also advancing the wider objective of encouraging green engineering and supporting the principles of a circular economy. The outcomes would provide insights into low-cost manufacturing solutions that align with both environmental preservation and technological advancement.

2. Objective of the Study

This study evaluated the performance and acceptability of an Innovated Arduino-based Computer Numerical Controller (CNC) Plotter Machine serving as a basis for Technology Model Diffusion. It investigated the machine's technical requirements, including design, function, ergonomics, safety, and cost, alongside assessing its quality, reliability, durability, functionality, conformance, and aesthetics.

3. Methods

3.1. Design

This study adopted a quasi-experimental research design, which aims to identify issues through the analysis and interpretation of numerical data relevant to the investigation (Campbell & Stanley, 2015). Furthermore, the study utilized a quantitative experimental design to ensure the project's outcome since the researchers manipulated the variables to test the machine's workability and efficiency. The independent variable was the Arduino-based Computer Numerical Control Plotter Machine, which the researchers made. On the other hand, the study's dependent variable was the machine's workability and efficiency. Quasi-experimental methods and survey research were employed in this study.

3.2. Respondents

The study utilized a random selection technique to identify respondent groups, ensuring a diverse and representative sample for evaluation. A total of 50 participants were included, comprising students from the College of Technology, industry experts, and faculty members, each playing a crucial role in validating the study through questionnaire-based assessments. Table 1 presents the demographic profile of the respondents, highlighting key differences in sex, age, group affiliation, and training experience. The majority were male (92%), with females making up only 8%, while college students constituted the largest group (60%), followed by industry experts (20%) and faculty members (20%). In terms of age, the highest proportion of respondents (42%) were between 16 and 18 years old, while 22% were aged 28-30 years. And regarding training, 30% had attended 9-16 hours, while another 30% had completed 17 or more hours of relevant training.

Table 1. Demographic profile of the respondents

Variables	f	%
Sex		
Male	46	92.00
Female	4	8.00
Age		
16-18 yrs old	21	42.00
19-21 yrs old	9	18.00
22-24 yrs old	2	4.00
25-27 yrs old	7	14.00
28-30 yrs old	11	22.00
Groups		
College Students	30	60.00
Industry Experts	10	20.00
Faculty	10	20.00
Number of Hours of Relevant Training Attended		
1 hour	14	28.00
2-4 hours	2	4.00
5-8 hours	4	8.00
9-16 hours	15	30.00
17 hours or more	15	30.00

3.3. Instrument

The research instruments for evaluating the Arduino-based CNC Plotter Machine involved statistical tools to ensure smooth data collection, with computing devices like laptops aiding in efficient encoding and cataloging. This approach helped identify discrepancies and errors, ensuring accuracy throughout data-gathering. The study measured the machine's quality, reliability, durability, functionality, conformance, and aesthetics through a scoring system, with parametric scales ranging from "Highly" to "Not" for each dimension. The project involved two phases: creating the plotter (finding parts, assembling, programming, testing, and troubleshooting) and evaluating its print quality, workability, and efficiency. A categorical assessment scale determined the level of acceptability, from "Very Highly Acceptable" to "Not Acceptable," based on the machine's performance. The ultimate goal is to implement the product in offices and schools, offering an affordable printing solution while minimizing environmental harm from ink cartridge waste.

3.4. Data-Gathering Procedure

To ensure the precision and trustworthiness of the findings, the researcher followed a structured process for collecting data. First, an official request letter was prepared and obtained from the Campus Director of a public university, authorizing the conduct of the study. Once consent was granted, the researcher took the initiative to personally hand out the questionnaires to the selected participants. Before administering the survey, the researcher provided a clear explanation of the study's purpose and the functionality of the Innovated Arduino-based Computer Numerical Controller Plotter Machine to ensure the respondents' informed participation. Once the questionnaires were completed, they were immediately collected to maintain the integrity of the data. This structured approach ensured a smooth and efficient data collection process, allowing for accurate and timely analysis.

3.5. Data Analysis

The responses collected through the survey questionnaires were counted, organized, and displayed in tabular form for further analysis. To gauge the respondents' views on the Innovated Arduino CNC Plotter Machine, the weighted mean was calculated, offering an understanding of its functionality and effectiveness. Furthermore, a t-test was conducted to evaluate whether the differences in the average validation outcomes were statistically significant, supporting the credibility and precision of the assessment.

4. Results and Discussion

4.1. Prior Arts of Arduino-based CNC Plotter Machine

CNC stands for Computer Numerical Control, a computer-controlled machine that receives instructions through a serial port from a computer and moves its actuators based on the received commands. Most of these machines are stepper motor-based, utilizing stepper motors to control movement along their axes. Speaking of axes, every CNC machine has a specific number of axes that are controlled by the computer program, determining its range of motion and functionality.

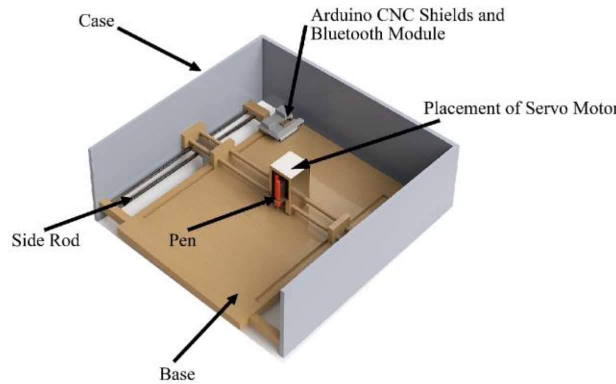


Fig. 1 Arduino CNC plotter machine controlled structure

A stepper motor-sometimes referred to as a step or stepping motor-is a type of brushless DC motor designed to break a complete rotation into uniform, discrete steps. It moves and holds its position without a feedback sensor, as long as it is properly sized for torque and speed. For the project, the Arduino Nano Dev board serves as the core, controlling actuator movement based on computer instructions. To regulate the speed and direction of the stepper motors, an L293D H-bridge motor driver was used (see Figure 2), which receives commands from the Arduino and controls the motors accordingly.

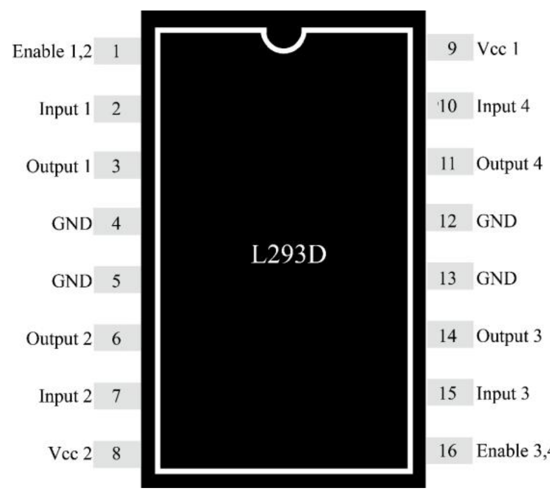


Fig. 2 L293D H bridge motor driver

To connect all the necessary components to the Arduino board, a circuit diagram was created. The initial image shows the proper wiring configuration that must be applied to both the stepper motors and the servo motor.

4.2. Innovated Arduino-based CNC Plotter Machine Technical Requirements

4.2.1. Design

The design of this research project, shown in Figure 3, consists of several components, including a wooden base, SS rods, a writing pen/laser, stepper motors, and a Bluetooth module. This design was created using SolidWorks, a 3D modeling software. Various features and commands in SolidWorks, such as rectangle, extrude boss, extrude cut, and mirror, were utilized to develop the 3D model. The model is designed in such a way that it will move in 4 directions, i.e., X-axis, Z-axis, Y-axis, and (-Y)-axis. The detailed dimension of the model is given in Figure 8.

Table 2. CNC plotter machine dimensions

Part	Dimension
Base	420mm x 297mm
SS Rod	390mm (side rod)
Pen	9.89mm
Case	419mm X 169.55mm

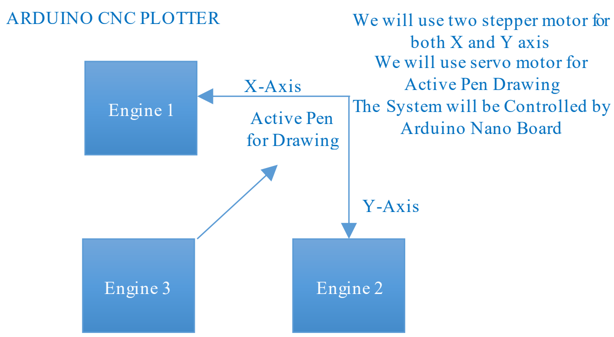


Fig. 3 CNC plotter machine design

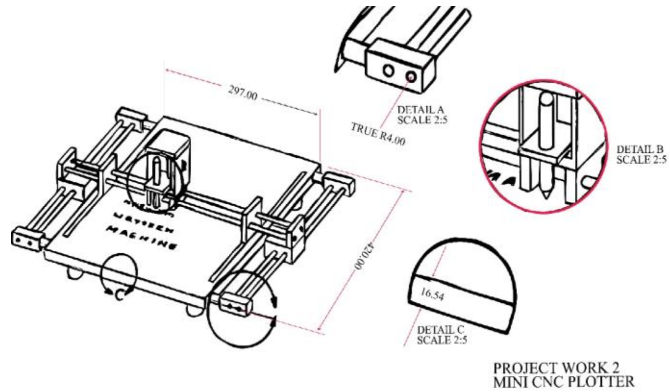


Fig. 4 CNC plotter machine dimension model

Table 3. Software used

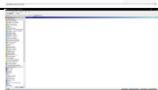
Software	Description
	**Solid Works** - This software is used for Computer-Aided Design (CAD) and Computer-Aided Engineering (CAE). It assisted in creating a 3D model of the project and analyzing the rods.
	**Ansys -** This software is primarily used for analyzing 3D models. Using it, the researchers were able to calculate the Equivalent Stress and Equivalent Strain for various components of the machine.
	**Arduino IDE**- The Arduino Integrated Development Environment (IDE) is a software platform for writing, compiling, and uploading C/C++ code to Arduino-compatible boards. It simplifies the process of developing and testing embedded systems projects.
	**Inkscape** - Inkscape's main vector graphics group is Scalable Vector Graphics; be that as it may, numerous different configurations can be imported and sent out. Inkscape can render crude vector shapes and content.

Fig. 5 Inkcape icon/inkscape platform

The researchers employed Inkscape to transform different images into G-code extension files. This application, a free and open-source vector graphics editor, allows the creation and editing of detailed vector designs such as diagrams, illustrations, charts, logos, artworks, and digital paintings. Inkscape mainly employs the Scalable Vector Graphics (SVG) file format but has the ability to import and export numerous other file types as well. Inkscape allows users to create basic vector forms like rectangles, ellipses, stars, spirals, arcs, polygons, and 3D boxes, as well as add text. These elements can be customized with solid fills, gradients, or patterns, and their outlines can be adjusted in terms of stroke style and transparency. Inkscape further aids in embedding and tracing raster images so that photos can be converted to vector graphics. Once a design is accomplished, the image can be translated into G-code and exported to processing software to generate the final output.

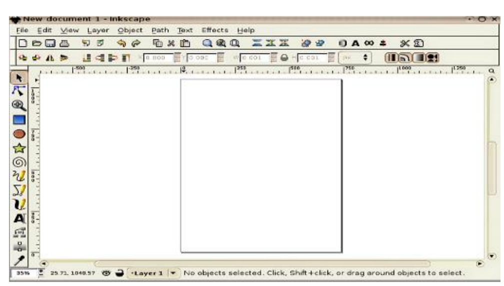


Fig. 6 Inkscape software

Grbl - Grbl is a high-performance, open-source software designed to manage machine motion and operate directly on an Arduino board.

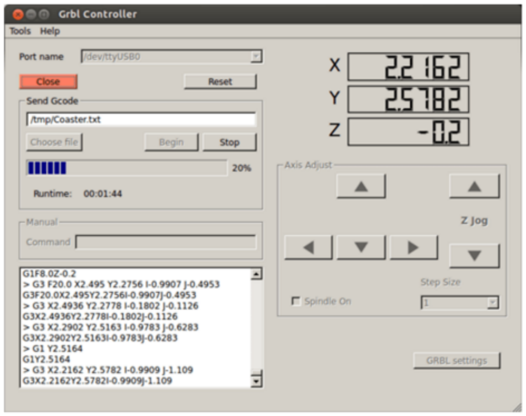


Fig. 7 Grbl controller

Creating G-Code File using Inkscape

The CNC plotter functions within a 20cm × 20cm workspace; therefore, Inkscape's document dimensions were adjusted to 40cm × 40cm-four times larger-because the plotter operates exclusively in the first quadrant. The axes are positioned at the motor's nearest end as the origin for easy modifications. To generate G-code for text, the text is selected, then converted using "Object to Path". Images are required to have a transparent background. Once inserted into the workspace, the image is traced as a bitmap with edge detection enabled and configured for eight scans to generate a black-and-white output. The "Object to Path" command then converts the traced image into G-code, following the same steps.

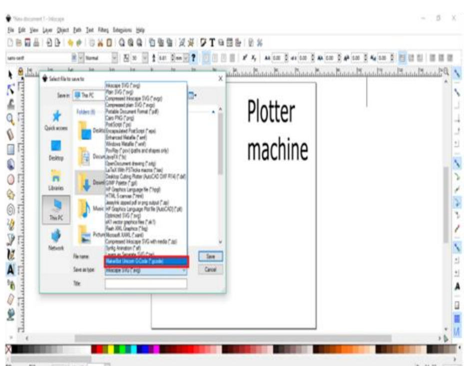


Fig. 8 Conversion of text to G-code

Programming and Calibration

Program Uploading Procedure: After all the procedures had been done, the main factor in making the project successful is to calibrate and upload the programming into the Arduino board through a USB cable. The following are the procedures for uploading the code to the board:

1. Extract the MI GRBL Zip File.
2. It will create the MI GRBL folder name.
3. Copy the folder and go to the Arduino area. Find the library and folder, and place it there.
4. Turn on the Arduino ID and go to the files.
5. Example: - MI GRBL download code -> connect Arduino code to PCTool "ARDUINO UNO" Select compt (where Arduino code connects), known bugs and upload code.
6. Now, download another Inkscape zip file extension (MI Extension).
7. After copying the folder, open Inkscape and navigate to the shared space extension area. Inside the "extensions" folder, locate the folder you just copied. Open this folder, select all its contents, and copy them. Then, go back one level and paste the copied files directly into the main "extensions" folder (outside the subfolder). Once this is done, you can proceed with any additional steps or modifications needed.
8. First, open the Inkscape folder to measure and create a simple G-Code.
9. Inkscape does not have a built-in format for storing files in G-code. So, it needs the installation of a plugin for the files to be converted and saved in G-code format.
10. After installation, change its size from pixels to mm. It also reduced the height and width to 90mm. This will enable the workspace where all the text and drawings will be written.
11. Now, draw the image you want and select "object to understand" and save the file to "MakerBot Unicon G-code."
12. Finally, the G code is ready and transmitted to the board, and the machine is ready to operate.

Coding

The following are some of the screenshots of the coding that was done for the movement of the CNC plotter machine:

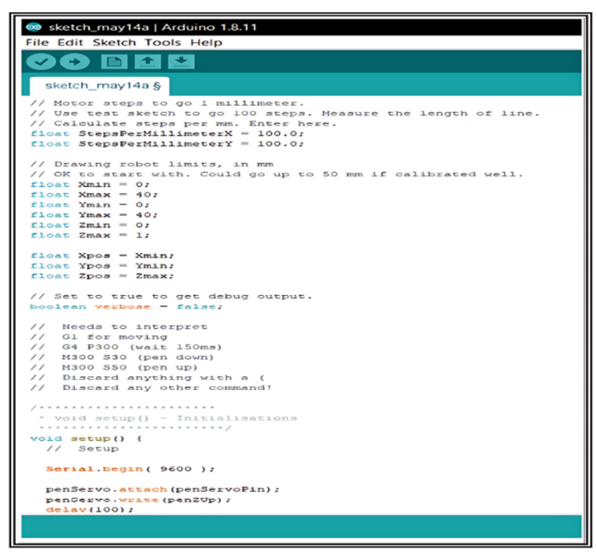


Fig. 9 Coding process of the coming line

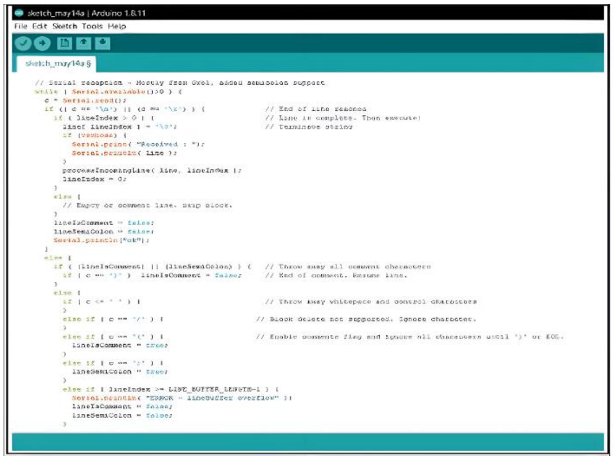


Fig. 10 Coding for positioning of axis and pen

Fig. 11 Coding for different positioning of the Axis

Analysis

Upper Rod. The static structural analysis of the upper rod (diameter=8mm) was done by applying a torque of 4.28281kgf.cm. It is valuable because the holding torque of the stepper motor was 4.28281kgf.cm.

Side Rod. The static structural analysis of the side rod (diameter=8mm) was done by applying a torque of 4.28281kgf.cm. It is also significant because the holding torque of the stepper motor was 4.28281kgf.cm.

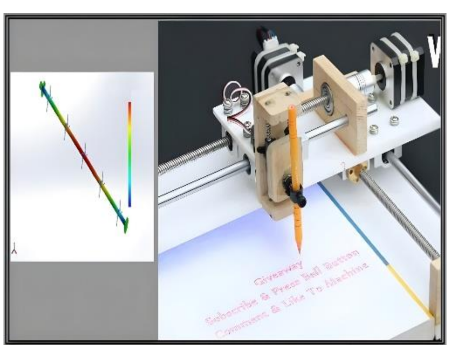


Fig. 12 Displacement of the upper rod

Pen: The static structural analysis of the pen was used in plotting the circuits by applying a pressure of 2.847e-006 MPa. The value was taken because the holding torque of the servo motor is 2.847e-006 MPa.

Table 4. Technical specification

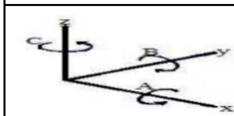
Compopnents	Description
	Stepper Motor- In this research, a brushless DC stepper motor was utilized, which divides a full rotation into a defined number of uniform steps. This component served as the heart of the CNC plotter. To achieve accurate control of the sketching mechanism (drawing pen), two stepper motors were employed-one for the x-axis and another for the y-axis-to regulate the CNC's size, speed type, precision, and router positioning.
	The CNC Axes- The right-hand coordinate system reflected the axes of the CNC plotter: the X, Y, and Z.
	Stepper Driver- This research study used two stepper motor drivers to control the motors. These drivers allow precise position control without feedback by managing continuous rotation. They offer adjustable current, multiple-step resolutions, and built-in translators for simple step and direction control.
	Servo Motor- The drawing pen's up-and-down motion along the Z-axis is controlled by the servo motor. It functions through electrical pulses of varying widths, known as Pulse Width Modulation (PWM), which are managed by the microcontroller. It adjusts the shaft's position via the control wire, representing movement along the Z-axis.
	Arduino- The Arduino Uno R3 microcontroller operates the stepper motors by way of programmed commands. It is an open-source platform made up of both software and hardware, so it is easy to use and adaptable. It has 14 digital and 6 analog I/O pins, making it expandable to many different expansion modules.

Table 5. Specification of Arduino Uno R3

Parameters	Specifications
Micro Controller	ATmega328P
Operating voltage	5V
Input volatge (recommended)	7-12V
Input volatge (limits)	8-20V
Digital I/O pins	14
DC current per I/O pins	40V
Flash Memory	32kb (of which 0.5 kb is used by the boot loader)
SRAM	2kb
EEPROM	1kb
Clock speed	16MHz

A microcontroller board features an integrated power supply, a USB port for connecting to a computer, and an ATmega microcontroller chip. It simplifies the creation of control systems by providing a pre-configured, programmable platform, removing the complexity of designing custom PCBs. Being open-source hardware, its schematics are freely available, allowing users to alter the design or develop customized versions.

Electronics System and Wiring

This section details the essential electronic components and wiring configuration required for building and designing the CNC plotter machine. Important parts consist of the Arduino UNO R3, a CNC V3 Shield combined with an A4988 driver and heatsink, stepper motors, a DC power supply, a pen holder, various connecting cables, and a USB-to-serial adapter. These elements are vital to the machine's electrical configuration and operational performance.

Connections

The wiring setup includes connecting the stepper motor driver to the CNC shield, which is then mounted onto the Arduino, as illustrated in Figure 8.

To keep the design straightforward, two drivers were utilized to operate the two stepper motors.

Software Tools

Arduino IDE: This open-source software enables users to write and upload code directly to the Arduino board (source: https://www.arduino.cc). Built on a simplified version of C/C++, it features extensive library support and code uploading capabilities.

After installing the software on a computer, users can write programs in C and must select the correct USB port from the Tools menu to connect to the Arduino. The code can then be checked for errors, and if none are present, a "Done Compiling" message will confirm successful verification. Finally, the verified program can be uploaded to the Arduino board. Figure 13 illustrates the Arduino Software IDE.

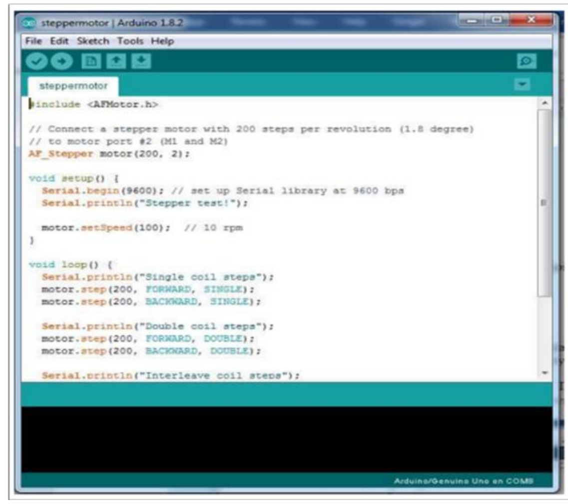


Fig. 13 Arduino software IDE

Processing

Processing is an open-source platform designed for creating electronic visual outputs. The GTCRL program within Processing enables the transmission of G-code files from the software interface to the CNC plotter. As shown in Figure 14, Processing Software displays the setup after launching the GTCRL application. To select the Arduino Uno port, users press the 'P' key, and when pressing 'G', they upload the chosen G-code file. Once the file is loaded, the CNC plotter immediately starts drawing. The operation can be halted at any point by pressing the 'X' key.

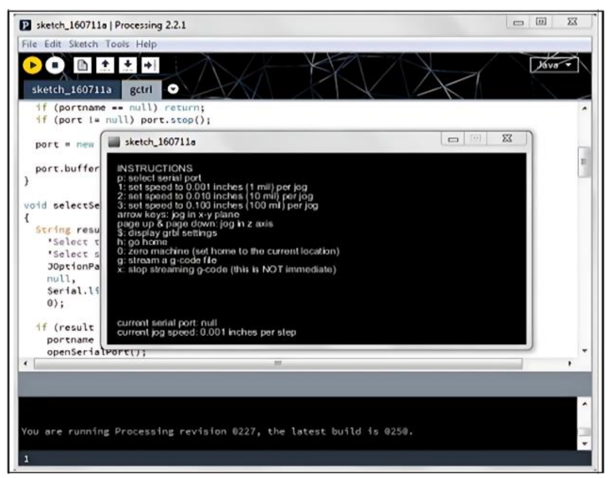


Fig. 14 Processing Software

4.2.2. Function

The CNC layout machine functions along three axes: X, Y, and Z. The X and Y axes work together to produce two-dimensional drawings on paper, aligned at a 90-degree angle to preserve precision. Any point in a space is defined by its X and Y coordinates with minimal error. The Z-axis is responsible for lifting and lowering the pen, laser, or axle, allowing precise control over the drawing process, particularly on transparent paper.

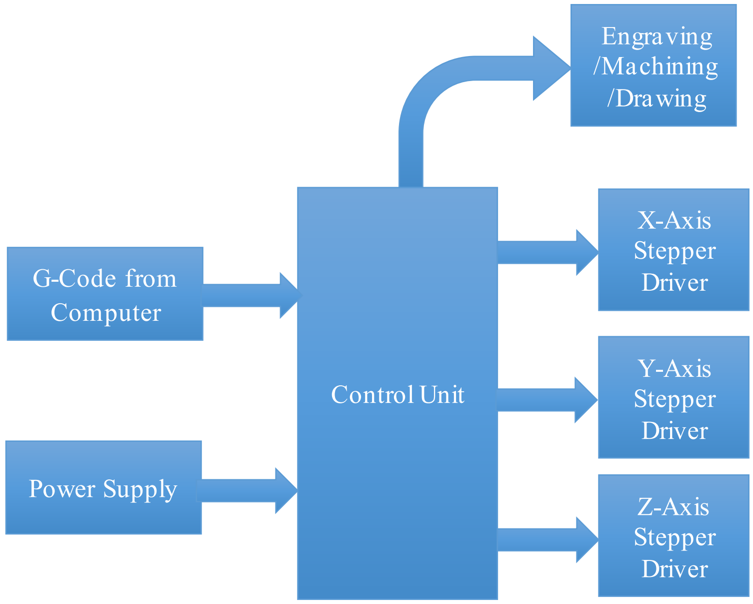


Fig. 15 Block diagram of the working of the CNC plotter machine

The software generates compatible links for the image to be drawn and sends them to the microcontroller via USB. The microcontroller processes these links and controls the machine's movement to create the image. The Arduino Uno ATmega328P is used and is common in Mini CNC Machines as the microcontroller.

Two SS rods and stepper motors are used for the X and Y axes, similar to a cartridge drive system. The Z-axis features a small servo motor, allowing precise pen movement. The machine is designed to draw on A3-sized paper (297mm × 420mm), which is mounted on the X-axis using an acrylic platform and glue.

To assemble, insert the L293D motor driver shield into the Arduino Uno, then connect the stepper motors, ensuring the ground connection remains unplugged. A 5V–7V power supply is connected to the motor driver's shield port.

Since the L293D motor shield was used, the AFMotor library must be added to the Arduino IDE. After restarting the IDE, go to File → Examples → Adafruit Motor Shield Library → Stepper, select the correct port and board, and upload the code. The stepper gearbox is adjusted from 2 to 1 for optimized movement.

4.2.3. Ergonomics

Ergonomics, also called Human Factors Engineering, focuses on optimizing the "fit" between individuals and their technological tools and environments by considering user capabilities and limitations (International Ergonomics Association, 2014). This discipline is crucial in workplace settings, particularly for physical ergonomics, which involves equipment like ergonomic chairs and keyboards, and in medical fields for individuals with conditions such as arthritis or carpal tunnel syndrome (Chauhan & Mathur, 2024).

Ergonomics plays a significant role in reducing costs by enhancing safety, thereby decreasing workers' compensation claims. For instance, ergonomic practices can prevent overextension injuries, which affect millions of workers annually, potentially saving industries billions (New South Wales Environment Protection Authority, 2017). Workplaces often employ reactive or proactive ergonomics approaches. Reactive ergonomics addresses issues after they arise, while proactive ergonomics identifies and mitigates potential problems before they become significant, as seen in practices that enhance workplace safety and health responses (Thompson III, 2011).

Ergonomic interventions aim to design feasible jobs, provide job satisfaction, and protect worker health (Alostaz et al., 2024). Despite its benefits, ergonomics often receives low attention in developing countries, affecting access to critical knowledge for improving work environments and productivity (Goyal et al., 2024).

4.2.4. Safety

Before testing, the developed device underwent proper calibration and was assessed in multiple modes using different inputs, including text and image files, to evaluate its precision. The complete time to sketch the gear was 2.4 minutes, which is relatively quicker than most commercial alternatives. However, some limitations were observed, including minor errors in the final image output. These errors were primarily due to the movement mechanism and motor vibrations.

Despite this, the device remains an open-source tool, making it freely accessible and compatible with a wide range of hardware and configurations. It is also user-friendly and easy to operate. One notable advantage is that the stepper motors do not miss any steps, ensuring a secure and precise operation. Additionally, the project is cost-effective, as it can be assembled using low-cost hardware.

However, due to its size and capacity, the machine is not suitable for high-load applications or tasks requiring significant cutting pressure. It is also unable to withstand larger cutting forces, limiting its application in heavy-duty machining.

4.2.5. Cost

The cost of materials for the Innovated Arduino-based CNC Plotter Machine is shown in Table 6. Computer Numerical Control (CNC) has revolutionized digital electronics and microcontrollers, inspiring the development of a compact CNC pen plotter using a custom-built PLC. This device is capable of sketching images on different surfaces, utilizing three stepper motors to manage movement along the X, Y, and Z axes. A key challenge is ensuring precise motor synchronization. Currently, data is hardcoded in binary format, with the pen marking for logic "1" and lifting for "0" before moving to the next position. Future improvements include processing G-Code from software like Inkscape to enhance automation. While the plotter currently functions as a 1D system, the long-term goal is a low-cost CNC machine for PCB design. Affordability is achieved by integrating a PC with an ATmega328 controller in an Arduino. A CNC plotter is a specialized printer that interprets machine code to execute precise movements. This 3D-controlled, 2D plotting system is ideal for PCB design and logo creation, with growing demand in universities and laboratories. The machine's simple yet robust design, low-cost components, and easy maintenance make it a practical and cost-effective solution.

Table 6. Cost for an innovated Arduino–based CNC plotter machine

Quantity	Item Description	UOM	Unit Cost	Total Cost (Php)
1	Stainless Steel Shafting 304 5/16" 20FT	length	517.00	517.00
1	Stainless Steel Shafting 304 3/8" 20FT	length	743.00	743.00
2	12v 1amp Barrel Adapter	pc	179.00	358.00
4	Foundations GI Flat Washer 3/16in 12 pcs	pack	59.50	238.00
2	Foundations GI Stove Bolt Round Head 3/16x1	pack	34.75	69.50
4	Foundations GI Stovebolt Round Head 1/8x1	pack	59.50	238.00
2	Foundations GI Stovebolt Round Head 5/32x1	pack	32.75	65.50
2	Foundations Gypsum Screw Wood 6x25 20 pcs	pack	34.75	69.50
2	KENDO (HD) Cable Tie 4.8x150mm 50pcs	pack	65.00	130.00
2	Male-Female Wires 40 pins 20cm	set	149.00	298.00
2	Arduino UNO R3 with USB Cable	pc	595.00	1,190.00
4	NEMA 17 Stepper Motor	pc	699.00	2,796.00
2	SG90 180 degrees servo	pc	189.00	378.00
4	A4988 Stepper Motor Driver	pc	199.00	796.00
1	Soldering Iron 220v 60w	pc	850.00	850.00
2	CNC Shield v3	pc	149.00	298.00
4	10mm LM8UU Linear Bearing	pc	60.00	240.00
4	10mm LM10UU Linear Bearing	pc	65.00	260.00
12	F623ZZ Bearing (3x10x4mm)	pc	45.00	540.00
2	L7806CV Voltage Regulator6v	pc	20.00	40.00
2	ESP8266 12E	pc	499.00	998.00
1	Plywood (1-inch diameter)	length	1,200.00	1,200.00
1	Glue Gun	pc	120.00	120.00
10	Glue Stick	pc	15.00	150.00
5	Solid Wire 22AWG	meter	10.00	50.00
1	Elmer's Glue	pc	80.00	80.00
2	Tumbling Blocks Tower (Jenga Blocks)	box	500.00	1,000.00
2	Bondpaper substance 20 8 1/2" x 13"	ream	220.00	440.00
2	Bondpaper substance 20 8 1/2" x 11"	ream	200.00	400.00
Total				**14,552.50**

4.3. The Acceptability of An Innovated Arduino-based CNC Plotter Machine

Table 7 presents the acceptability of an innovative Arduino-based CNC Plotter Machine. It shows that the innovative Arduino-based CNC Plotter Machine achieved a high level of acceptability across all evaluated constructs, with an overall mean score of 4.59 ± 0.59. Among the constructs, quality received the highest mean score (4.80 ± 0.76), suggesting that the respondents perceived the machine as well-designed and efficient. Aesthetics also scored highly (4.70 ± 0.34), indicating that the machine's physical design and user-friendly interface contributed positively to its acceptance. Meanwhile, reliability, durability, functionality, and conformance all scored 4.50 and above, emphasizing that the machine met performance expectations and operational standards. According to Zhang et al., product acceptability in technological innovations is primarily driven by quality, reliability, and functionality, reinforcing the significance of these constructs in the assessment (Zhang et al., 2024).

Table 7. Acceptability of an innovated Arduino-based CNC plotter machine

Constructs	Mean±SD	Verbal Interpretation
Quality	4.80±0.76	Highly Acceptable
Reliability	4.50±0.82	Highly Acceptable
Durability	4.50±0.65	Highly Acceptable
Functionality	4.50±0.43	Highly Acceptable
Conformance	4.52±0.56	Highly Acceptable
Aesthetics	4.70±0.34	Highly Acceptable
Average	**4.59±0.59**	**Highly Acceptable**

Legend: 1.00-1.80 (Not Acceptable); 1.81-2.60 (Less Acceptable); 2.61-3.40 (Moderately Acceptable); 3.41-4.20 (Acceptable); 4.21-5.00 (Highly Acceptable)

The high acceptability ratings across all criteria suggest that the CNC plotter machine successfully meets industry and academic standards, making it a viable tool for precision-based applications in education and manufacturing. The machine's reliability and durability ratings (4.50 each) imply its capacity for consistent performance over time. This aligns with Kalusivalingam et al.'s (2020) findings that robust hardware design enhances operational stability in automated systems. Additionally, the strong conformance rating (4.52) signifies that the machine adheres to required specifications, an essential factor in technology adoption (Wang et al., 2023).

Given these results, the machine's potential for wider implementation is promising, particularly in educational institutions and small-scale industries seeking cost-effective, high-precision solutions. Future studies may explore further enhancements in software integration and material sustainability to maximize the machine's efficiency and environmental impact.

4.3.1. Crafted Technology Model Based on the Findings

The core components of this Arduino-based CNC plotter machine include a power supply, an FTDI module, an Arduino Uno R3, and Easy Drivers connected to stepper motors controlling the X, Y, and Z axes. The power supply provides two essential voltage levels: +5V for the ATMEGA328 microcontroller and Easy Drivers, and +12V for the stepper motors. A 10kΩ resistor is used as a pull-up for the RESET pin, ensuring stable operation. The system also incorporates a 16 MHz crystal oscillator paired with two 22 pF capacitors to maintain precise timing for the ATMEGA328.

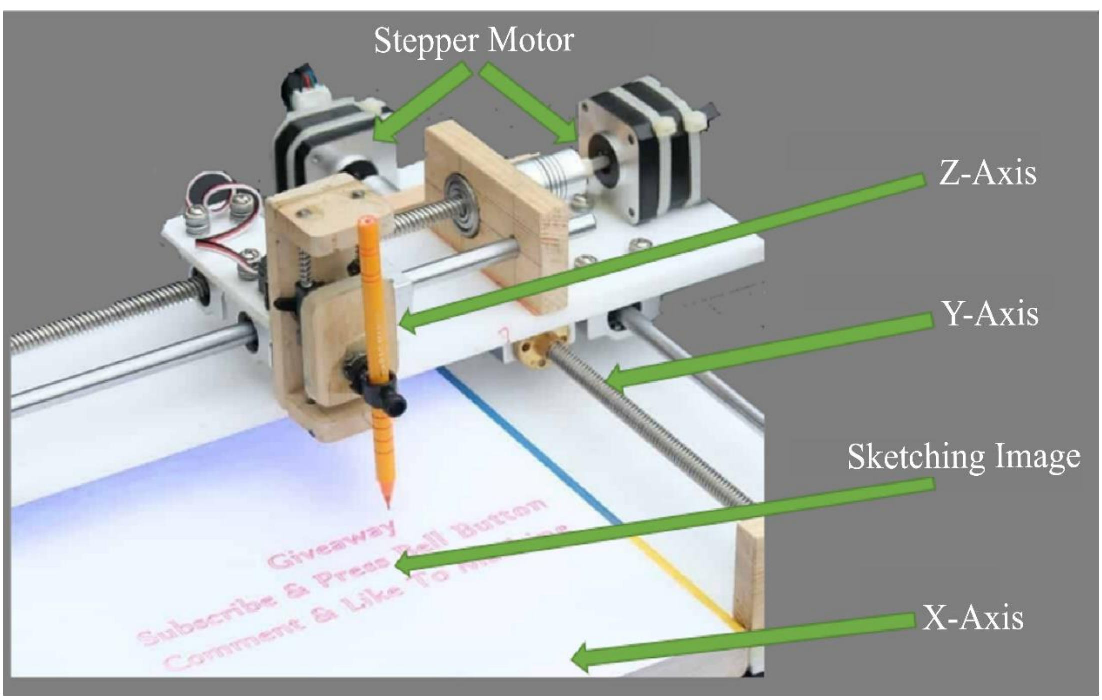


Fig. 16 Crafted technology model

Communication between the controller and the computer is facilitated through an FTDI 232 module, which serves as a serial-to-USB converter. The FTDI module's output is connected to the RXD and TXD pins (pins 2 and 3) of the ATMEGA328, enabling data transfer. The processed signals from the ATMEGA328 are sent to the Easy Drivers, each of which has 16 pins, though only 9 are utilized in this system. Four pins control the two stepper motor coils (Coil A and Coil B), while two pins supply the necessary 5V input. The CNC plotter machine operates on three axes: X, Y, and Z, to facilitate precise three-dimensional movement. The machine receives numerical instructions from a part-program, which translates design data into electrical signals. These signals are then relayed to the stepper motors, guiding their movement to specific coordinate points. The input device used for communication is a DB9 serial communication port.

Central to the system is the Machine Control Unit (MCU), which includes both a Data Processing Unit (DPU) and a Control Loop Unit (CLU). When the part program is received, the DPU processes and translates the commands into the machine's internal code. The interpolator within the DPU then calculates the motion's intermediate position in the Basic Length Unit (BLU) before passing it to the CLU for execution. The combination of advanced tools, software, and techniques significantly enhances the system's efficiency, ensuring precise plotting and optimized performance for various applications.

5. Conclusion and Recommendations

Drawing from the results and in-depth examination of the research, it is concluded that the Technology Diffusion of the developed Arduino-based Computer Numerical Control (CNC) Plotter Machine satisfies the necessary standards and functions effectively as a reliable tool for both campus maintenance operations and technical education. It is recommended that the diffusion and practical application of this technology be implemented for maintenance personnel and in technology and engineering laboratories to enhance efficiency, precision, and hands-on learning experiences.

5.1. Limitations of the Study

A limitation of this research is the absence of large-scale experimental data to analyze the complete operational performance of the CNC plotter machine. The study was mostly concerned with designing and developing an affordable CNC plotter and determining its acceptability to users, instead of carrying out thorough performance testing or quantitative analysis of similarities with commercial products. Therefore, the study lacks detailed information on long-term accuracy, longevity, or efficiency under different operating scenarios.

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References

[1] Murad BS. Alostaz et al., "Ergonomics in Spine Surgery: A Systematic Review," *Spine*, vol. 49, no. 16, pp. E250-E261, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[2] Michael Benjamin Brown, "*A Novel Accuracy Analysis Method of Dynamic CNC Machine Tool Motion by Parallel Integration of Nano-Precision Linear Scales*," University of California, 2017. [Google Scholar]

[3] Donald T. Campbell, and Julian C. Stanley, *Experimental and Quasi-Experimental Designs for Research*, Ravenio Books, 2015. [Google Scholar] [Publisher Link]

[4] Nupur Chauhan, and Yash Mathur, "Analysing the Impact of Ergonomic Elements on Stress Among Female Corporate Employees," *Fostering Industry-Academia Partnerships for Innovation-Driven Trade*, pp. 123-130, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[5] Yangke Ding, Chao Shen, and Dingzhong Feng "Pricing and Collection for Printer Cartridge Recycling Under Retailers' Ordering and Collection," *Journal of Cleaner Production*, vol. 276, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[6] Vanessa Forti et al., The Global E-Waste Monitor 2020: Quantities, Flows and the Circular Economy Potential, United Nations Institute for Training and Research, 2020. [Online]. Available: https://ewastemonitor.info/gem-2020/

[7] Sahil Goyal, Sudhir Kumar Singh, and Haripada Bhunia, "Occupational Hazards and Safety in Secondary Steelmaking Industry: A Review," *Safety in Extreme Environments*, vol. 6, no. 3, pp. 219-234, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[8] International Ergonomics Association, What is Ergonomics (HFE)?, 2014. [Online]. Available: https://iea.cc/about/what-is-ergonomics/

[9] Ehsan Naderi Kalali et al., "A Critical Review of the Current Progress of Plastic Waste Recycling Technology in Structural Materials," *Current Opinion in Green and Sustainable Chemistry*, vol. 40, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[10] Aravind Kumar Kalusivalingam et al., "Enhancing Process Automation using Reinforcement Learning and Deep Neural Networks," *International Journal of AI and ML*, vol. 1, no. 3, pp. 1-23, 2020. [Google Scholar] [Publisher Link]

[11] Amit Kumar et al., "E-Waste: An Overview on Generation, Collection, Legislation and Recycling Practices," *Resources, Conservation and Recycling*, vol. 122, pp. 32-42, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[12] Kang Liu et al., "A Global Perspective on E-Waste Recycling," *Circular Economy*, vol. 2, no. 1, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[13] Zhongchuang Liu, Siu Hua Chang, and Gilles Mailhot, “Emerging Biochemical Conversion for Plastic Waste Management: A Review,” *Molecules*, vol. 30, no. 6, pp. 1-25, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[14] Anna Louise, More Than 4,000 Toxic Chemical Present in Plastic Were Hazardous to Human Health and Environment, Study Reveals, Nature World News, 2024. [Online]. Available: https://www.natureworldnews.com/articles/61022/20240319/more-4-000-toxic-chemical-present-plastic-hazardous-human-health.htm

[15] Mohsen Soori et al., “Sustainable CNC Machining Operations, A Review,” *Sustainable Operations and Computers*, vol. 5, pp. 73-87, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[16] New South Wales Environment Protection Authority, The Waste Hierarchy, 2017. [Online]. Available: https://www.epa.nsw.gov.au/Your-environment/Recycling-and-reuse/warr-strategy/The-waste-hierarchy

[17] Sara Raad Qasim, Haider Mohammad, and Mustafa Falah, “Accurate and Cost-Effective Mini CNC Plotter,” *International Journal of Computer Applications*, vol. 975, pp. 10-15, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[18] Shanti Quinto et al., “Exploring the E-Waste Crisis: Strategies for Sustainable Recycling and Circular Economy Integration,” *Recycling*, vol. 10, no. 2, pp. 1-27, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[19] Ankit et al., “Electronic Waste and Their Leachates Impact on Human Health and Environment: Global Ecological Threat and Management,” *Environmental Technology & Innovation*, vol. 24, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[20] Mohammad Mahdi Sarkhoshkalat et al., *Circular Economy and the Recycling of E-Waste*, New Technologies for Energy Transition Based on Sustainable Development Goals: Factors Contributing to Global Warming, pp. 319-354, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[21] Philipp Sauerbier, James Anderson, and Douglas J. Gardner, “Surface Preparation and Treatment for Large-Scale 3D-Printed Composite Tooling Coating Adhesion,” *Coatings*, vol. 8, no. 12, pp. 1-10, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[22] M. Ismail Shahib, Glen Cletus Dsouza, and R.P. Vijayakumar, “A Review on End-of-Life Waste Toner Powder: Recovery, Utilization and Upcycling,” *Waste Management*, vol. 204, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[23] III. Thompson Horace A, “Enhancing Workplace Safety and Health Response: Proactive and Reactive Practices,” *Brief*, vol. 41, no. 4, pp. 23-31, 2012. [Google Scholar]

[24] Yingxuan Wang et al., “A Scoping Review of Implementation Science Theories, Models, and Frameworks-An Appraisal of Purpose, Characteristics, Usability, Applicability, and Testability,” *Implementation Science*, vol. 18, no. 1, pp. 1-15, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[25] *Some Industrial Chemicals IARC Monographs on the Evaluation of Carcinogenic Risks to Humans,* World Health Organization, Volume 115, 2018. [Publisher Link]

[26] Jasmin Wüthrich, “*Recycling of Cartridges in a Closed Loop Circular Economy*,” Master Thesis, Hochschule für Wirtschaft FHNW, 2022. [Google Scholar] [Publisher Link]