ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Paper ID #49602

Analysis of Energy Consumption and Theoretical Assessment of Welding Efficiency in Augmented Reality Arc Welding and Digital Manufacturing

Dr. Omar Ahmed Raheem Al-Shebeeb, West Virginia University

Dr. Al-Shebeeb is a Teaching Assistant Professor in the Industrial and Management Systems Engineering (IMSE) at West Virginia University (WVU). He finished his Ph.D. in the IMSE Department at WVU (2019). Then, he started his job as an Academic Program Director at Greenville Technical College. While Dr. Al-Shebeeb was pursuing his Ph.D. degree at WVU, he was working as a Graduate Teaching Assistant in the IMSE Department for four years. Dr. Al-Shebeeb obtained his M.S. and B.S. degrees in Production (Manufacturing) Engineering from the Production and Metallurgy Engineering Department at the University of Technology, Iraq. Dr. Al-Shebeeb was working as an Assistant Professor (2011-2013) and Instructor (2007-2009) at the University of Diyala, Iraq. He has taught several courses in the mechanical engineering, engineering management, and production (manufacturing) engineering fields. His areas of research interest are in Design for Manufacturing and Assembly (DFMA) and design efficiency, design thinking, productivity improvement, advanced manufacturing and technologies, subtractive and additive manufacturing, quality control, manufacturing facilities design and material handling, and CAD/CAM/CIM/CIE systems and applications. He has several publications in journals, conferences and book chapters. He is an active member of American Society for Engineering Education (ASEE), American Society of Mechanical Engineers (ASME), Society of Manufacturing Engineers (SME), Society of Automotive Engineering (SAE) International, Institute of Industrial and Systems Engineers (IISE), Industrial Engineering and Operations Management (IEOM), and WVU IE Leaders.

Austin Harper
Ahmed Shoyeb Raihan, West Virginia University

Analysis of Energy Consumption and Theoretical Assessment of Welding Efficiency in Augmented Reality Arc Welding and Digital Manufacturing

Omar Al-Shebeeb
Department of Industrial and Management Systems Engineering (IMSE)
West Virginia University
Morgantown, WV 26501
Omar.al-shebeeb@mail.wvu.edu

Ahmed Shoyeb Raihan
Department of Industrial and Management Systems Engineering (IMSE)
West Virginia University
Morgantown, WV 26501
ar00065@mix.wvu.edu

Austin Harper
Department of Industrial and Management Systems Engineering (IMSE)
West Virginia University
Morgantown, WV 26501
aoharper@mix.wvu.edu

Abstract:

Industrial production is about to undergo a revolution thanks to the upcoming generation of innovative manufacturing technologies. Proficiency in cutting-edge technologies such as augmented reality (AR), artificial intelligence (AI), and the Internet of Things (IoT) is essential for contemporary engineers as digitalization spreads. AR is one of these that has a lot of promises to improve industrial operations and training. In order to give students a practical education on welding and plasma cutting procedures, we utilize the Miller MobileArcTM AR Welding System in this study. This paper's main goal is to use a series of exercises to get students ready for smart manufacturing environments. In a safe, interactive augmented reality setting, these exercises focused on learning butt, tee, and lap joints, enabling trainees to advance their welding abilities. Students also use Fusion 360 to create plasma cutting tool paths, combining realistic simulations with CAD models. A thorough examination of material efficiency and energy consumption is made possible by the data gathered from AR welding sessions, including scores throughout performance ranges. Correlating process parameters with energy consumption, material deposition rates, and overall efficiency in creating products is the main objective of the theoretical evaluation. This research pursues to improve students' comprehension of smart manufacturing processes while offering insightful information about sustainable production methods by fusing computational analysis with augmented reality-based training. The results demonstrate how AR technologies may be used to maximize training results and resource efficiency in welding operations, which are in line with Industry 4.0 objectives.

Keywords:

Augmented Reality (AR) Welding, Smart Manufacturing, Energy Consumption Analysis, Welding Efficiency, Theoretical Evaluation, CAD Toolpath Simulation, Advanced Manufacturing Technologies, Operator Training Optimization

1. Research Objectives and Scopes

This paper served as a vehicle to prepare students for working with smart manufacturing technologies using three exercises to support their learning. These exercises aimed to develop student's proficiency with creating butt, tee, and lap joints using the Miller MobileArc™ AR Welding System. Students also used computer aided design (CAD) software, Fusion360, to generate a plasma cutter toolpath for part designs provided through eCampus. Once the data for AR welding and plasma cutting tool paths was collected, a computational analysis was performed to evaluate energy consumption, material deposition rate, and deposited material quantity for each scenario.

This paper exercises required several deliverables. First, using the AR welding setup students collected scores for each joint type in three ranges: good (89-100), decent (61-88), and bad (0-60). In total there were nine observations collected for the AR welding exercise. Two CAD files were provided to students and a plasma cutter toolpath was generated for each product–two paths in total. The tool path was then simulated, outputting path statistics such as machining time and distance. After generating the Fusion360 models, students made calculations to approximate the energy needed to produce Pokecenter and Aircraft designs. Using this data relationships were developed between process parameters to expand upon student's understandings.

2. Introduction

Advanced manufacturing technologies are revolutionizing industrial production, particularly through the integration of Augmented Reality (AR), Artificial Intelligence (AI), and the Internet of Things (IoT). In today's manufacturing environment, these technologies are crucial for engineers as they navigate the complexities of digitalization. Several studies have shown that augmented reality can be used to enhance training and operational efficiency in industrial settings. AR can facilitate immersive learning by allowing trainees to interact with complicated processes such as welding and plasma cutting in a safe, interactive manner (Storto (2018) Mani et al., 2014).

One technology that shows promise for disrupting the manufacturing space is AR. SAP describes AR as, "an interactive experience that enhances the real world with computer-generated perceptual information," (SAP). Using peripherals like smart glasses to project a virtual display on the user's environment to create an interactive learning space. Applications of this technology are being used to assist with operator training, operation, maintenance, and quality of manufacturing equipment (SAP). In this lab, students will explore the opportunity that AR welding presents to improve safety during new operator training while maintaining a quality learning experience.

The Miller MobileArcTM AR Welding System illustrates how AR can be applied in educational contexts to provide students with practical training on welding techniques, including butts, tees, and lap joints. The hands-on approach aligns with contemporary pedagogical strategies emphasizing experiential learning, which has been shown to improve motivation as well as skill acquisition among students (Mani et al., 2014). Additionally, the integration of CAD tools such as Fusion 360 with AR training enhances the learning experience by enabling students to create and simulate plasma cutting tool paths, effectively bridging the gap between theoretical knowledge and practical application (Prete & Primo, 2021).

AR technologies have the potential to improve training outcomes as well as evaluate material efficiency and energy consumption during manufacturing processes. By correlating process parameters with performance metrics, researchers can identify optimal conditions for resource utilization, which is essential for sustainable manufacturing practices (Kim & Moylan, 2018). The ability to gather and analyze data from AR training sessions provides valuable insights into energy consumption and material deposition rates, contributing to the overarching goals of Industry 4.0 (Singh et al., 2019). This data-driven approach not only enhances operational efficiency but also supports the development of sustainable production methods, aligning with the increasing demand for environmentally responsible manufacturing practices (Yu et al., 2020).

In conclusion, the integration of AR and AI technologies in training and operational processes is crucial for preparing students and professionals for the demands of smart manufacturing environments. As industries continue to evolve, the role of immersive technologies in enhancing training outcomes and resource efficiency will likely expand, paving the way for innovative solutions that meet the challenges of modern manufacturing (Casuso et al., 2021).

3. Methodology

Using the Miller MobileArc™ AR Welding System, students practiced making three types of welds–see Figure 1 for examples. The results for each weld were photographed during the lab session and later aggregated into a data table for computational analysis.

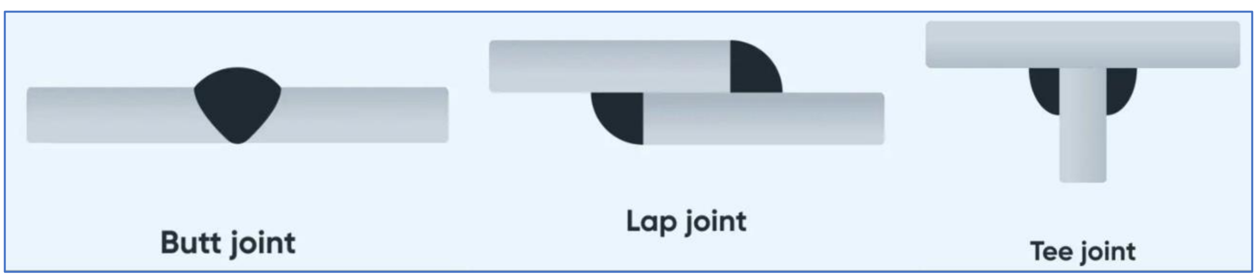

Figure 1: Joint types practiced using AR welding [12]

For plasma cutting, students were provided with the two product CAD files–see Figure 2 for images of both assemblies. These products were imported to Fusion360 to conduct the following exercise.

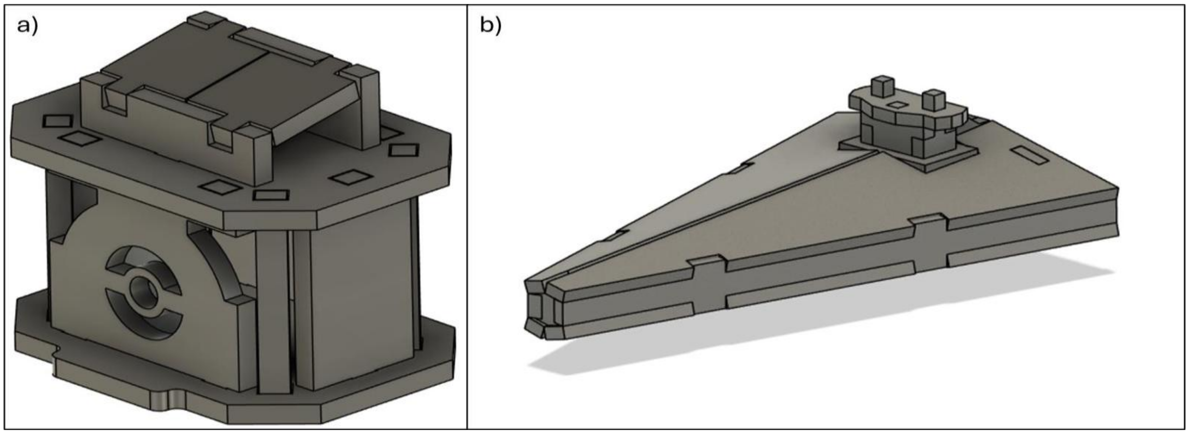

Figure 2: Images of products from the provided CAD files a) Pokecenter b) Aircraft

First the products needed to be disassembled, and individual panels laid flat on a working surface– see Figure 3. This surface represents the 12 by 12 inches stock material that the panels will be cut from. Once these panels are on the work surface, a toolpath is generated for the outlines of each panel which will provide the plasma cutter with G-Code to manufacture the parts. The plasma cutter has a nozzle diameter and kerf width of 1 millimeter with a feed rate of 40 inches per minute.

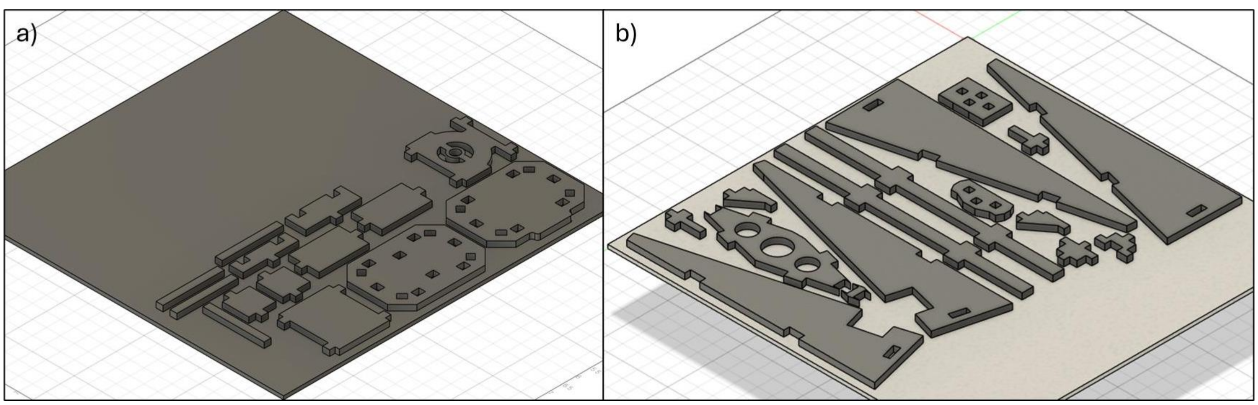

Figure 3: Images of product components laid out on the workpiece a) Pokecenter b) Aircraft

3.1 Augmented Reality Arc Welding

The first objective of this project focuses on developing proficiency in welding using an augmented reality (AR) system. The team aimed to become proficient in three types of welding joints: butt, tee, and lap joints. Each joint type requires a different technique and approach. These welding joints were all practiced during several sessions to ensure accuracy and skill development.

In Figures 4-12, each one is broken up into three sections: the scores, visualizations of the individual data points that make up the score, and the completed weld. Each Total Score is an average of the Categorical Scores: Work Angle, Travel Angle, Contact-Tip-to-Work Distance (CTWD), Travel Speed, and Aim. The Work Angle is the angle the electrode points at the work surface. The Travel Angle is the angle at which the electrode is being pointed in the direction of travel, also known as the Drag angle. The CTWD is the distance between the contact point of the welding torch and the workpiece. The Travel Speed measures the speed at which the torch moves along the specified path. Finally, the Aim measures the accuracy at which the torch remains within the specified path for the desired joint.

For the AR exercise, the first joint welded was a tee joint which is the joining of a top piece placed perpendicularly on a flat base piece. From the initial trials, the bad result presented here has a Total Score of 57. While the work and travel angles have good scores, the others are lagging with travel speed being the lowest at 27. By looking at the travel speed chart in Figure 4b, you can see the inconsistent travel speeds and the effect that this has on the weld in Figure 4c. Comparing the graph to the weld, there are mounds of welding materials and several rough lines joining the surfaces.

CTWD = Contact Tip to Work Distance (Welding Gap)
AIM = Is to stay at the center of the welding path with lowest or zero deviation.

Figure 4: Tee Joint, a) Bad Score, b) Score Visualizations, c) AR welded joint

Through aim improvements, the decent score was 82 for the tee joint in Figure 5. This weld is smoother with a more consistent travel speed, however, the score for this category was only 27 points higher and not good enough to bring it to the next level.

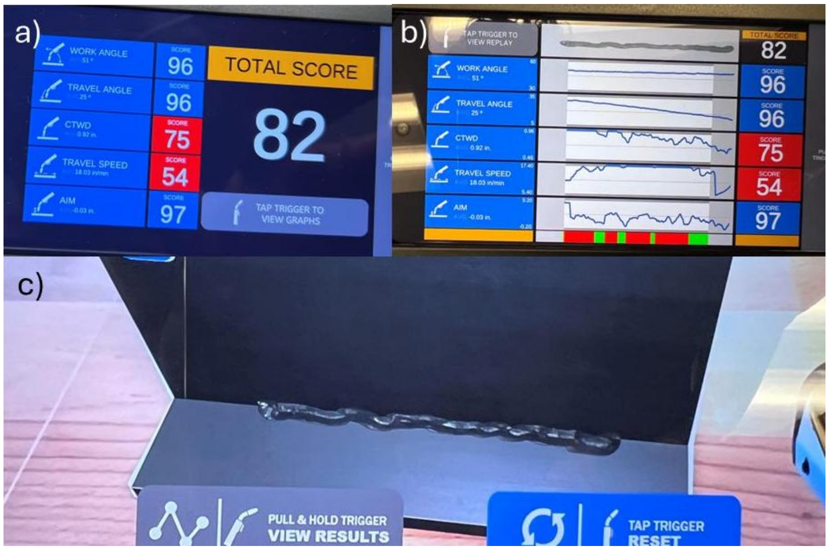

Figure 5: Tee Joint, a) Decent Score, b) Score Visualizations, c) AR welded joint

Finally, after several attempts to get a good score the CTWD and travel speed were improved for the best Total Score performance of 96 in Figure 6. While the travel speed is not very consistent, it was within an acceptable range for a good score while still being the lowest Categorical Score.

Figure 6: Tee Joint, a) Good Score, b) Score Visualizations, c) AR welded joint

The second joint that was practiced using the AR welding technology was the lap joint. This weld joins two overlapping plates, placing one flush on top of the other and welding the edge of the top piece to the surface of the bottom plate. While beginning trials for this weld, a bad score of 44 was obtained by students. The lowest Categorical Score for this weld was Travel Speed, showing a massive slow down towards the end of the weld. In Figure 7c, you can see that at the end there was a larger stacking of material on the weld with a thinner quicker finish.

Figure 7: Lap Joint, a) Bad Score, b) Score Visualizations, c) AR welded joint

Building on the lessons learned from the bad weld, there was a focus to enhance Travel Speed and CTWD. This resulted in a decent Total Score of 73, with Travel Speed and CTWD improving to 30 and 76 respectively. Looking at their graphs in Figure 8b, there was a slow start and consistent middle for the Travel Speed with a slow finish. The CTWD trailed off towards the end, getting further from the workpiece as the travel speed started to decrease.

Figure 8: Lap Joint, a) Decent Score, b) Score Visualizations, c) AR welded joint

Finally, a good Total Score of 96 was achieved with this last trial. While the travel speed was inconsistent, this was balanced out by slowing down when speeding up too much. The problem with this last weld was the low CTWD being the only score below 90.

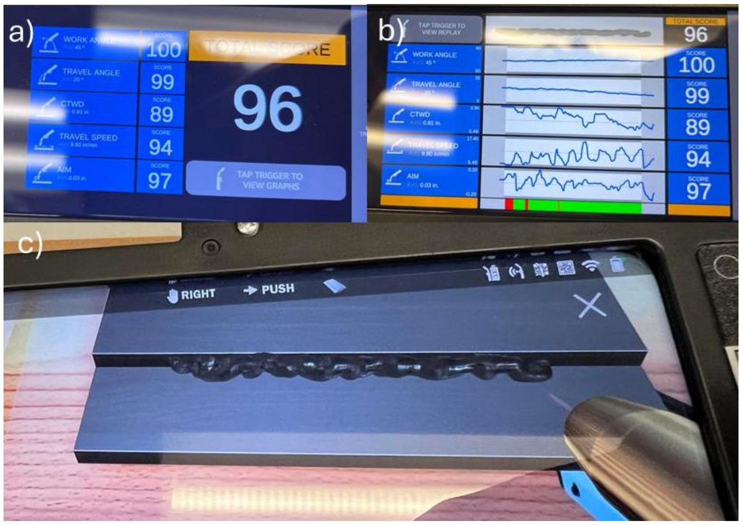

Figure 9: Lap Joint, a) Good Score, b) Score Visualizations, c) AR welded joint

The final joint to weld was the butt joint which joins two workpieces together without overlapping, see Figure 10c. This joint proved to be difficult, starting with a bad Total Score of 30 in Figure 10. Two Category Scores were the problem: a 0 for Work Angle and 49 for Travel Speed. While Travel Speed was inconsistent for this weld, the Work Angle was severely limited this attempt.

Figure 10: Butt Joint, a) Bad Score, b) Score Visualizations, c) AR welded joint

With more trials came a decent Total Score of 74. Three categories proved to be an issue with this weld as the Work Angle, CTWD, and Travel Speed were low scores. The Work Angle was consistent across the weld; however, it was not at the right angle for this weld. The lowest score was the Travel Speed which varied and created a bumpy weld–see Figure 11c.

Figure 11: Butt Joint, a) Decent Score, b) Score Visualizations, c) AR welded joint

The last exercise for this lab was to get a good Total Score for the butt weld which was accomplished with a score of 89. This proved to be the most difficult weld for the students but looking at Figure 12b, the Categorical Scores proved to be sufficient to get a good score. For this joint, the struggle was keeping a consistent Travel Speed while maintaining the other categories being scored.

Figure 12: Butt Joint, a) Good Score, b) Score Visualizations, c) AR welded joint

In Table 1, the Total Scores have been compiled to make comparing the results easier. When looking at the bad scores the butt joint was the most difficult at 30, while the tee joint was easiest at 57. The decent scores were similar for the lap and butt joints–73 and 74 respectively–while the tee joint was 82. Finally, the tee and lap joints proved to be easily done, after some practice a Total Score of 96 for both was achieved. However, even with practice the butt joint was difficult to master, achieving a good Total Score of 89.

Table 1: Consolidated Welding Total Score Results

Tee Joint			Lap Joint			Butt Joint		
Good	Decent	Bad	Good	Decent	Bad	Good	Decent	Bad
96	82	57	96	73	44	89	74	30

3.2 Plasma Cutting

A toolpath was generated for each of the designs (Pokecenter and Aircraft) provided to the students. The first product was a Pokecenter while the other will make an Aircraft. Figure 13 shows the Pokecenter's toolpath. It begins on the left side of the plate and carves out the parts cutting towards the right side, ending after the circular internal pattern is cut.

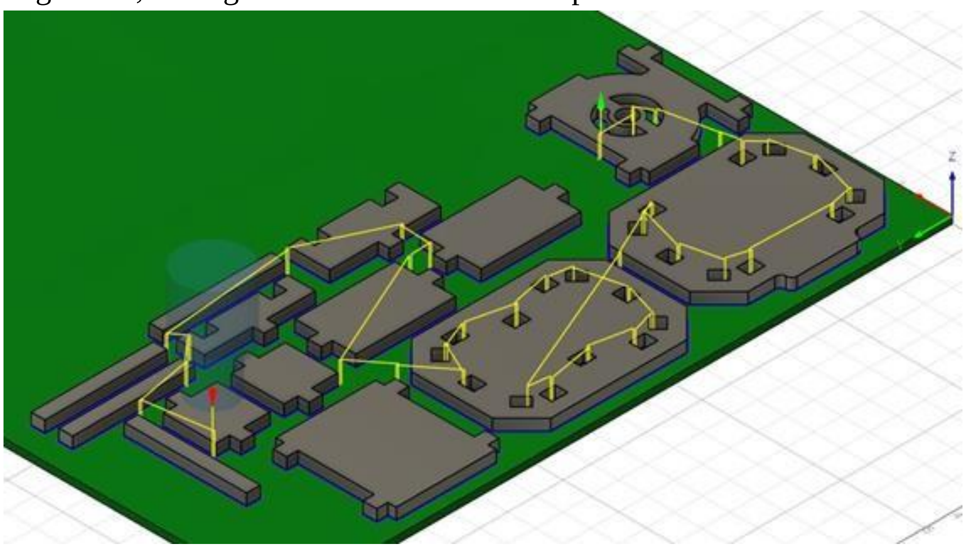

Figure 13: Toolpath generated for Pokecenter design

The aircraft's toolpath is shown in Figure 14. This path starts with the middle pieces and moves to the left to cut out the outside of those pieces and the circles on that side. Then the tool moves to the right side of the plate to cut out those outlines. After that the tool moves back to the left side to cut out the internal rectangles before moving back to the right side to do the same.

Once the toolpaths are generated the cutting process can be simulated using the 'Simulate with Machine' option. After simulation the program will provide users with data about the machining time and distance traveled by the nozzle. In Figure 15, the machining time for the Pokecenter was 3 minutes and 25 seconds and the machining distance was 15.692 feet or 188.304 inches.

Figure 16 displays the statistics for the aircraft toolpath, showing a machining time of 5 minutes and 11 seconds and a distance of 25.989 feet or 311.868 inches. This time and distance is significantly more than that of the Pokecenter manufacturing requirements due to the complexity and size of this assembly.

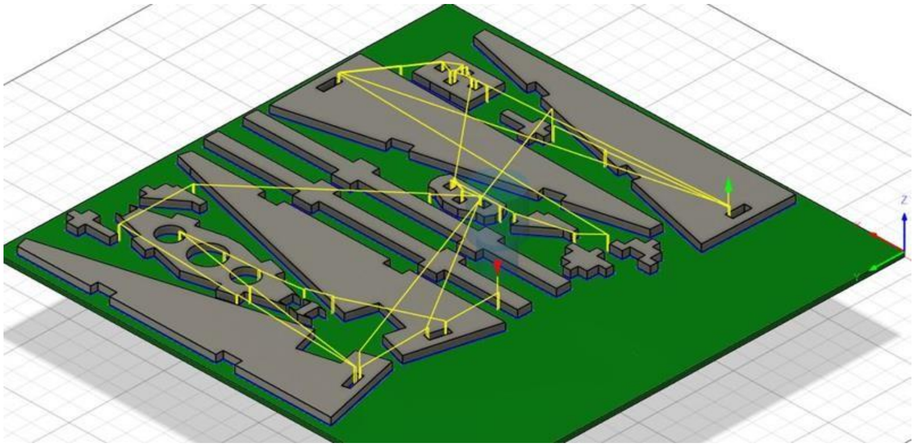

Figure 14: Toolpath generated for Aircraft design

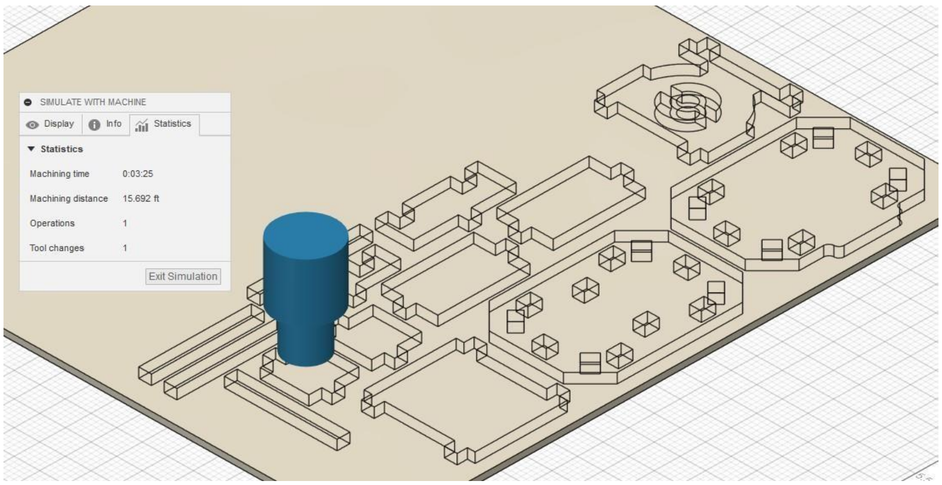

Figure 15: Toolpath statistics for the Pokecenter design

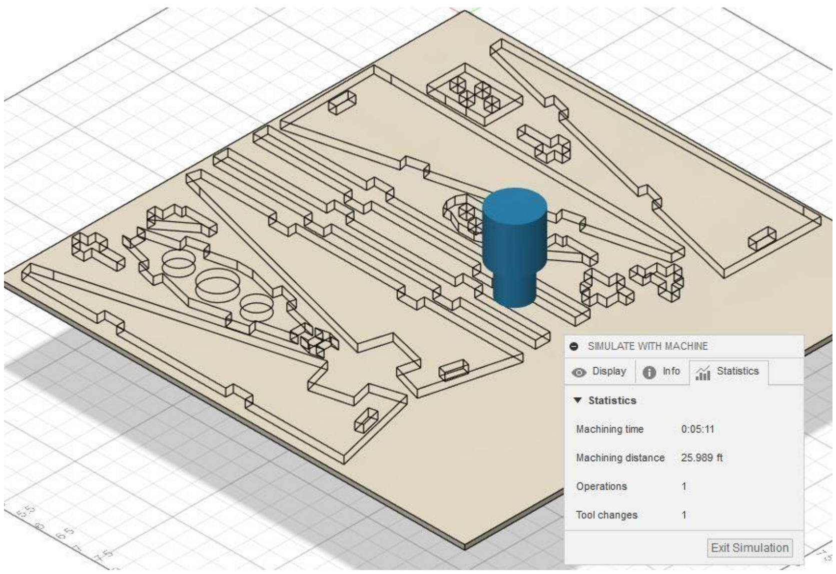

Figure 16:Toolpath statistics for the aircraft design

3.3 Welding Analysis

Once the pieces are laser cut the next step would be assembly. In this lab students did not produce physical products, however, there are valuable estimations which can be calculated. For this product, welding was deemed the appropriate joining method. Figure 17 & 18 show the codes for each spot which should be welded during assembly for both designs. In this analysis students analyzed the Pokecenter and the Aircraft designs.

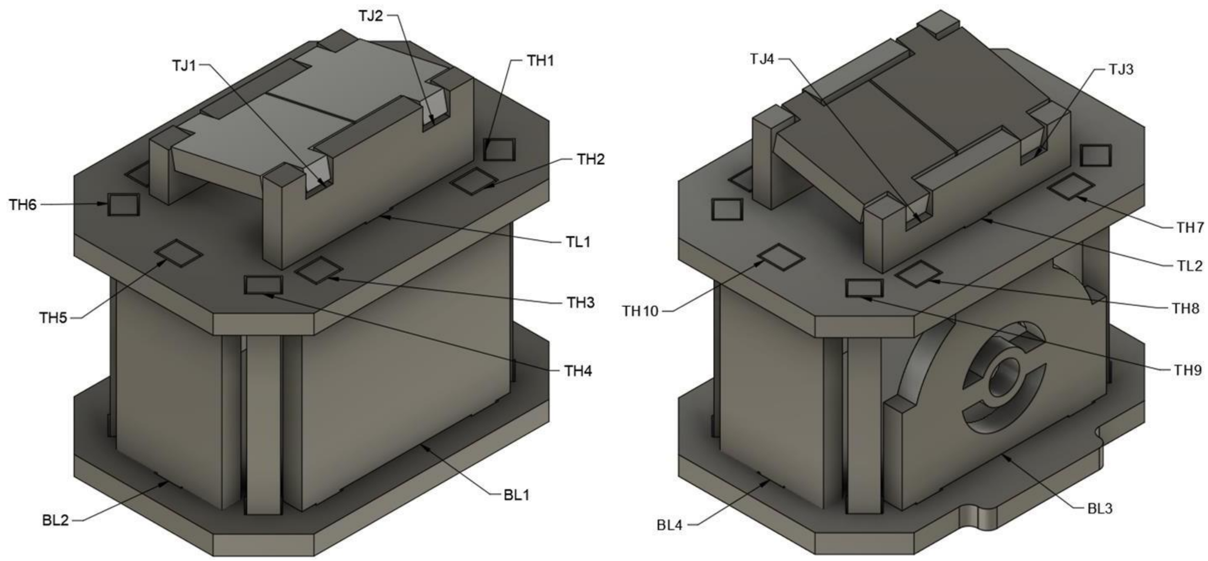

Figure 17: Isometric views of Pokecenter design with welding codes

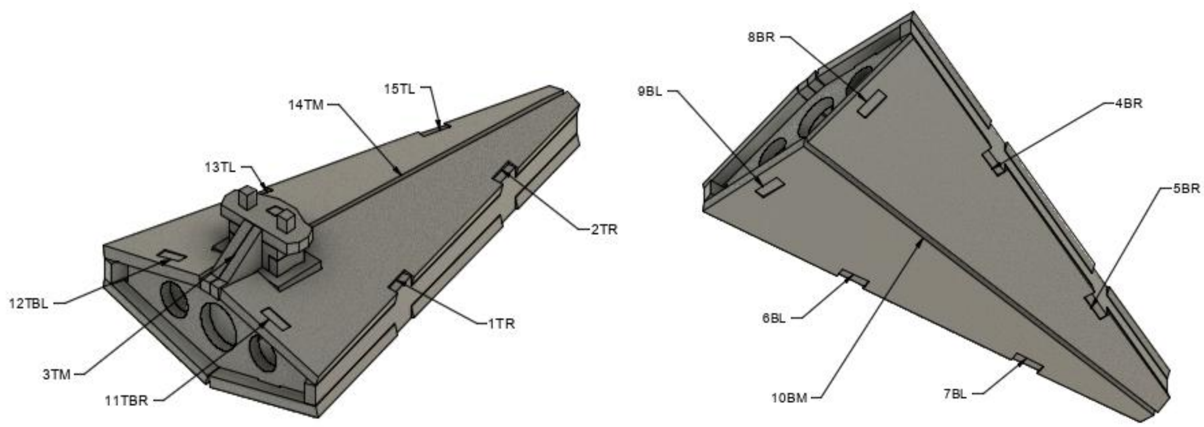

Figure 18: Isometric views of Aircraft design with welding codes

Using the welding code diagram as a guide, Table 4 & 5 were calculated to determine the energy expended to assemble Pokecenter and Aircraft designs. For this product there are two types of joints, lap and tee, which run at two different currents, 100A and 125A respectively. Using the table given to students in Table 2 the values for travel speed, arc length, and metal deposited are used for the energy calculation.

Table 2: Welding data table provided to students

Current (A)	Travel Speed (in/min)	Arc Length (in)	Metal Deposited (gm/in)
100	10	0 - 1/8	1
125	12	1/8 - 3/8	1.333

In Table 3 there is a list of variables used in the equations that were required for this analysis. Three equations were used in addition to some other simple algebra for the formulation of Table 4.

Table 3: Variable Descriptions

Variable	Description	Unit
W	Energy	KJ
E	Voltage	V
I	Current	A
T	Welding Time	sec
R	Resistance	Ω
S	Travel Speed	in/min
L	Welding Length	in

$$E = I * R$$

Equation 1: Voltage Equation

$$T = \frac{60 * L}{S}$$

Equation 2: Welding Time Equation

$$W = E * I * T$$

Equation 3: Energy Equation

To calculate the energy needed, the welding length needed to be acquired from Fusion 360, which can be seen in Table 4 along with the rest of the calculations. Each row in Table 4 & 5 corresponds to a welding code on the diagram in Figures 17 and 18. Calculations were made for each weld and are totaled at the bottom of the table for relevant results. For the Pokecenter, the total welding length needed was 20.662 in, total welding time was 113.434 seconds, total metal deposited was 24.171 grams, and the total energy expended was 403.463 KJ. On the other hand, for the Aircraft design, the total welding length needed was 20.877 in, total welding time was 120.76 seconds, total metal deposited was 24.92 grams, and the total energy expended was 454.93 KJ

Table 4: Pokecenter Welding analysis calculations

Weld line	Welding Type	Welding Code	Current (A)	Voltage (V)	Travel Speed (in/min)	Arc Length (in)	Welding Length (in)	Metal Deposition (gm/in)	Welding Time (sec)	Metal Deposited (gm)	Deposition Rate (gm/sec)	Energy (KJ)	Energy/ Length (KJ/in)
1	Lap	TH1	100	28.20	10	0 - 1/8	0.900	1	5.400	0.900	0.167	15.228	16.92
2	Lap	TH2	100	28.20	10	0 - 1/8	0.900	1	5.400	0.900	0.167	15.228	16.92
3	Lap	TH3	100	28.20	10	0 - 1/8	0.900	1	5.400	0.900	0.167	15.228	16.92
4	Lap	TH4	100	28.20	10	0 - 1/8	0.900	1	5.400	0.900	0.167	15.228	16.92
5	Lap	TH5	100	28.20	10	0 - 1/8	0.900	1	5.400	0.900	0.167	15.228	16.92
6	Lap	TH6	100	28.20	10	0 - 1/8	0.900	1	5.400	0.900	0.167	15.228	16.92

7	Lap	TH7	100	28.20	10	0 - 1/8	0.900	1	5.400	0.900	0.167	15.228	16.92
8	Lap	TH8	100	28.20	10	0 - 1/8	0.900	1	5.400	0.900	0.167	15.228	16.92
9	Lap	TH9	100	28.20	10	0 - 1/8	0.900	1	5.400	0.900	0.167	15.228	16.92
10	Lap	TH10	100	28.20	10	0 - 1/8	0.900	1	5.400	0.900	0.167	15.228	16.92
11	Tee	TL1	125	35.25	12	1/8 - 3/8	2.000	1.333	10.000	2.666	0.267	44.063	22.03
12	Tee	TL2	125	35.25	12	1/8 - 3/8	2.000	1.333	10.000	2.666	0.267	44.063	22.03
13	Tee	BL1	125	35.25	12	1/8 - 3/8	2.169	1.333	10.845	2.891	0.267	47.786	22.03
14	Tee	BL2	125	35.25	12	1/8 - 3/8	1.100	1.333	5.500	1.466	0.267	24.234	22.03
15	Tee	BL3	125	35.25	12	1/8 - 3/8	2.169	1.333	10.845	2.891	0.267	47.786	22.03
16	Tee	BL4	125	35.25	12	1/8 - 3/8	1.100	1.333	5.500	1.466	0.267	24.234	22.03
17	Lap	TJ1	100	28.20	10	0 - 1/8	0.281	1	1.686	0.281	0.167	4.755	16.92
18	Lap	TJ2	100	28.20	10	0 - 1/8	0.281	1	1.686	0.281	0.167	4.755	16.92
19	Lap	TJ3	100	28.20	10	0 - 1/8	0.281	1	1.686	0.281	0.167	4.755	16.92
20	Lap	TJ4	100	28.20	10	0 - 1/8	0.281	1	1.686	0.281	0.167	4.755	16.92
Total	-	-	-	-	-	-	20.662	-	113.434	24.171	-	403.463	-

Table 5:Aircraft Welding analysis calculations

Weld line	Welding Type	Welding (code)	Current (A)	Voltage (V)	Travel Speed (in/min)	Are Length (in)	Welding Length (in)	Welding Time (sec)	Metal Deposited (gm)	Deposition Rate (gm/sec)	Energy (KJ)	Energy/ Length (KI/in)
1	Lap	ITR	125	35.25	12	1/8-3/8	0.5	2.5	0.67	0.53	11.02	22.03
2	Lap	2TR	100	28.2	10	0-1/8	0.5	3	0.50	0.33	8.46	16.92
3	Butt	3TM	125	35.25	12	1/8-3/8	0.5	2.5	0.67	0.53	11.02	22.03
4	Lap	4BR	100	28.2	10	0 -1/8	0.5	3	0.50	0.33	8.46	16.92
5	Lap	SBR	125	35.25	12	1/8-3/8	0.5	2.5	0.67	0.53	11.02	22.03
6	Lap	68L	100	28.2	10	0-1/8	0.5	3	0.50	0.33	8.46	16.92
7	Lap	78L	125	35.25	12	1/8 3/8	0.5	2.5	0.67	0.53	11.02	22.03
8	Lap	88R	100	28.2	10	0-1/8	0.5	3	0.50	0.33	8.46	16.92
9	Lap	98L	125	35.25	12	1/8 3/8	0.5	2.5	0.67	0.53	11.02	22.03
10	Butt	10BM	125	35.25	10	1/8 3/8	7.639	45.83	10.18	0.03	201.94	26.44
11	Lap	11TBR	125	35.25	12	1/8 3/8	0.5	2.5	0.67	0.53	11.02	22.03
12	Lap	12TBL	100	38.2	10	0 1/8	0.5	3	0.50	0.33	11.46	22.92
13	Lap	13TL	125	35.25	12	1/8 3/8	0.5	2.5	0.67	0.53	11.02	22.03
14	Butt	14TM	100	28.2	10	0 1/8	5.738	34.43	5.74	0.03	97.09	16.92
15	Lap	15TL	125	35.25	12	1/8-3/8	0.5	2.5	0.67	0.53	11.02	22.03
16	Tee	16TL	100	38.2	10	0 -1/8	0.5	3	0.50	0.33	11.46	22.92
17	Tee	178R	125	35.25	12	1/8-3/8	0.5	2.5	0.67	0.53	11.02	22.03
Total	-	-	-	-	-	-	20.877	120.76	24.92	-	454.93	-

Tables 6 and 7 were used to calculate the amount of scrap material produced while manufacturing a Pokecenter. The areas and volumes of each piece from Fusion 360 are presented in Table 5 while the calculations using this data to predict the scrap materials are in Table 6. For the scrap calculations, it was assumed that the raw material piece is a 12 by

12 inches metal sheet that is 0.125 inches thickness. From this stock material there was a 76.94% scrap area and scrap volume for one Pokecenter. We discussed the Pockecenter design only here because the Aircraft design has close results to it.

Table 6: Areas and volumes of Pokecenter design

Piece	Area (in^2)	Volume (in^3)
Bottom	7.804	0.9755
Top	7.417	0.9271
Leg 1	0.55	0.0688
Leg 2	0.55	0.0688
Leg 3	0.55	0.0688
Leg 4	0.55	0.0688
Door	3.133	0.3916
Side 1	2.08	0.26
Side 2	2.08	0.26
Back	4.104	0.513
Top Front	0.92	0.115
Top Back	1.42	0.1775
Top Roof 1	1.026	0.1283
Top Roof 2	1.026	0.1283

Table 7: Scrap calculations for Pokecenter design

Total Area Raw Material (in^2)	Total Area (in^2)	Area not used (in^2)	% Area not used	Total Volume Raw Material (in^3)	Total Volume of Parts (in^3)	Volume not Used (in^3)	% Volume not used
144	33.21	110.79	76.94%	18	4.1513	13.8488	76.94%

4. Discussion

This discussion evaluates AR welding for safe skill development, plasma cutting for production planning, and welding analysis for resource optimization. AR welding challenges include depth perception issues, especially for complex joints. Plasma cutting simulations revealed resource-intensive production for larger designs. Welding analysis focused on energy costs, material scrap rates, and deposition rates, highlighting opportunities for process and sustainability improvements.

4.1 AR Welding

The AR welding practice helped students develop a familiarity with the basics without the risks associated with starting welding. It gave students an opportunity to simulate these skills in a classroom environment while maintaining a high safety standard. When analyzing the results presented in Table 1, the most difficult weld using AR was the butt joint which had both the worst good and bad Total Scores. Using technology was more challenging due to the abnormal depth perception created by looking through the tablet and trying to operate in real space. This is a limitation of the technology which was somewhat improved using the helmet but was still uncanny to use for a physical task.

4.2 Plasma Cutting

CAD Software provides users with powerful tools to design products and simulate their manufacturing process. This data can then be utilized to plan production levels to adequately meet demand. For these exercises, students simulated the plasma cutter toolpaths for two designs (Pokecenter and Aircraft). If these products were manufactured the aircraft would require more resources to produce due to the longer machining time and distance. This decreases the number of products you could produce on a single machine during a day of production.

4.3 Welding Analysis

Welding is a commonly used joining method for metal assembly, so it is imperative that we be able to calculate the resources required to manufacture products with this process. Tables 4 and 6 detail these calculations and resources using Equations 1-3. The total energy, from Table 4, needed to weld the Pokecenter would be 403.463 kJ which is also 0.112 kWh. From this conversion we can find out the energy costs that would go into welding one of these products. For example, the commercial rate for First Energy is $0.03283/kWh so the energy cost to weld one Pokecenter would be approximately $0.00368. This is a relatively small amount for one product, however, if a company were to mass produce these it would become a necessary consideration for the company’s bottom line. Additionally, companies must consider how material resources will affect sustainability and profitability. For the Pokecenter product there is a scrap rate of 76.94%, which means there is well over half the stock that is being wasted. To reduce scrap, parts for two Pokecenters can be cut from one sheet of raw material. By adding a second product to the raw material the scrap rate would be reduced to 53.875%. Even with this improved scrap rate there is still room for further improvement. Based on the percentage of leftover materials, four Pokecenters can be cut from a single 12 inch by 12 inch stock material leaving 7.75% scrap left over. While this is theoretically possible; part placement would need to be optimized to confirm this result. By considering the impact of material resources, higher sustainability can be achieved in manufacturing design.

The discussion addressed specific questions to evaluate understanding and knowledge of the arc welding process, serving as a method to assess theoretical comprehension of arc welding principles.

<u>Question 1:</u> Which of the primary variables (current, voltage, and travel speed) had the greatest effect upon deposition rate?

Answer: The deposition rate of welding material is an important consideration when welding planning. This rate will be affected by three primary variables: current, voltage, and travel speed. The largest effects will come from the current because both travel speed and voltage increase proportionally with this value. Equation 1 demonstrates the proportional increase in voltage by the welding machine resistance. Additionally, Table 2 was used to develop an assumed linear relationship between travel speed and current. Therefore, the variable which will influence the deposition rate most is the current.

<u>Question 2:</u> What is the effect of current upon deposition rate? Explain with graph.

Answer: To assess the effects of current deposition rate graphically; the same linear assumptions from Table 2 used in Question 1 was applied between current and metal deposited too. Using these relationships the deposition rate of increasingly large current values was calculated in Table 8. Additionally, Figure 18 was created to visualize the positively increasing nature of the relationship between current and voltage.

Table 8: Calculating deposition rate for different currents

Current (A)	Voltage (V)	Welding Length (in)	Metal Deposited (gm/in)	Metal Deposition (gm)	Travel Speed (in/min)	Welding Time (sec)	Deposition Rate (gm/sec)
100	28.20	2.000	1.000	2	10.000	12.000	0.167
110	31.02	2.000	1.133	2.2664	10.800	11.111	0.204
120	33.84	2.000	1.266	2.5328	11.600	10.345	0.245
130	36.66	2.000	1.400	2.7992	12.400	9.677	0.289
140	39.48	2.000	1.533	3.0656	13.200	9.091	0.337
150	42.30	2.000	1.666	3.332	14.000	8.571	0.389
160	45.12	2.000	1.799	3.5984	14.800	8.108	0.444

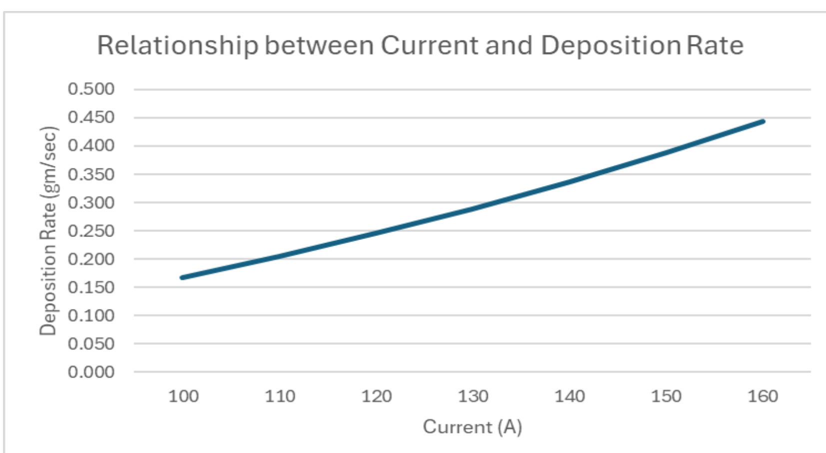

Figure 19: Graph showing the relationship between current and deposition rate

<u>Question 3:</u> What is the effect of travel speed upon deposition rate?

Answer: Using Table 7, as the travel speed increases there is also an increase in deposition rate. This is because as the current increases so does the process heat which instigates faster deposition of material and requires higher travel speeds.

<u>Question 4:</u> If the weight of a single used electrode during the Arc welding is 48 gm, estimate how many electrodes will you consume to finish the actual welding by considering 15% waste during the Welding?

Answer: Before welding it is essential to ensure there is enough electrode material to finish the product. This can be estimated using the total lengths of the product's welds and the metal deposition given in Table 2. Therefore, Table 8 was calculated for each current value due to the metal deposition differences. The total metal needed to assemble the Pokecenter is 24.171 grams and with a 15% scrap rate it is 27.797. Thus, only 61.8% of the electrode will be utilized when assembling one Pokecenter. Which means while assembling multiple Pokecenters the welder will need to keep extra electrodes on hand to ensure there is enough stock.

Table 9: Electrode usage calculations

Current (A)	Total Welding Length (in)	Metal Deposition (gm/in)	Metal Deposited (gm)	Total Metal Needed	Total Metal Needed with Scrap	Electrodes Used
100	10.124	1	10.124	24.171	27.797	0.618
125	10.538	1.333	14.047			

5. Conclusion

In conclusion, this work provided students with an opportunity to explore and familiarize themselves with augmented reality (AR) as well as welding training with the use of this technology, alongside learning the use of CAD for CNC plasma cutting. Using AR technology, participants had the option to refine their welding abilities in a controlled, without risky environment. This vivid experience considered exact criticism and expertise improvement in the making of different welding joints, including tee, butt, and lap joints. Although the group didn't completely meet the objective score of 95% across every single joint type, significant upgrades were made, exhibiting the advantages of AR as a preparation device in assembling conditions.

The use of CNC plasma cutting, directed by computer aided design plans, further enhanced the task by underscoring accuracy and productivity in metal manufacture. By producing and enhancing device ways in Fusion 360, the group acquired active involvement in present day computerized manufacture procedures. The plasma cutter activity showed the way that a viable G-Code can add to limiting material waste, lessening energy utilization, and working on by and large cutting proficiency. These perspectives are basic for manageability in assembling operations, lining up with industry objectives of decreasing environmental impact.

Finally, the assessment of energy consumption and material waste featured the significance of advancing welding boundaries to upgrade both productivity and supportability. By changing variables like current, voltage, and travel speed, the group had the option to recognize the ideal equilibrium for material use and energy productivity. This project successfully demonstrated how modern technologies like augmented reality and CNC plasma cutting can be integrated to not only improve manufacturing accuracy but also contribute to more sustainable production practices.

6. Suggested Future Improvements

To build upon the findings and conclusions of this project, the following future work is proposed:

- **Real-Life Application**
  - Transition of AR welding skills to actual welding tasks and assess real-world effectiveness.
- **AR Welding Improvements**
  - Enhance AR depth perception for complex joints using better rendering and feedback systems.
  - Conduct long-term studies to evaluate skill retention and proficiency.
- **Plasma Cutting Optimization**
  - Implement advanced nesting algorithms to reduce material waste.
  - Explore energy-efficient plasma cutting technologies for sustainability.
- **Welding Efficiency**
  - Perform cost-benefit analysis comparing AR and CNC training with traditional methods.
- **Integration of Advanced Technologies**
  - Apply IoT for real-time process monitoring and data-driven improvements.

Bibliography

[1] Casuso, J., González, J., & García, A. (2021). Model for the prediction of deformations in the manufacture of thin-walled parts by wire arc additive manufacturing technology. *Metals*, 11(5), 678. https://doi.org/10.3390/met11050678

[2] SAP, "What is Augmented Reality (AR)?" [Online]. Available: https://www.sap.com/products/scm/industry-4-0/what-is-augmented-reality.html

[3] Kim, H., & Moylan, S. (2018). Literature review of metal additive manufacturing defects. *NIST AMS*, 100-16. https://doi.org/10.6028/nist.ams.100-16

[4] Mani, M., Sutherland, J. W., & Hurst, S. (2014). Sustainability characterization for additive manufacturing. *Journal of Research of the National Institute of Standards and Technology*, 119, 16. https://doi.org/10.6028/jres.119.016

[5] Prete, P., & Primo, A. (2021). Innovative methodology for the identification of the most suitable additive technology based on product characteristics. *Metals*, 11(3), 409. https://doi.org/10.3390/met11030409

[6] Singh, R., Gupta, A., & Kumar, A. (2019). Evaluating the strategic potential of AMT in Indian manufacturing industries. *International Journal of Management Concepts and Philosophy*, 12(1), 100-117. https://doi.org/10.1504/ijmcp.2019.10019729

[7] Storto, G. (2018). A double-DEA framework to support decision-making in the choice of advanced manufacturing technologies. *Management Decision*, 56(1), 123-138. https://doi.org/10.1108/md-09-2016-0644

[8] Yu, Y., Zhang, Y., & Wang, Y. (2020). Prediction of weld reinforcement based on vision sensing in GMA additive manufacturing process. *Metals*, 10(8), 1041. https://doi.org/10.3390/met10081041

[9] Zhang, Y., & Khanal, R. (2024). Artificial intelligence and operational efficiency of Chinese manufacturing firms. *INTCJ*, 1(1), 1-15. https://doi.org/10.69659/qcqt7937

[10] Iatsyshyn, O., & Koval, V. (2020). Application of augmented reality technologies for education projects preparation. *CTE Workshop Proceedings*, 1, 1-6. https://doi.org/10.55056/cte.318

[11] Dwivedi, Y. K., et al. (2021). Artificial intelligence (AI): Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. *International Journal of Information Management*, 57, 102-116. https://doi.org/10.1016/j.ijinfomgt.2019.08.002

[12] S. Slid, "5 Types of Welding Joints Explained," 5 March 2023. [Online]. Available: https://fractory.com/types-of-welding-joints/