Team 514: Safe CNC

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Abstract

The abstract is a concise statement of the significant contents of your project. The abstract should be one paragraph of between 150 and 500 words. The abstract is not indents.

Keywords: list 3 to 5 keywords that describe your project.

Acknowledgement

These remarks thanks those that helped you complete your senior design project. Especially those who have sponsored the project, provided mentorship advice, and materials. 4

- Paragraph 1 thank sponsor!
- Paragraph 2 thank advisors.
- Paragraph 3 thank those that provided you materials and resources.
- Paragraph 4 thank anyone else who helped you.

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Notation

A17	Steering Column Angle
A27	Pan Angle
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AAA	American Automobile Association
AARP	American Association of Retired Persons
AHP	Accelerator Heel Point
ANOVA	Analysis of Variance
AOTA	American Occupational Therapy Association
ASA	American Society on Aging
BA	Back Angle
BOF	Ball of Foot
BOFRP	Ball of Foot Reference Point
CAD	Computer Aided Design
CDC	Centers for Disease Control and Prevention
CU-ICAR	Clemson University - International Center for Automotive Research
DDI	Driver Death per Involvement Ratio
DIT	Driver Involvement per Vehicle Mile Traveled

	Difference between the calculated and measured
Difference	BOFRP to H-point
DRR	Death Rate Ratio
DRS	Driving Rehabilitation Specialist
EMM	Estimated Marginal Means
FARS	Fatality Analysis Reporting System
FMVSS	Federal Motor Vehicle Safety Standard
GES	General Estimates System
GHS	Greenville Health System
H13	Steering Wheel Thigh Clearance
H17	Wheel Center to Heel Pont
H30	H-point to accelerator heel point
HPD	H-point Design Tool
HPM	H-point Machine
HPM-II	H-point Machine II
HT	H-point Travel
HX	H-point to Accelerator Heel Point
HZ	H-point to Accelerator Heel Point
IIHS	Insurance Institute for Highway Safety
L6	BFRP to Steering Wheel Center

Chapter One: EML 4551C

1.1 Project Scope

1.1.1 Project Description

The objective of this project is to assess the safety risks the computer numerical control (CNC) machine poses and implement effective safeguards that align with industry standards to protect users and eliminate the need for personal protective equipment (PPE). Team 514 was tasked with safeguarding the CNC machine that is located in the Department of Mechanical Engineering's senior design (SD) room at the FAMU-FSU College of Engineering (COE). The CNC machine is an automated machining device that manufactures metal and plastic parts. The model is Carbide 3D's Shapeoko3 CNC router. The current conditions of the CNC machine and shop environment do not allow the safe use of the machine and present a hazard to users and bystanders.

1.1.2 Key Goals

- To address these safety challenges, the project focuses on designing and implementing functional safeguards for the CNC machine in the SD room. These safeguards aim to achieve the following interconnected objectives: Ensure safe operating conditions for users and bystanders near the CNC machine.
- Protect users from running parts, potential projectiles, and biohazards generated by the CNC machine's normal operation.
- Develop an intuitive user interface and safeguard system to minimize the potential for user error.

To achieve these goals, Team 514 will engineer safeguards that protect the user. The intent is to exceed these primary goals, but these will ensure that the basic needs presented by the sponsor are met.

1.1.3 Market

While the project's focus is on safeguarding the CNC for the SD room, the developed product can have applications beyond this project. Secondary markets will include:

- Machine shops
- Manufacturing companies (i.e. Danfoss, Hass Automation, Trumpf, BMW, etc.)
- Hobbyists and enthusiasts with personal machines
- Colleges and universities with engineering programs
- Carbide 3D, the manufacturer of the Shapeoko 3 CNC router

Markets for this project are not as easily identifiable because of the tailored needs of the sponsor. However, the final product and its technologies could interest these groups upon successful safeguarding.

1.1.4 Assumptions

To ensure the project remains focused and within the defined scope, Team 514 has identified assumptions that will help in the development of the CNC safeguards.

These assumptions are as follows:

- Users will have a general understanding of proper CNC use.
- The machine will be properly maintained.
- The machine will be stationary while in use.
- Adequate power will be provided and accessible.

- A debris vacuum and waste container will be provided but integrated appropriately.
- PPE will not be required or used by the operator or bystanders.
- The sponsor will provide sufficient space in the SD room for the machine's operation and the implementation of.
- Only compatible materials will be used with the machine (i.e. safeguards will not stop hazards caused by unsupported materials).
- Safeguards will use the same tools as supplied by Carbide 3D.
- Instructors will not need to provide additional training an using the safeguards.

By following these assumptions, team 514 will stay within the project scope.

1.1.5 Stakeholders

The stakeholders of this project are Dr. Shayne McConomy, Dr. Eric Hellstrom, the FAMU-FSU COE, and the COE machine shop (see Table 1). Dr. McConomy has invested interest in improving the shop for students, both in its safety and the tools available to students. Dr. Hellstrom is an advisor on the project and invests time and energy into the team's research and design process. Outside of the assigned points of contact, future students of Dr. McConomy and the FAMU-FSU College of Engineering will benefit from the success of this project. The project will broaden the range of tools available for future senior design projects and allow for greater creativity.Dr. Hellstrom is an advisor on the project and invests time and energy into the team's research and design process.

Table 1: Stakeholders

Sponsor	Dr. McConomy
Advisor	Dr. Hellstrom
Monetary Stakeholder	FAMU-FSU College of Engineering
End User	Students

1.2 Customer Needs

The team interviewed the project sponsor, Dr. McConomy, about customer needs for safeguarding the CNC machine. The following table organizes the questions asked to the customer concerning the CNC machine, as well as their responses and the interpreted need.

Table 2: Customer Needs

Question:	Response:	Interpreted Need:
What is your biggest goal for this project?	Follow the top three methods of the hierarchy of safety: elimination, substitution, and engineering controls.	PPE is not factored into the safety rating of the product. No administrative controls or PPE.
What features are most important to you?	Natural understanding of how to use the product, intuitive, not need someone to show	Users are able to understand how to use the safeguards and stay safe.

	them how to stay safe with the machine.	
What functions are fundamental for the product?	Dust and chip mitigation, impact protection (projectiles), accidental contact, protect collet from improper bits.	Contain particle matter, remove opportunities for contact during use, prevent machine misuse.
How do you want the safeguard to look?	No particular aesthetics, shouldn't interfere with operations, no extreme wiring (cable management), accommodate for vacuum hose to move with the machine	Visual design is not a priority, but the machine will operate freely and efficiently. Wiring is kept neat to prevent tangling or interference. Allows option for vacuum.
How frequently is the machine used?	Won't be used very much in off season, daily in regular season. Can run for 2+ hours at a time. Would like to have the machine shut off if no one is present in the senior design room.	During busy project seasons the machine will be used frequently. Implement safety shutoff if there isn't anyone in the room.

How would you prefer to open the safeguard to access the CNC machine?	Think of ways that you have to load materials into the machine (check for max volume from manufacturer specifications) *Cabinet door from McConomy's old 3d printers were annoying, couldn’t reach everything he needed to.	Ease of access, size and weight of materials. Consider potential risks when loading like accidental activation.
What injuries do you expect that could occur while using the CNC machine?	Hands/fingers, eyes, chip-related cuts, (brush hanger to remind students to use brush, etc.)	Most common injuries are related to particle matter or misuse.
What materials are used in the CNC machine by the students?	Aluminum, wood, plastics (acrylic, carbonate, plexiglass). Way to stop if wrong material is inserted (steel)	Safeguard against incorrect material use in the machine. The machine will not start if there is an unacceptable material on the cutting surface.

How often would the machine be serviced?	Once a semester or year. Fixes should not take longer than a day per semester. Isolating vibrations that could break our things. Anything that has the potential to break should be easily replaceable/fixable with minimal tools (same hardware as carbide 3d uses)	Easily accessible for maintenance. Anything that may break will be easily and quickly replaceable. Standardize tooling. Isolate excessive vibrations caused by the machine. Ergonomic and easy to move.
How accessible should it be (should safety override quick use/function)?	Yes	Safety overrides use regardless of machining stages.
How automated do you want the safeguards to be? (Automatic vs manual)	Not necessarily automated or manual but self-explanatory	Safeguards will not require administrative controls such as training.

1.2.1 Explanation of Results

During the interview with the customer, questions were asked to better understand what is wanted from the product. Expected/common injuries with the machine? Service schedule?

Expected materials used with the machine? Expected accessibility? Moreover, whether aspects should be automated or not?

The customer emphasized that PPE should not factor into the product's design, particle matter should be managed, and misuse (such as incorrect material usage) should be prevented. The product's aesthetics should be deprioritized compared to the functionality of the product. The machine should expect a high frequency of use for about half of the year. A requested function was auto-shut-off when no one was present to operate it. Safety is the top priority, and safeguards should not require training.

1.3 Functional Decomposition

1.3.1 Hierarchy Chart

Functional decomposition breaks down the overall function of a system into smaller parts. A hierarchy of functions (see *Figure 1)* was created and is explained in detail. The hierarchy shows the connection between all the systems and subfunctions down to their fundamental functions. To outline the relationship between each system and subfunction, a cross-functional matrix has been included.

The information used for the functional decomposition came from the question-and-answer session with the customer, Dr. McConomy. The insights provided by him were used to create the functions for the safeguard and will help guide future decision making.

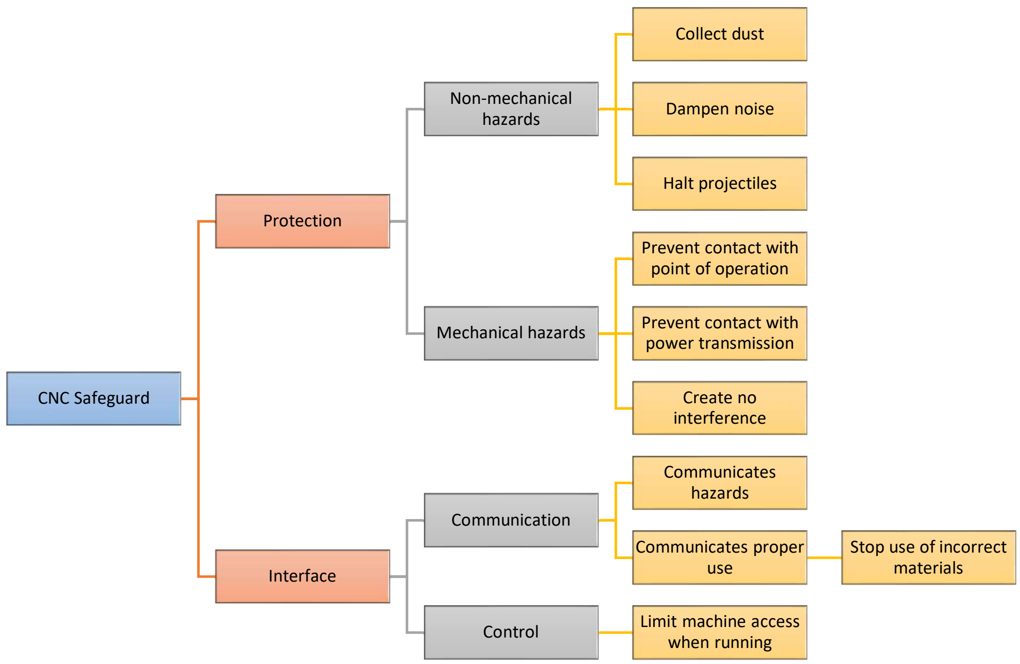

Figure 1: Functional Decomposition Hierarchy Chart

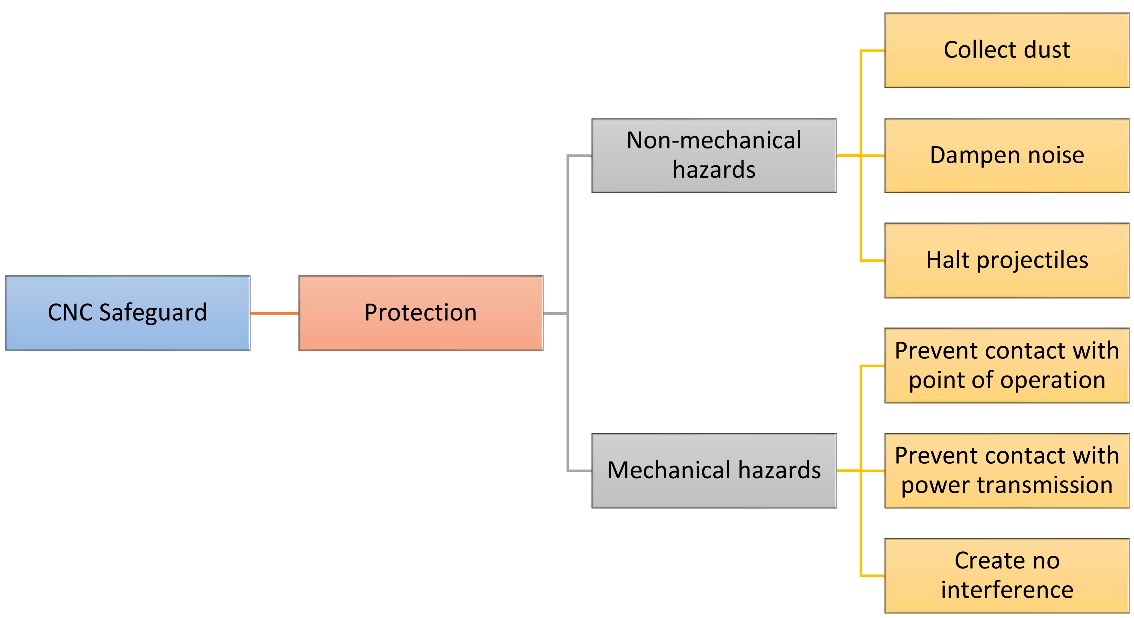

Figure 2: Functional Decomposition Hierarchy Chart for Protection

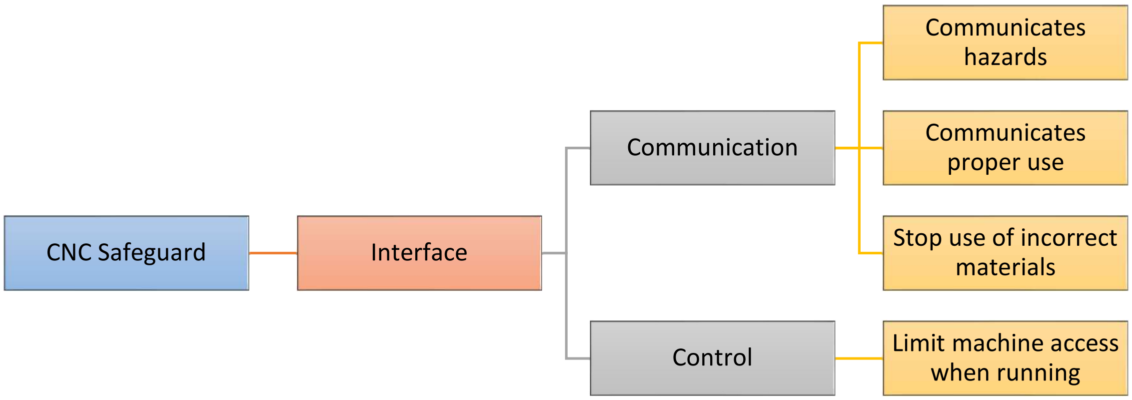

Figure 3: Functional Decomposition Hierarchy Chart for Interface

1.3.2 Explanation of Results

The safeguard has two main systems: protection and interface. The protection system is based on the need for no PPE during machine use. This requirement was split into two categories of protection functions: non-machine hazards and machine hazards.

The first protection function is to protect users from non-machine hazards. There are three categories of non-machine hazards the user would be exposed to: dust/fine particles, projectiles, and noise. To manage the dust and fine particles, the safeguard should be able to collect whatever byproducts are generated while the CNC machine runs. Projectiles cannot be collected due to their size and speed. To manage projectiles, there must be a shield between the point of operation and the user to prevent contact. Finally, the last byproduct is noise. Sound dampening will help reduce machine noise in the room.

The second protection function is to protect users from mechanical hazards. Mechanical hazards include the point of operation (such as rotating bits) and power transmission components (such as moving belts). These protection functions should not interfere with the point of operation and power transmission components as well.

The second system is the interface, how the user is interacting with the safeguard and the CNC machine. Interface functions are categorized into communication and controls. For communication, the interface should communicate potential hazards and proper use to the user. An example of proper use is making sure the correct materials are being used in the CNC machine. For controls, the user should have limited access to the machine while it is running.

1.3.3 Connection to Systems and Smart Integration

The following table (see *Table 3*) organizes the subsystems of the project and shows their relationship to each of the functions. The columns are the systems, and the rows are the functions. The functions associated with each of these systems are marked with an “X”.

Table 3: Functional Decomposition Cross Reference Table

Function	**System**		
	Protection	**Interface**	**Total**
Collect dust	X		1
Dampen noise	X		1
Halt projectiles	X		1
Prevent contact with point of operation	X		1

Prevent contact with power transmission	X		1
Create no interference	X	X	2
Communicates hazards		X	1
Communicates proper use		X	1
Limit machine access when running	X	X	2
Total	7	4	11

The protection system has more fundamental functions than the interface system. Safety guidelines from the Occupational Safety and Health Administration (or OSHA) specify that physical blockades and barriers are the best for preventing injury. The main objective of the project is to keep the user of the CNC machine safe, which will be mainly accomplished by physical protection. The interface system is necessary for the user to interact with the physical safeguards.

There will be crossover and interaction between the systems of the product. Proper integration of the systems is necessary to provide safety to the user. Both protection and interface systems will function to not interfere with the normal operation of the machine or limit access to the machine while it is running. Ways of integrating these systems to best fulfill the objectives of the project will be explored so that protection and interface work together to make the product simple, intuitive, and – above all – safe for users.

1.3.4 Action and Outcomes

The protection subfunctions are critical in this project. The function of protecting the user from dust and particles produced by the machining process will be completed by collecting the dust particles once they are emitted, transferring them away from the user, and storing them where they will not become a hazard. For larger chips and projectiles, the safeguards must provide a force great enough to counteract and deflect the forces of the projectiles to keep them from impacting the user. The safeguards will suppress noise produced by the CNC machine to an acceptable level to protect users from hearing damage.

Preventing injury to users due to contact of the body with the mechanical functions of the machine, such as drill bits and moving belts, is to be achieved by stopping careless human action and thoughtless mistakes. The safeguards will block any human contact with these mechanical hazards presented by the CNC machine during its regular functioning.

The system is responsible for communicating hazards with the user. Before someone can use the CNC machine, critical information will be passed to the user regarding proper use and the dangers presented by incorrect use. The overall interface will prevent all access to the machine while it is running. For both protection and interface systems, function execution will not interfere with the machine's processes.

1.4 Target Summary

1.4.1 Introduction to Targets

Establishing clear targets and metrics is important for tracking progress and ensuring each function is successfully met. Based on the functions in the hierarchy chart (see Figure 1), a list of targets and metrics were mapped to each function. This helps validate that the design meets the functional needs. A summary of the full list of targets and metrics is listed in Table C-1 in Appendix C.

1.4.2 Critical Targets

From the list of functions, three critical functions were selected (see Table 4). These critical functions were selected based on the functional decomposition cross reference table totals (see Table 3) and the core objective of the project.

Table 4: Critical Targets

Function	**Target**	**Metric**
Halt Projectiles	≥ 4,000 N	Impact force
Create no interference	Fully operable	User observation
Limit machine access while running	2 ± 0.2 mm (about 0.08 in)	Clearance

For the function "Halt Projectiles," the target is to withstand up to 4,000 N. The goal is for the safeguard to withstand and halt a projectile exerting up to 4,000 N of force. This means the material must absorb the projectile's energy without failing. The target was derived from OSHA standards for hard hats. To validate this target, the material will undergo impact testing in the materials lab at the College of Engineering.

For the function “Create No Interference,” the target is for the machine to be fully operable. The goal is for the safeguard to not be an obstacle to the machine when it runs. The target was derived from user observation. To validate this target, the machine will be observed during trial runs with the safeguard in place.

For the function “Limit Machine Access When Running,” the target is for any opening used for accessories, or cables to have the gap between the object and safeguards to be approximately 2 ± 0.2 mm. This target was derived from the average thickness of an adult human finger, approximately 16-20 mm. The goal is to prevent users from inserting fingers or objects into the machine while it’s running. To validate this target, any gaps will be measured with a caliper and tested by a user while the machine is powered off by attempting to insert a finger.

1.4.3 Non-Mechanical Target and Metrics

For the function “Collect Dust,” the target is for particulate levels to be under 5 mg/m^3. The goal is to collect dust to keep the senior design room air particulate level below the target. The target was derived from OSHA standards. To validate this target, an air quality monitor will be used before, while, and after the machine runs.

For the function “Dampen Noise,” the target is for noise levels to be under 85 dB. The goal is to dampen noise to keep the sound levels below target in the senior design room. The target was derived from OSHA standards. To validate this target, a decibel meter will be used while the machine is running.

1.4.4 Mechanical Target and Metrics

For the function “Prevent Contact with Point of Operation While Running,” the target is for any opening to the safeguard while it is running to be 0 +/- 0.5 mm (about 0.02 in). The goal is for the safeguard to prevent access to the point of operation such as the bit while the machine runs. The target was derived from user observation. To validate this target, openings to the safeguard once it is closed will be measured with a caliper.

For the function “Prevent Contact with Power Transmission while Running,” the target, goal, derivation, and validation is the same as the function “Prevent Contact with Point of Operation While Running.”

1.4.5 Interface Targets and Metrics

For the function “Communicates Hazards,” the target is for users to know the potential hazards associated with running the machine. The target was derived OSHA standards for machines. To validate this target, users of the machine will be surveyed.

For the function “Prevent Use of Incorrect Materials,” the target is for users to only use the correct materials in the machine. The goal is to make sure no new hazards will be created from using improper materials. The target was derived from the machine’s operating manual. To validate this target, users of the machine will be surveyed.

1.4.7 Targets and Metrics Beyond Functions

The targets and metrics that go beyond the functions listed in the hierarchy chart are listed here. These include managing cables, wearing PPE, disassembling quickly, and limiting vibrations.

For the function “Manage Cables,” the target is to limit the visibility of cables. The goal is to make sure all cables stay out of the way of the working space. The target was derived from user observation. To validate this target, the sponsor’s opinion will be surveyed.

For the function “Wearing PPE,” the target is for the safeguard to meet OSHA standard 1910 so that users are still safe without wearing PPE. This target was derived from a customer need. To validate this target, the machine will be run and observed for additional safety hazards that have not been safeguarded to the OSHA standard 1910.

For the function “Disassemble Quickly,” the target is for the safeguard to be disassembled in less than one day. The goal is for the safeguard to be easily broken down to decrease the machine maintenance downtime. The target was derived from user observation. To validate this target, the disassembly of the machine will be timed.

For the function “Limit Vibrations,” the target is for the displacement of the machine safeguard to be less than 5 ± 0.5 mm. The goal is for the safeguard to be stable and not move around while the machine is running. The target was derived from user observation. To validate this target, the safeguard will be measured from its original position after the machine runs.

1.5 Concept Generation

1.5.1 Introduction

The primary methods used in developing ideas were brainstorming, crap Shoot and the Morphological Chart techniques. Initially, all group members brainstormed solutions individually, generating a wide range of ideas without limits—many of which being overzealous, found in Appendix D (100 Concepts for CNC safeguarding). However, some ideas emerged repeatedly amongst team members, sticking out as the most intuitive design concepts. These repeated ideas were further developed by analyzing project needs and functions. Expanding on the fundamental conceptual ideas, a morphological chart was created, and the medium and high-fidelity concepts were fleshed out by taking the best concepts and combining them. The morphological chart can be found in Appendix E (morphological chart).

1.5.2 High Fidelity concepts

Table 5: High Fidelity Concepts Chart

Idea	Door type	Lock mechanism	Vibrations dampening method	Interface #1	Interface #2
High Fidelity concept #1	Hatch	Lock valve (hydraulic lock)	Rubber feet on base	Safeguard activated signal lights	N/A
High Fidelity concept #2	Roll cover	Latch	Secure to table	Safeguard activated signal lights	N/A
High Fidelity concept #3	Oven door	Lock valve (hydraulic lock)	Rubber feet on base	Mounted interior lights	N/A

Hatch opening CNC safeguard will be a cube shaped safeguard made from an undecided material. The access point to the safeguard will be the front and top panels lifting upwards with the assistance of hydraulics. The router will sit inside the safeguard fully on top of rubber feet to minimize vibrations. To secure the hatch so that the user is unable to access the machine, the hydraulics will lock and there will possibly be an additional latch lock for extra security. An emergency stop button will be included as well as signal lights to communicate to the user.

The roll covers safeguard will be a Tonneau cover style opening, completely enclosed. The method of securing the opening is a latch lock towards the bottom of the safeguard, this removes machine access while it is running. The safeguard may be secured to the table it's sitting on to reduce the potential for vibrations by increasing the total mass. There will be an emergency stop button and signal lighting to communicate to the user.

A final high-fidelity concept is a solid box with an oven door opening that is assisted by hydraulics. The hydraulics will lock so that the user is unable to access the router. The safeguard may sit on rubber feet to reduce vibrations. There will be lights mounted to the inside of the safeguard to provide visibility to the user and will also act as communication to the user. There is a potential for the CNC router to sit on tracks and may slide out of a drawer for easy access by the user.

1.5.3 Medium Fidelity Concepts

Table 6: Medium Fidelity Concepts Chart

Idea	Door type	Lock mechanism	Vibrations dampening method	Interface #1	Interface #2

Medium Fidelity Concept #1	Bifold door	Latch	Vibration absorbing base	Safeguard activated signal lights	Drawer
Medium Fidelity Concept #2	Sliding door (vertical)	Bolt lock	Stiff vibration absorbing springs	Safeguard activated signal lights	Drawer
Medium Fidelity Concept #3	Sliding door (horizontal)	Bolt lock	Vibration absorbing base	Safeguard activated signal lights	Drawer
Medium Fidelity Concept #4	Double sliding door (horizontal)	Bolt lock	Vibration absorbing base	Safeguard activated signal lights	N/A
Medium Fidelity Concept #5	Reverse oven door	Lock valve (hydraulic lock)	Rubber feet on base	Mounted interior lights	Drawer

Medium Fidelity #1: The shield has a bifold door similar to a closet door that opens to access the machine. It locks with a latch. A vibration-absorbing base goes inside the shield and sits under the machine. The machine also sits on top of a drawer that rolls out to make it easier to access.

Medium Fidelity #2: The shield has a slide door that slides up to access the machine. It locks with a bolt. The bottom of the shield sits on springs to absorb vibrations. The interface has signal lights to communicate to the user. The machine also sits on top of a drawer that rolls out to make it easier to access.

Medium Fidelity #3: The shield has a track door that slides open to the right or left to access the machine. It locks with a bolt. A vibration-absorbing base sits under the shield. The interface has signal lights to communicate to the user. The machine also sits on top of a drawer that rolls out to make it easier to access.

Medium Fidelity #4: The shield has a double track door with doors that open to the right and left to access the machine. It locks with a bolt. A vibration-absorbing base sits under the shield.

Medium Fidelity #5: The shield has a reverse “oven” door with hydraulics that opens upwards to access the machine. It locks with lock valves attached to the hydraulics. Rubber feet connect to the shield to absorb vibrations. Lights are mounted inside the shield so the user can see better when accessing the machine. The machine also sits on top of a drawer that rolls out to make it easier to access.

1.6 Concept Selection

1.6.1 Introduction

Concept selection uses a rigorous process to narrow the top eight concept ideas to one final selection. House of Quality, Pugh, AHP (Analytic Hierarchy Process), and Final Rating were the matrixes used to select. These matrixes are described in detail below.

Instead of using the selection process for each individual feature (such as door types, latches, vibration controls, etc.), the selection process was used on fully thought-out concepts with a list of associated features. Using a selection process for concepts over features has a list of benefits and disadvantages. The disadvantage is that it is less rigorous. However, the advantage is that it saves time. The other justification is that the concepts are relatively simple and are easy to compare and rank.

1.6.2 House of Quality Results

The House of Quality gave the relative weight of each engineering characteristic. Among the most important were limiting machine access, preventing contact with the point of operation, and preventing contact with power transmission while running. These are unsurprising results, as the machine itself and its points of movement and operation present the largest safety concern with which the project is dealing with. Any access to the router while it is machining a part is cause for hazard, as objects and body parts could get caught in these moving parts and injure the user. The engineering characteristics with the least weight included disassembly time, displacement caused by vibrations, and dampening the noise caused by the machine while it runs.

The house of quality is intended to generate the proper evaluation criteria for the Pugh and Analytic Hierarchy Process. All criteria are important, but since there can be a lot of criteria with some overlap, not all are significant in determining the quality of the concept ideas. The group decided that no criteria would be cut out even though specific criteria were weighted more significantly because this project did not have too many criteria, making each critical to evaluating the concepts.

1.6.3 Pugh Chart Results

The Pugh Chart is a tool to compare engineering characteristics of a datum – the baseline for comparison – against the top eight concept designs. The datum was chosen to be the Carbide 3D Nomad Enclosure. Each of the team's concepts are rated to be better (+), worse (-), or satisfactory (S) at the characteristic compared to the datum. The scores are then summed up for an overall rating.

For the second iteration, concept 3 (High Fidelity Concept #3: Oven Door) from the first round was selected to be the new datum. The whole process was repeated with four of the top concepts from the first iteration (roll cover door, vertical sliding door, horizontal sliding door, and double sliding door). After the scores were summed up for an overall rating, the top three concepts were chosen. The concept dropped was the roll cover door.

1.6.4 AHP Results

The Analytic Hierarchy Process (AHP) is a tool to rank the importance of engineering characteristics against each other. Throughout the process, each characteristic's weight is calculated. Next, each of the top three design concepts from the Pugh results are ranked against each other on how well they accomplish the characteristics.

The consistency ratio is 0.974. A consistency ratio of less than 0.1 (or 10%) is considered acceptable. This indicates that this AHP comparison is not reasonably consistent. This is due to the engineering characteristic #8: limit access to the machine when running. Because this is such an important characteristic for safety, it was consistently rated higher compared to almost all other characteristics. This resulted in a higher than desirable consistency ratio.

Table 7: AHP Consistency

Avg Consistency	Consistency index	Consistency Ratio
28.495	1.500	0.974

1.6.5 Final Selection

The final selection process uses a structured evaluation matrix to score each design concept based on weighted engineering characteristics. This generated a final score for each concept. The concept with the highest alternative value was selected. This process ensures that the chosen concept design aligns with the project's needs.

Table 8: Final Selection Alternative Values

Concept	Alternative Value
Medium Concept #2, Vertical Sliding Door	0.302
Medium Concept #3, Horizontal Sliding Door	0.338
Medium Concept #4, Double Sliding Door	0.270

As seen in Table 8, Medium Concept #3 with the horizontal sliding door had the highest alternative value at 0.338. In Figure 4 below there is an isometric view of the horizontal sliding door concept with the highest alternative value.

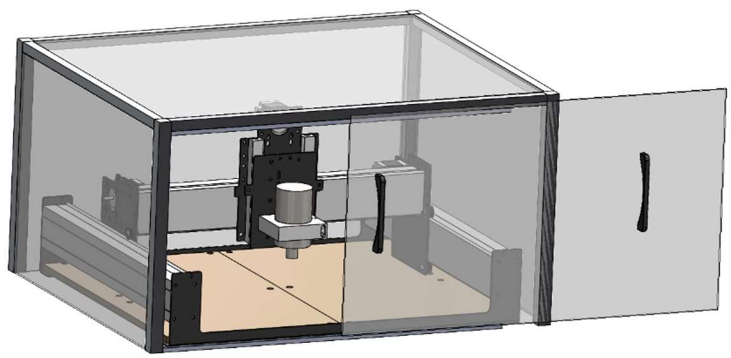

Figure 4: Horizontal Sliding Door Concept

1.8 Spring Project Plan

Chapter Two: EML 4552C

2.1 Spring Plan

Project Plan.

Build Plan.

Appendices

Appendix A: Code of Conduct

1. Mission Statement

Team 514 is dedicated to developing a professional, respectful, and collaborative environment that upholds the highest standards of integrity and accountability. Our team's objective is to guarantee that all members contribute to the project's objectives by requiring punctuality, dedication, and innovation throughout the project, and supporting each other with active communication and participation. To guarantee the success of Team 514's project and the personal development of each team member, we are committed to a culture of mutual support, open communication, and constant improvement by following this code of conduct.

2. Outside Obligations

Amanda Garcia-Menocal

University Obligations: Tues & Thurs 3:30 PM – 7:45 PM

Work Obligations: Mon, Wed, Fri 6:30 AM – 3:00 PM, Tues & Thurs 6:30 AM – 3:00 PM (Hours are Occasionally Flexible)

Personal Obligations: Mon 3:30 PM – 5:00 PM, Wed 6:00 PM – 7:30 PM

Carlton Walker

University Obligations: Mon & Wed 8:00 AM – 12:30 PM, , Tue & Thurs 12:30 PM - 7:45 PM,

Work Obligations: Will have work schedule in February.Malik

University Obligations: Mon, Tue, Wed, Thurs 11:00 AM – 12:15 PM, Tue & Thurs 3:30 PM – 7:45 PM

Work Obligations: Will have work schedule next week.

Sam Byers

University Obligations: Mon & Wed 8:00 AM – 9:15 AM and 11:00 AM – 12:15 PM, Tues & Thurs 11:00 AM – 12:15 PM and 3:30 PM – 7:45 PM

Shelby Gerlt

University Obligations: Tues & Thurs 11:00 AM – 7:45 PM.

Work Obligations: Flexible, changes weekly.

Personal Obligations: Sun 8:00 – 12:00 PM

3. Team Roles
    a. Test Engineer – Shelby Gerlt
    b. Electrical Engineer – Malik Grant (electrical)
    c. Supply Chain Engineer – Sam Byers
    d. Design Engineer – Carlton Walker (development & prototyping (CAD))
    e. Structural Engineer – Amanda Garcia-Menocal
4. Communication
    a. Team members will use Microsoft Teams, emails, Zoom, and text messaging to keep in contact. Texts and phone calls are for rapid and urgent communication. Email response time should be kept within a 6-hour window to ensure email delivery and transaction professionalism, and group messages should be acknowledged within 3 hours on normal workdays. Each team member is expected to have a working and regularly checked means of communication.

b. Any reason for being tardy or absent from team events or meetings should be communicated to the whole team within 36 hours (about 3 days) prior to the absence, giving ample time to account for the absence.

c. If unable to notify within the 36-hour time frame, reasoning must be reasonably urgent as agreed upon by 4/5 of the team.

d. Tasks will be documented, communicated, and distributed during meetings via Microsoft Teams. All documents will be uploaded and stored within the Teams files manager.

5. Dress Code

a. The project location is expected to be within the College of Engineering, so we will abide by the college's dress standards at a minimum. But there is no required dress code for team meetings.

b. During group presentations, a strict business formal dress code will be enforced.

c. For sponsor and adviser meetings the dress code is expected to be business casual unless specified otherwise.

6. Attendance Policy

a. The group will meet in person at least once per week to work on assignments or discuss a plan for future assignments.

b. Attendance to group meetings is required.

c. Any reason for being tardy or absent from team meetings should be communicated to the whole team within 36 hours (about 3 days) prior to the absence, giving ample time to account for the absence.

d. If unable to notify within the 36-hour time frame, reasoning must be reasonably urgent as agreed upon by 4/5 of the team.

e. If a group member is absent from a meeting without notice or the reasoning is not justified, the team member will be given a warning.

f. Three absences from group meetings will result in a formal discussion with all group members about punctuality and attendance.

g. Four or more absences will result in a meeting with the advisor/sponsor.

7. Group Notification Procedure

   a. The team will communicate primarily through Microsoft Teams.

   b. Alternate communication will be through text messages for emergencies.

   c. Organization of team meetings, all files, and remote meetings will be channeled through Microsoft Teams.

8. Meeting Etiquette Standards

   a. Team members are expected to maintain an appropriate appearance for meetings with the advisor, the sponsor, etc.

   b. Team members are expected to refrain from being under the influence under any circumstance during meetings.

9. Procedure Prior to Meetings with Advisor or TA's

   a. Use all available resources for research and preparation, including fellow team members and other design teams.

   b. If it is an internal conflict that is impacting the project's progress, the group should discuss and create a plan of action to solve and prevent further conflict. If the conflict cannot be resolved internally, someone from the team will contact the advisor.

   c. Hold a team meeting to discuss and create a set of questions that need to be addressed with the advisor or TAs.

10. Procedure to Contact Advisor

a. One person from the team will be selected to contact the advisor by email and copy the rest of the team onto the message.
b. If the advisor is met in person, a summary of the meeting should be included.

11. Preferred Outcomes of Meetings with Advisor
    a. The advisor will act as an impartial party to ensure that no team bias is overlooked in the issue being discussed.
    b. All parties will come to an understanding and move forward based on the advisor's input and respond professionally.
12. Amendment Procedure
    a. Amendments will be proposed as outlined in this document.
    b. Arguments for the amendment will be presented, along with arguments against the amendment and/or for an alternative amendment.
    c. Votes will be held on the Teams communication platform for or against the amendment, and a 4/5 decision must be reached.
    d. Repeat a – c until solution is reached.
    e. Failure to effectively and timely resolve an issue that prevents the team from moving forward, an advisor will be brought in as above mentioned.
13. Statement of Understanding

"We, Senior Design Team 514, hereby state that we understand the contents of this Code of Conduct and, having signed below will uphold our duties to our team members and sponsor to our utmost ability. We agree that this document is fair to all members and will aid in the execution of this project."

Signed:

X Amanda Garcia-Menocal Date: 09-10-2024/01-07-2025

X Carlton Walker Date: 09-10-2024/01-07-2025

X Malik Grant Date: 09-10-2024/01-07-2025

X Samuel Byers Date: 09-10-2024/01-07-2025

X Shelby Gerlt Date: 09-10-2024/01-07-2025

Appendix B: Functional Decomposition

Appendix C: Target Catalog

Table C-1: *Target Catalog*

Function	**Target**	**Metric**
Collect Dust	< 5 mg/m^3	Particulates
Dampen Noise	< 85 dB	Decibel
Halt Projectiles	≥ 4,000 N	Impact force
Prevent contact with point of operation while running	0.5 ± 0.5 mm (about 0.02 in)	Clearance
Prevent contact with power transmission while running	0.5 ± 0.5 mm (about 0.02 in)	Clearance
Create no interference	Fully operable	User observation
Communicated hazards	Customer knows potential hazards	User opinion
Prevent use of incorrect materials	Customer uses proper materials	User opinion
Limit machine access while running	2 ± 0.2 mm (about 0.08 in)	Clearance
Manage cables	Visibility of wires/aesthetics	Sponsor opinion
Wearing of Personal Protective Equipment	OSHA standard 1910	Safety Rating

Disassemble quickly	< 1 day	Time
Limit vibrations	5 ± 0.5 mm	Displacement

Appendix D: Concept Generation

100 Concepts for CNC safeguarding

1. Curtain-type shield that is closed around machine while in use. Utilizes a heavy plastic that can deflect projectiles away from users.
2. Removable containment box that is locked into place before machine operation.
3. Hair salon-style debris collection vacuum with a fan that blows the debris to one area of the enclosure and collects it all without having to follow the router.
4. A bio-mechanical robot that performs all the dangerous functions of inserting parts, changing bits, etc.
5. A smart robot with voice control to initiate functions (like a phone bot with pre-programmed commands) and responds with safety instructions as well as communicates what safeguards need to be activated before the machine can run.
6. Control panel programmed to only allow machine operation when all safeguards are active (has representative lights that show when safeguards are active).
7. Manual locks on separation device (door) that have a sensor which only allows machine operation if locks are engaged.
8. Automatic locks on separation device (door) which auto locks when machine is running (preventing access).
9. Lock dependent power. The machine only has power when locks are engaged. If locks are disengaged while machine is running, power is cut.
10. A drop-down guard with enough room for material to be put in the workspace but not enough room for limbs etc.

11. Proximity sensor device that must be on your person/someone. The device has a heat sensor where if the temperature reading gets below 80 deg F the machine will shut off or if the device gets further than close range (outside the room) the machine will shut off the machine.
12. AOPD/laser light curtain system. If an object passes through the AOPD that is surrounding the machine automatically shuts off.
13. Alarm system for when the area gets too hot. If the area containing the machine gets above a certain temperature, machine operation stops and sounds an overheating/fire warning.
14. Hand gloves integrated with the walls of machine container to interact with the machine/parts so no contact injuries can occur with sharp object/pinch points.
15. Mini van style door that slides open and close and has a viewing window.
16. Drone ascends holding the machine while its running to separate users from the machine.
17. Location tracking device that can sense projectiles and catch/deflect them away from users. Looks like a baseball glove and catches flying pieces.
18. Room motion detection: if enough time passes with no movement the machine automatically shuts off.
19. Chainmail covers a frame that can be pulled back/off to access machine and locked down to stop projectiles.
20. Mandatory login to use the machine, if it is the first time using it (or it's been 6 months), presents a training/tutorial video on the safeguards and user must answer questions regarding machine safety.

21. Vibration Absorber: Styrofoam-like material the machine sits on, absorbs vibrations and prevents the machine from moving.
22. Simple Plexiglass Frame: Polycarbonate sheets that slide into aluminum frame inserts. Opening the front sheet slides out.
23. Hydraulic Hood: A hydraulic capsule that operates like a car hood that goes over the entire machine. The machine will not start until the hydraulic capsule is closed which triggers the pressure sensors.
24. The "On" Sensor: A sensor that is connected to the machine and receives a signal when the start button is pressed. Once the machine is on, the latch to the opening locks.
25. The Box: A fully enclosed box that goes over the machine. To access the machine, the box is just taken off.
26. Stickers: Sticker signs go on the outside of the hood. The signs display a table of materials to use and not use.
27. Room Sensor: A heat sensor that senses the heat signatures of people in the room. If no one is present in the room, the machine automatically shuts off.
28. The Fabric Dome: A tough ripstop fabric that drapes over a wire spherical frame with an elastic along the bottom to keep it closed tight. To access, the fabric is just lifted.
29. Mounted Lights: Lights mounted inside the shield to illuminate the machine and prevent users from cutting themselves with sharp objects.
30. The Drawer: A rollout that allows the machine to be easily accessed like a drawer. When loaded and ready to run, the platform is rolled back into the shield.

31. The Big Door: A massive door in the front that opens and creates a huge opening to access the machine.
32. The Flat Hydraulic Door: A flat hydraulic door that opens like a reverse oven door.
33. The Garage Door: A collapsible garage door that rolls up on a curved box.
34. Sound Proofing: Sound proofing foam lines the inside of the shield to help reduce noise decibels and vibrations.
35. The One-Two Actuator: Sensors mounted inside the shield sense motion. If the front shield door is closed and the motion sensor is activated, the door locks shut.
36. The Cylinder: Polycarbonate or a similar material is molded into a cylinder. The machine is accessed by a sliding door that rotates around the cylinder and creates a large opening.
37. "**Air Dome**" a multilayer inflatable protective cover to prevent contact, collect dust, and prevent projectiles.
38. 'Steel box' cover to go over the CNC and catch projectile but lacks visibility, dust collection, and is heavy.
39. A plastic-esque enclosure that covers the CNC, made of flexible material but is also thin, will be zipped up in the front to allow access and has a capacitive touch to turn off the CNC if a material impacts the wall and breaks the circuit.
40. Clear flexible clear curtain that hangs from the ceiling, it moves like a shower curtain and is impenetrable to stop projectiles from piercing through.
41. Two mini robot arms with a laser grid that allows the material to be placed but while running stops the user from touching the surface and catches projectiles coming from the machine.

42. An aluminum framed enclosure with an access hatch that opens like an elevator door, the door stops the access of the power button while open. The sides will be made from flexible acrylic to sustain momentary impacts and resist crack propagation. The panels can be replicable and a wood and acrylic hybrid to reduce cost of acrylic and allows visibility and workable material to make holes without potentially shattering the acrylic.
43. A high strength fan that blows projectiles down to the ground while the CNC is on to stop from hitting people and collecting dust. The fan will also be pointed at the user when they come close to prevent contact with the CNC.
44. A mini drone that guards the CNC and prevents people from getting too close by zapping them and catches projectiles with a net before it hits users.
45. A steel frame with a full steel back panel to enclose the CNC, the panels will be made from plexiglass for its visibility and strength.
46. A carbon fiber and glass front shield that can be picked up and placed over the CNC to prevent projectiles. (Like at bank tellers.)
47. A wooden box made from cedar, with bifold doors.
48. A giant pyramid that surrounds the concert to redirect projectiles away and not impact perpendicular to the shield.
49. A diamond glass hybrid shield to resist chipping and scratches.
50. An AI that predicts when the machine will throw a projectile and slows the machine or directs the projectile away from the user and detects if the user gets too close to the machine and moves the machine out of the away to avoid danger.

51. The use of a ‘rain shower’ system that holds all the dust down to stop airborne dust and chip throwing.
52. A camera and microphone system that watches the machine and tells the user to step back if they are too close and will not let the machine turn on if the work piece is not placed properly.
53. Buying a CNC router that has all the necessary safeguards and functions.
54. Purchase an already manufactured enclosure and change it to our specifications, to allow for the vacuum tube to pass through, machine operation while the enclosure is closed and impact resistance to projectiles.
55. A box that goes over the CNC made of wood for price and ease of replacement and a foam pad that the CNC sits on.
56. A circular shower like curtain that moves around the cnc and hangs from a stand that’s on the floor for mobility.
57. The CNC is moved to a dedicated room that only authorized personnel can access.
58. A polycarbonate clam shell locks with 3000 psi when machine is running, pulls vacuum from under the machine, removes most of the oxygen in the environment to prevent fire.
59. Automatic wall made of a steel mesh frame, fitted with tungsten spikes to prevent wandering hands, ascends from the floor around the machine.
60. 7 ft 5 in tall, 5 ft wide robot, AI compatible, will protect user from router by performing all actions, it will block users from projectiles and actively monitor the attached accessories to ensure function.

61. A PPE applier will apply PPE to all persons entering the room, this PPE will not be removeable by the user.
62. A room dedicated to the CNC, completely transparent for 360° view, has a door for access to set router up, the CNC will not run if there is someone in the room, cameras mounted to the outside will ensure there is always someone in the vicinity.
63. Proximity sensors in the room, anyone closer than a specified distance will be stopped from nearing the CNC by an audio warning, if this warning is ignored the CNC will shut off.
64. A steel framed polycarbonate box with a door that opens upwards around the CNC, inside it is equipped with fire extinguishers. A secondary box, much larger, for the user to reside in while the CNC is running, this is where all controls and screens will be, a pressure sensor in the floor will ensure there is a person there, may lock the user in during running.
65. A steel box equipped with a Tonneau cover that automatically opens and closes when necessary.
66. A steel box with a car hood top, it locks when the machine is running, it will seal if fire is detected.
67. When someone enters the room, they are equipped with a personal hazmat suit, air connections will not be necessary.
68. The CNC will be mounted inside a polycarbonate gyroscope that is fitted with a fire suppression system, this will reduce the effect of vibrations.

69. The CNC is mounted in a double lined polycarbonate gyroscope. The inner layer will have 2 mm holes approximately 6 mm apart on the entire surface, the outer layer will be solid. A vacuum will pull debris out of the 2mm holes. If a fire is sensed the 2 mm holes will seal and remove all oxygen from the environment. The gyroscope will lock position, and the top half will open for loading material.
70. A class 4 laser cage, multiple lasers will be mounted around the machine with a separation of 2 mm, this will prevent users from interfering with the machine and will also prevent projectiles from harming users.
71. A tungsten frame mounted with an elongated class 4 laser on 5 sides, secured to the base of the machine.
72. A floor to ceiling enclosure for the CNC, only accessible through a slat at the bottom for inserting material. All other functions will be done with a da Vinci robot that is mounted to the inside of the enclosure.
73. A CNC steel frame, with a polycarbonate sliding door that slides into the rest of the frame for total access, locks when the machine is powered and opens when all function has stopped.
74. A transparent polycarbonate or acrylic enclosure around the CNC. Use a safety interlock mechanism on the doors that automatically locks them when the machine is running. Sliding doors on tracks that move horizontally, and a dust collection system (vacuum) integrated with an auto start/stop function that is synced with the machines operation.
75. A steel and polycarbonate enclosure mounted to the base of the CNC, with outward opening hinged doors with an automatic safety lock, the spindle will be equipped with

sealed brush skirts to direct dust into the vacuum system and to act as an extra barrier to protect from the point of contact.

76. A steel enclosure with a 8 in by 8 in viewing window made of polycarbonate, the door will be a lift-up guillotine style door assisted by gas struts, when the machine is running it will be locked in the down position, an indicator light system to communicate machine status, and a material verification system using RFID or barcode scanners to ensure only approved materials are used.
77. A polycarbonate enclosure mounted on a steel frame with bifold automatically locking doors, mounted on rubberized feet for vibration control, and acoustic foam inside for noise dampening. Enclosure will be equipped with an automatic gas-based fire suppression system. A pressure plate to ensure the user is not leaving the machine unattended. If the router meets an excessive amount of resistance when initiating machining it will automatically shut down all operations.
78. The machine is fully enclosed and a camera inside the enclosure is projected onto a screen that the users can see.
79. Safety training module integration would be on-screen training that ensures users know how to operate safely. Without training no user would be able to use the machine.
80. AI-based safety algorithm – AI that monitors user actions and shuts down the machine in case of unsafe behavior.
81. Swivel arm protective screens – Swivel arms that allow users to adjust screens easily for comfort.

82. Voice-activated safety system – Voice commands to start, stop, or initiate emergency shutdown.
83. Safety routine software – Software that runs checks on all safety mechanisms before starting. The software will check throughout process while machine is running while using an enclosed box over machine.
84. Kevlar-reinforced panels – Panels made of Kevlar for protection against flying debris.
85. Laser Perimeter safety fence. A laser grid surrounding the machine that stops operation when the beam is interrupted by a user or object entering the danger zone.
86. A pressure-sensitive mat placed around the machine that detects when a user is standing too close and shuts off the machine if necessary to prevent accidental contact.
87. A camera system that provides a live feed of the machine's operation, allowing users to monitor the process from a safe distance or from outside the room.
88. Sensors that continuously monitor the machine's temperature and vibration levels to prevent overheating or mechanical failures, alerting the user and pausing the machine if abnormal conditions are detected.
89. Magnetic locks that secure all machine access points while the CNC machine is operational, preventing accidental exposure to moving parts.
90. A remote control system allowing the machine to be operated from a safe distance, removing the need for the user to be physically present near the machine while it is running.

91. A system that prevents the machine from operating unless all safety features (like the enclosure and shields) are securely in place, ensuring the user can't start the machine in an unsafe configuration.
92. A visible laser warning grid projected on the floor around the machine, indicating the safe operating distance to help users maintain a safe boundary without needing PPE.
93. Adjustable guard rails that automatically rise and form a protective barrier when the machine is in operation, retracting once it is safe.
94. Wearable emergency stop devices that allow users to instantly halt the machine with the press of a button, providing an immediate response to unexpected danger.
95. A UV light system integrated into the machine's housing to sterilize surfaces and air within the enclosure, preventing exposure to harmful substances during machine use.
96. Smart gloves equipped with sensors that communicate with the machine, ensuring that it stops immediately if the gloves enter a danger zone or come too close to moving parts.
97. An air curtain that creates a physical barrier of high-velocity air around the machine, preventing debris and particles from escaping into the work area, while still allowing visibility and access.
98. Wireless safety beacons that are placed around the room and alert users when they enter zones with high vibration or noise levels, ensuring they stay in safe areas without needing PPE.
99. An infrared body detection system that tracks the user's body position in relation to the machine, automatically slowing down or shutting off the machine if the user gets too close to danger zones.

100. A system that generates an electromagnetic field around the machine to contain metallic debris or parts that may become dislodged during operation, preventing them from escaping into the user’s workspace.

Appendix E: Morphological chart

Feature(s)	Cover	Lock Mechanism	Cable pass through	Vibration/ sound dampening
Box	Box that comes up and over	Bolt lock to allow operation	Cables passes through the top and sides	'Foam' under the cnc and safeguard
Frame	Box that comes apart	Latch that closes circuit	Cables pass through a channel in the back	'Foam' under the cnc
Hatch	Box that opens like a car's trunk	Bolt lock to allow operation	Cables are run under the safeguard	Rubber feet under cnc
Roll cover	Cover rolls back like a bread container	Lock and key	Cables run through the side not the front or top	Rubber pad under both cnc and safeguard
Slide	Door slides up and out of the way	Bolt lock to allow operation	Cables run through the sides to clear door	Concrete pad under cnc and safeguard

Appendix F: Concept Selection

Table F-1: *Binary Pairwise Comparison*

Binary Pairwise Comparison										
Customer Needs	Criteria Comparison									
	1	2	3	4	5	6	7	8	9	Total
1. Collect Dust	-	1	0	0	0	0	1	1	0	3
2. Dampen Noise	0	-	0	0	0	0	0	0	0	0
3. Halt Projectiles	1	1	-	0	0	1	1	1	0	5
4. Prevent Contact with Power Transmission	1	1	1	-	0	1	1	1	0	6
5. Prevent Contact with Point of Operation	1	1	1	1	-	1	1	1	0	7
6. Create No Interference	1	1	0	0	0	-	1	1	0	4
7. Communicates Hazards	0	1	0	0	0	0	-	0	0	1
8. Stops Use of Incorrect Materials	0	1	0	0	0	0	1	-	0	2
9. Limit Machine Access While Running	1	1	1	1	1	1	1	1	-	8
Total	5	8	3	2	1	4	7	6	0	n-1=8

Table F-2: *House of Quality*

Customer Requirements	Engineering Characteristics												
	Improvement Direction	↓	↓	↑	↓	↓	↓	↑	↑	↑	↑	↓	↓

	Units	mg/m^3	dB	N	mm	mm	n/a	n/a	mm	n/a	n/a	days	mm
	Importance Weight Factor	Particulates	Decibel	Impact force	Clearance (operation)	Clearance (transmission)	User Observation	User Opinion	Limit When Run	Sponsor Opinion	Safety Rating	Time	Displacement
1. Collect Dust	4	9	1	0	0	0	0	3	0	1	1	3	0
2. Dampen Noise	1	0	9	1	0	0	0	1	0	1	3	0	1
3. Halt Projectiles	6	1	1	9	3	1	0	3	1	1	3	0	0
4. Prevent Contact with Power Transmission	7	0	0	0	1	9	1	0	3	3	9	0	0
5. Prevent Contact with Point of Operation	8	0	0	0	9	1	1	0	9	3	9	0	0
6. Create No Interference	5	1	0	0	9	9	9	0	9	3	1	0	1
7. Communicates Hazards	2	0	0	3	0	0	1	9	0	3	0	0	0
8. Stops Use of Incorrect Materials	3	0	0	3	0	0	0	9	0	1	0	0	0
9. Limit Machine Access While Running	9	0	0	0	9	9	0	0	9	3	1	0	0

Raw Score	1224	47	19	70	223	203	62	76	225	107	174	12	6
Relative Weight %	%	3.840	1.552	5.719	18.219	16.585	5.065	6.209	18.382	8.742	14.216	0.980	0.490
Rank Order	#	9	10	7	2	3	8	6	1	5	4	11	12

Table F-3: Pugh Charts

Concept Key	
1	High Concept #1, Hatch Door
2	High Concept #2, Roll Cover Door
3	High Concept #3, Oven Door
4	Medium Concept #1, Bifold Door
5	Medium Concept #2, Vertical Sliding Door
6	Medium Concept #3, Horizontal Sliding Door
7	Medium Concept #4, Double Sliding Door
8	Medium Concept #5, Reverse Oven Door

Pugh Legend	
+	Better
-	Worse
S	Satisfactory

Pugh Chart: Iteration 1									
Selection Criteria	Carbide 3d Nomad Enclosure	Concepts							
		1	2	3	4	5	6	7	8
1. Particulates	Datum	+	+	+	+	+	+	+	+
2. Decibel		S	S	+	+	S	+	+	S
3. Impact Force		S	S	S	S	S	S	S	S
4. Clearance Operation		-	-	-	-	-	-	-	-
5. Clearance Transmission		-	-	-	-	-	-	-	-
6. User Opinion (haz + mat)		+	+	+	+	+	+	+	+
7. Limit When Run		S	S	S	S	S	S	S	S
8. Sponsor Opinion		-	+	-	-	S	-	-	-
9. Safety Rating		-	-	S	-	S	S	+	S
10. Time		+	+	S	-	+	+	S	-
11. Displacement		S	+	+	+	S	S	S	S
# of Pluses (+)		3	5	4	4	3	4	4	2
# of Minuses (-)		4	3	3	5	2	3	3	4
Selection		-2	3	2	-4	4	2	2	-3

Pugh Chart: Iteration 2					
Selection Criteria	High Concept #3	Concepts			
		2	5	6	7
1. Particulates	Datu m	-	S	S	+
2. Decibel		+	-	+	+

3. Impact Force		S	+	+	-
4. Clearance Operation		S	+	S	-
5. Clearance Transmission		+	S	-	-
6. User Opinion (haz + mat)		+	+	-	+
7. Limit When Run		S	S	S	S
8. Sponsor Opinion		+	+	S	+
9. Safety Rating		-	+	+	S
10. Time		-	+	S	+
11. Displacement		+	-	+	+
# of Pluses (+)		5	6	4	6
# of Minuses (-)		3	2	2	3
Selection		3	7	5	4

Table F-4: *Analytical Hierarchy Process*

Development of Candidate Set of Criteria Weights {W}													
Criteria Comparison Matrix [C]													
Engineering Characteristics	Particulates	Decibel	Impact force	Clearance (operation)	Clearance (transmission)	User Observation (interference while	User Opinion (hazard	Limit When Run	Sponsor Opinion (cable management)	Safety Rating	Time	Displacement	Total
1. Particulates	1.00	7.00	0.14	0.11	0.11	1.00	3.00	0.14	5.00	0.33	7.00	5.00	29.84
2. Decibel	0.14	1.00	0.11	0.14	0.14	0.14	0.20	0.11	0.33	0.14	1.00	1.00	4.47

3. Impact Force	7.00	9.00	1.00	3.00	0.33	1.00	7.00	0.33	5.00	3.00	5.00	5.00	46.67
4. Clearance Operation	9.00	7.00	0.33	1.00	5.00	3.00	9.00	1.00	7.00	5.00	7.00	7.00	61.33
5. Clearance Transmission	9.00	7.00	3.00	0.20	1.00	3.00	9.00	1.00	7.00	3.00	7.00	7.00	57.20
6. User Observation	1.00	7.00	1.00	0.33	0.33	1.00	5.00	0.11	9.00	3.00	7.00	7.00	41.78
7. User Opinion (haz + mat)	0.33	5.00	0.14	0.11	0.11	0.20	1.00	0.11	1.00	0.33	3.00	3.00	14.34
8. Limit When Run	7.00	9.00	0.33	1.00	1.00	9.00	9.00	1.00	9.00	5.00	9.00	9.00	69.33
9. Sponsor Opinion	0.20	3.00	0.20	0.14	0.14	0.11	1.00	0.11	1.00	0.33	1.00	1.00	8.24
10. Safety Rating	3.00	7.00	0.33	0.20	0.33	0.33	3.00	0.20	3.00	1.00	9.00	9.00	36.40
11. Time	0.14	1.00	0.20	0.14	0.14	0.14	0.33	0.11	1.00	0.11	1.00	7.00	11.33
12. Displacement	0.20	1.00	0.20	0.14	0.14	0.14	0.33	0.11	1.00	0.11	0.14	1.00	4.53
Total	38.02	64.00	7.00	6.53	8.79	19.07	47.87	4.34	49.33	21.37	57.14	62.00	n-1=10

Normalized Criteria Comparison Matrix [NormC]													
Engineering Characteristics	1	2	3	4	5	6	7	8	9	10	11	12	Criteria Weights {W}
1. Particulates	0.026	0.109	0.020	0.017	0.013	0.052	0.063	0.033	0.101	0.016	0.123	0.081	0.054
2. Decibel	0.004	0.016	0.016	0.022	0.016	0.007	0.004	0.026	0.007	0.007	0.018	0.016	0.013
3. Impact Force	0.184	0.141	0.143	0.460	0.038	0.052	0.146	0.077	0.101	0.140	0.088	0.081	0.138
4. Clearance Operation	0.237	0.109	0.048	0.153	0.569	0.157	0.188	0.230	0.142	0.234	0.123	0.113	0.192
5. Clearance Transmission	0.237	0.109	0.429	0.031	0.114	0.157	0.188	0.230	0.142	0.140	0.123	0.113	0.168

6. User Observation	0.026	0.109	0.143	0.051	0.038	0.052	0.104	0.026	0.182	0.140	0.123	0.113	0.092
7. User Opinion (haz + mat)	0.009	0.078	0.020	0.017	0.013	0.052	0.021	0.026	0.020	0.016	0.053	0.048	0.031
8. Limit When Run	0.184	0.141	0.048	0.153	0.114	0.472	0.188	0.230	0.182	0.234	0.158	0.145	0.187
9. Sponsor Opinion	0.005	0.047	0.029	0.022	0.016	0.006	0.021	0.026	0.020	0.016	0.018	0.016	0.020
10. Safety Rating	0.079	0.109	0.048	0.031	0.038	0.017	0.063	0.046	0.061	0.047	0.158	0.145	0.070
11. Time	0.004	0.016	0.029	0.022	0.016	0.007	0.007	0.026	0.020	0.005	0.018	0.113	0.024
12. Displacement	0.005	0.016	0.029	0.022	0.016	0.007	0.007	0.026	0.020	0.005	0.003	0.016	0.014
Total	1	1	1	1	1	1	1	1	1	1	1	1	1

Consistency Check		
Weighted Sum Vector {Ws}=[C]{W}	Criteria Weights {W}	Consistency Vecotr {Cons}={Ws}./{W}
0.778	0.054	14.280
0.182	0.013	13.871
2.141	0.138	15.562
3.158	0.192	16.459
2.560	0.168	15.267
1.328	0.031	42.758

0.371	0.187	1.978
3.074	0.020	153.302
0.273	0.070	3.889
1.028	0.024	43.725
0.296	0.014	20.661
0.193	1.003	0.192

Avg Consistency	Consistency index	Consistency Ratio
28.495	1.500	0.974

Tables F-5: *Analytical Hierarchy Process for Design Alternatives*

Concept Key	
1	Medium Concept #2, Vertical Sliding Door
2	Medium Concept #3, Horizontal Sliding Door
3	Medium Concept #4, Double Sliding Door

Concept Key	
1	Medium Concept #2, Vertical Sliding Door
2	Medium Concept #3, Horizontal Sliding Door
3	Medium Concept #4, Double Sliding Door

Random Index	1.51

Particulates [C]			
Concept	Vert Sliding	Horiz Sliding	Double Slide
Vert Sliding	1.00	1.00	5.00
Horiz Sliding	1.00	1.00	5.00
Double Slide	0.20	0.20	1.00
Total	2.20	2.20	11.00

Normalized Particulates [NormC]				
Concept	1	2	3	Design Alternative Priorities {Pi}
1	0.455	0.455	0.455	0.455
2	0.455	0.455	0.455	0.455
3	0.091	0.091	0.091	0.091
Total	1	1	1	1

Consistency Check		
Weighted Sum Vector {Ws}=[C]{Pi}	Criteria Weights {Pi}	Consistency Vecotr {Cons}={Ws}./{Pi}
1.364	0.455	3.000
1.364	0.455	3.000
0.273	0.091	3.000

Avg Consistency	Consistency index	Consistency Ratio
3.000	0.000	0.000

Decibel [C]

Normalized Decibel [NormC]

Concept	Vert Sliding	Horiz Sliding	Double Slide
Vert Sliding	1.00	0.14	0.14
Horiz Sliding	7.00	1.00	1.00
Double Slide	7.00	1.00	1.00
Total	15.00	2.14	2.14

Concept	1	2	3	Design Alternative Priorities {Pi}
1	0.067	0.067	0.067	0.067
2	0.467	0.467	0.467	0.467
3	0.467	0.467	0.467	0.467
Total	1	1	1	1

Consistency Check		
Weighted Sum Vector {Ws}=[C]{Pi}	Criteria Weights {Pi}	Consistency Vecotr {Cons}={Ws}./{Pi}
0.200	0.067	3.000
1.400	0.467	3.000
1.400	0.467	3.000

Avg Consistency	Consistency index	Consistency Ratio
3.000	0.000	0.000

Impact Force [C]			
Concept	Vert Sliding	Horiz Sliding	Double Slide
Vert Sliding	1.00	1.00	1.00
Horiz Sliding	1.00	1.00	1.00

Normalized Impact Force [NormC]				
Concept	1	2	3	Design Alternative Priorities {Pi}
1	0.333	0.333	0.333	0.333
2	0.333	0.333	0.333	0.333

Double Slide	1.00	1.00	1.00
Total	3.00	3.00	3.00

3	0.333	0.333	0.333	0.333
Total	1	1	1	1

Consistency Check		
Weighted Sum Vector {Ws}=[C]{Pi}	Criteria Weights {Pi}	Consistency Vector {Cons}={Ws}./{Pi}
1.000	0.333	3.000
1.000	0.333	3.000
1.000	0.333	3.000

Avg Consistency	Consistency index	Consistency Ratio
3.000	0.000	0.000

Clearance Operation [C]			
Concept	Vert Sliding	Horiz Sliding	Double Slide
Vert Sliding	1.00	1.00	3.00
Horiz Sliding	1.00	1.00	3.00
Double Slide	0.33	0.33	1.00
Total	2.33	2.33	7.00

Normalized Clearance Operation [NormC]				
Concept	1	2	3	Design Alternative Priorities {Pi}
1	0.429	0.429	0.429	0.429
2	0.429	0.429	0.429	0.429
3	0.143	0.143	0.143	0.143
Total	1	1	1	1

Consistency Check

Avg Consistency	Consistency index	Consistency Ratio

Weighted Sum Vector {Ws}=[C]{Pi}	Criteria Weights {Pi}	Consistency Vecotr {Cons}={Ws}./{Pi}
1.286	0.429	3.000
1.286	0.429	3.000
0.429	0.143	3.000

3.000	0.000	0.000

Clearance Transmission [C]			
Concept	Vert Sliding	Horiz Sliding	Double Slide
Vert Sliding	1.00	1.00	0.33
Horiz Sliding	1.00	1.00	0.33
Double Slide	3.00	3.00	1.00
Total	5.00	5.00	1.67

Normalized Clearance Transmission [NormC]				
Concept	1	2	3	Design Alternative Priorities {Pi}
1	0.200	0.200	0.200	0.200
2	0.200	0.200	0.200	0.200
3	0.600	0.600	0.600	0.600
Total	1	1	1	1

Consistency Check		
Weighted Sum Vector {Ws}=[C]{Pi}	Criteria Weights {Pi}	Consistency Vector {Cons}={Ws}./{Pi}
0.600	0.200	3.000
0.600	0.200	3.000
1.800	0.600	3.000

Avg Consistency	Consistency index	Consistency Ratio
3.000	0.000	0.000

User Opinion [C]			
Concept	Vert Sliding	Horiz Sliding	Double Slide
Vert Sliding	1.00	1.00	1.00
Horiz Sliding	1.00	1.00	1.00
Double Slide	1.00	1.00	1.00
Total	3.00	3.00	3.00

User Opinion [NormC]				
Concept	1	2	3	Design Alternative Priorities {Pi}
1	0.333	0.333	0.333	0.333
2	0.333	0.333	0.333	0.333
3	0.333	0.333	0.333	0.333
Total	1	1	1	1

Consistency Check		
Weighted Sum Vector {Ws}=[C]{Pi}	Criteria Weights {Pi}	Consistency Vector {Cons}={Ws}./{Pi}
1.000	0.333	3.000
1.000	0.333	3.000
1.000	0.333	3.000

Avg Consistency	Consistency index	Consistency Ratio
3.000	0.000	0.000

Limit When Run [C]			
Concept	Vert Sliding	Horiz Sliding	Double Slide
Vert Sliding	1.00	1.00	3.00
Horiz Sliding	1.00	1.00	3.00

Limit When Run [NormC]				
Concept	1	2	3	Design Alternative Priorities {Pi}
1	0.429	0.429	0.429	0.429
2	0.429	0.429	0.429	0.429

Double Slide	0.33	0.33	1.00
Total	2.33	2.33	7.00

3	0.143	0.143	0.143	0.143
Total	1	1	1	1

Consistency Check		
Weighted Sum Vector {Ws}=[C]{Pi}	Criteria Weights {Pi}	Consistency Vector {Cons}={Ws}./{Pi}
1.286	0.429	3.000
1.286	0.429	3.000
0.429	0.143	3.000

Avg Consistency	Consistency index	Consistency Ratio
3.000	0.000	0.000

Sponsor Opinion [C]			
Concept	Vert Sliding	Horiz Sliding	Double Slide
Vert Sliding	1.00	1.00	1.00
Horiz Sliding	1.00	1.00	1.00
Double Slide	1.00	1.00	1.00
Total	3.00	3.00	3.00

Sponsor Opinion [NormC]				
Concept	1	2	3	Design Alternative Priorities {Pi}
1	0.333	0.333	0.333	0.333
2	0.333	0.333	0.333	0.333
3	0.333	0.333	0.333	0.333
Total	1	1	1	1

Consistency Check

Avg Consistency	Consistency index	Consistency Ratio

Weighted Sum Vector {Ws}=[C]{Pi}	Criteria Weights {Pi}	Consistency Vector {Cons}={Ws}./{Pi}
1.000	0.333	3.000
1.000	0.333	3.000
1.000	0.333	3.000

3.000	0.000	0.000

Safety Rating [C]			
Concept	Vert Sliding	Horiz Sliding	Double Slide
Vert Sliding	1.00	0.20	0.20
Horiz Sliding	5.00	1.00	1.00
Double Slide	5.00	1.00	1.00
Total	11.00	2.20	2.20

Safety Rating [NormC]				
Concept	1	2	3	Design Alternative Priorities {Pi}
1	0.091	0.091	0.091	0.091
2	0.455	0.455	0.455	0.455
3	0.455	0.455	0.455	0.455
Total	1	1	1	1

Consistency Check		
Weighted Sum Vector {Ws}=[C]{Pi}	Criteria Weights {Pi}	Consistency Vector {Cons}={Ws}./{Pi}
0.273	0.091	3.000
1.364	0.455	3.000
1.364	0.455	3.000

Avg Consistency	Consistency index	Consistency Ratio
3.000	0.000	0.000

Time [C]			
Concept	Vert Sliding	Horiz Sliding	Double Slide
Vert Sliding	1.00	1.00	3.00
Horiz Sliding	1.00	1.00	3.00
Double Slide	0.33	0.33	1.00
Total	2.33	2.33	7.00

Time [NormC]				
Concept	1	2	3	Design Alternative Priorities {Pi}
1	0.429	0.429	0.429	0.429
2	0.429	0.429	0.429	0.429
3	0.143	0.143	0.143	0.143
Total	1	1	1	1

Consistency Check		
Weighted Sum Vector {Ws}=[C]{Pi}	Criteria Weights {Pi}	Consistency Vector {Cons}={Ws}./{Pi}
1.286	0.429	3.000
1.286	0.429	3.000
0.429	0.143	3.000

Avg Consistency	Consistency index	Consistency Ratio
3.000	0.000	0.000

Displacement [C]			
Concept	Vert Sliding	Horiz Sliding	Double Slide
Vert Sliding	1.00	0.20	0.20
Horiz Sliding	5.00	1.00	1.00

Displacement [NormC]				
Concept	1	2	3	Design Alternative Priorities {Pi}
1	0.091	0.091	0.091	0.091
2	0.455	0.455	0.455	0.455

Double Slide	5.00	1.00	1.00
Total	11.00	2.20	2.20

3	0.455	0.455	0.455	0.455
Total	1	1	1	1

Consistency Check		
Weighted Sum Vector {Ws}=[C]{Pi}	Criteria Weights {Pi}	Consistency Vector {Cons}={Ws}./{Pi}
0.273	0.091	3.000
1.364	0.455	3.000
1.364	0.455	3.000

Avg Consistency	Consistency index	Consistency Ratio
3.000	0.000	0.000

User Observation (interference while running)			
Concept	Vert Sliding	Horiz Sliding	Double Slide
Vert Sliding	1.00	1.00	1.00
Horiz Sliding	1.00	1.00	1.00
Double Slide	1.00	1.00	1.00
Total	3.00	3.00	3.00

User Observation (interference while running)				
Concept	1	2	3	Design Alternative Priorities {Pi}
1	0.091	0.455	0.455	0.333
2	0.091	0.455	0.455	0.333
3	0.091	0.455	0.455	0.333
Total	0.27272727	1.36363636	1.36363636	1

Consistency Check

Avg Consistency	Consistency index	Consistency Ratio

Weighted Sum Vector {Ws}=[C]{Pi}	Criteria Weights {Pi}	Consistency Vector {Cons}={Ws}./{Pi}
1.000	0.333	3.000
1.000	0.333	3.000
1.000	0.333	3.000

3.000	0.000	0.000

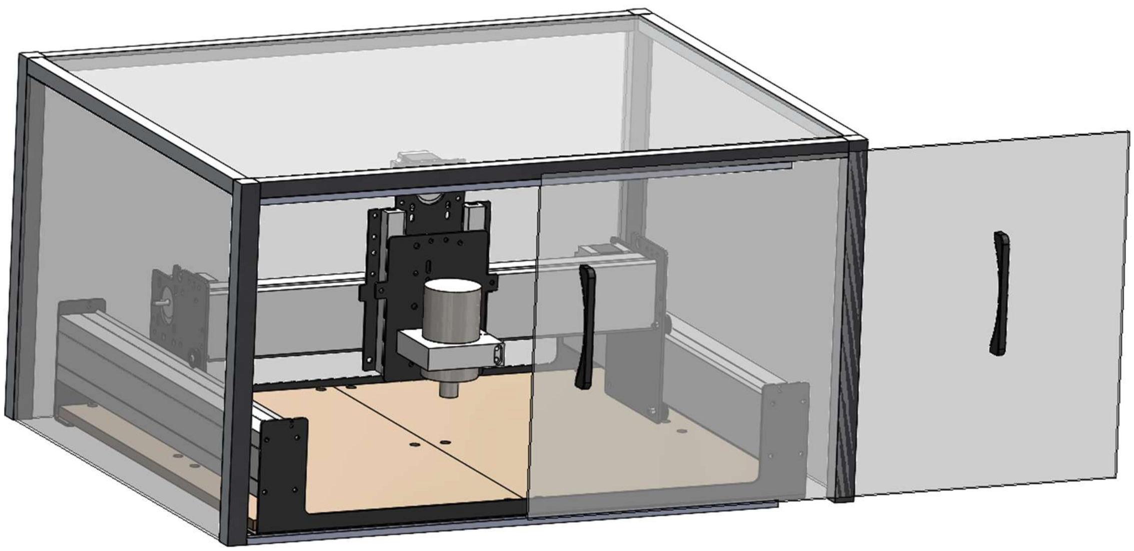

Figure F-1: *Horizontal Sliding Door Concept*

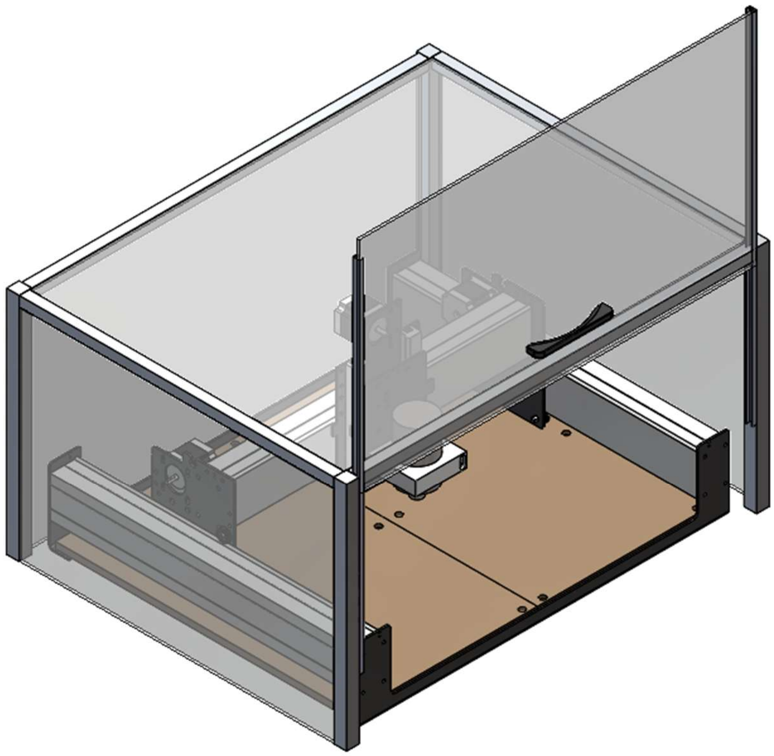

Figure F-2: *Vertical Sliding Door Concept*

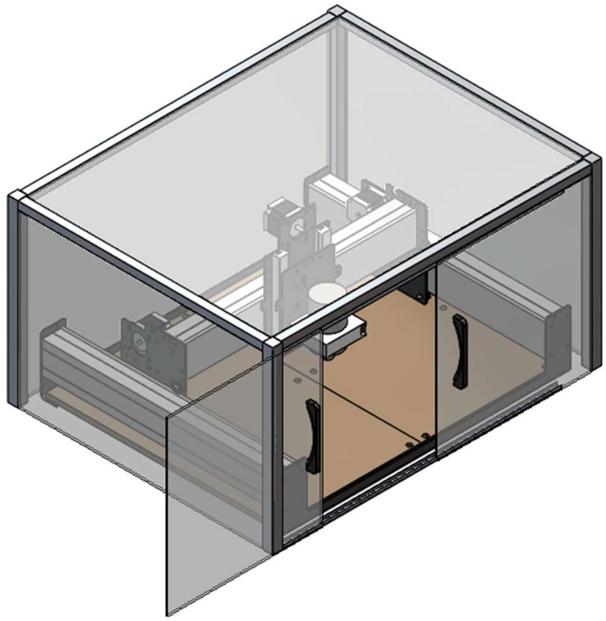

Figure F-3: *Double Sliding Door Concept*

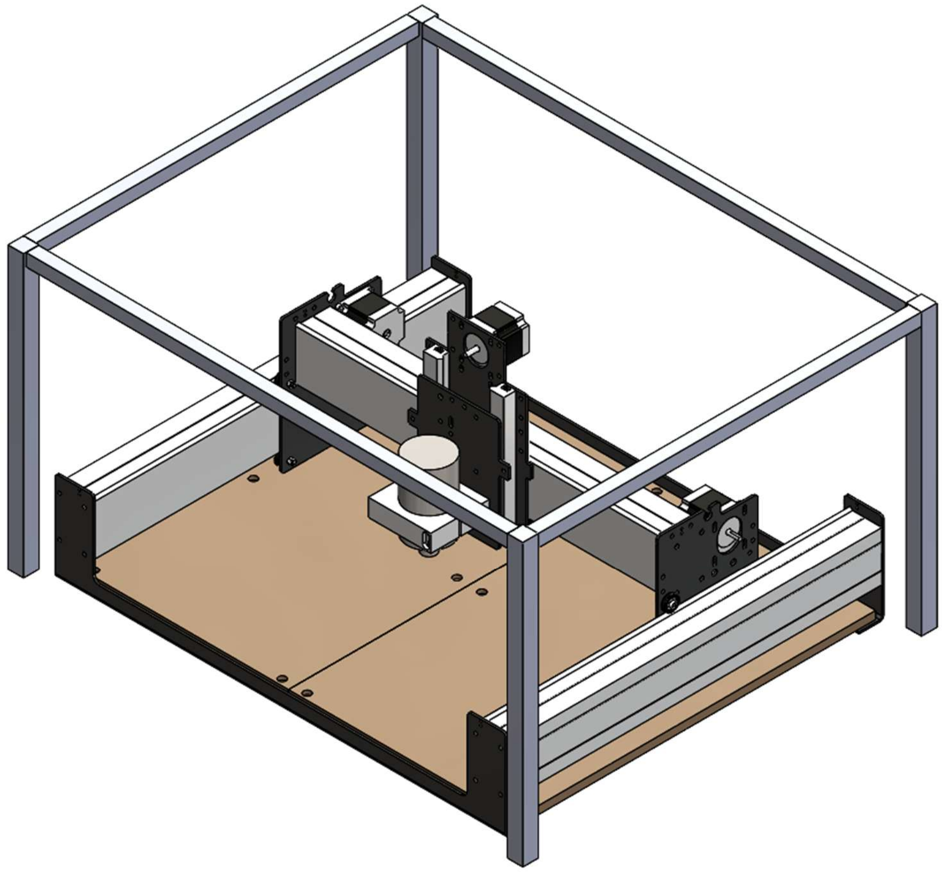

Figure F-4: *Glassless Isometric View of the Safeguard Frame*

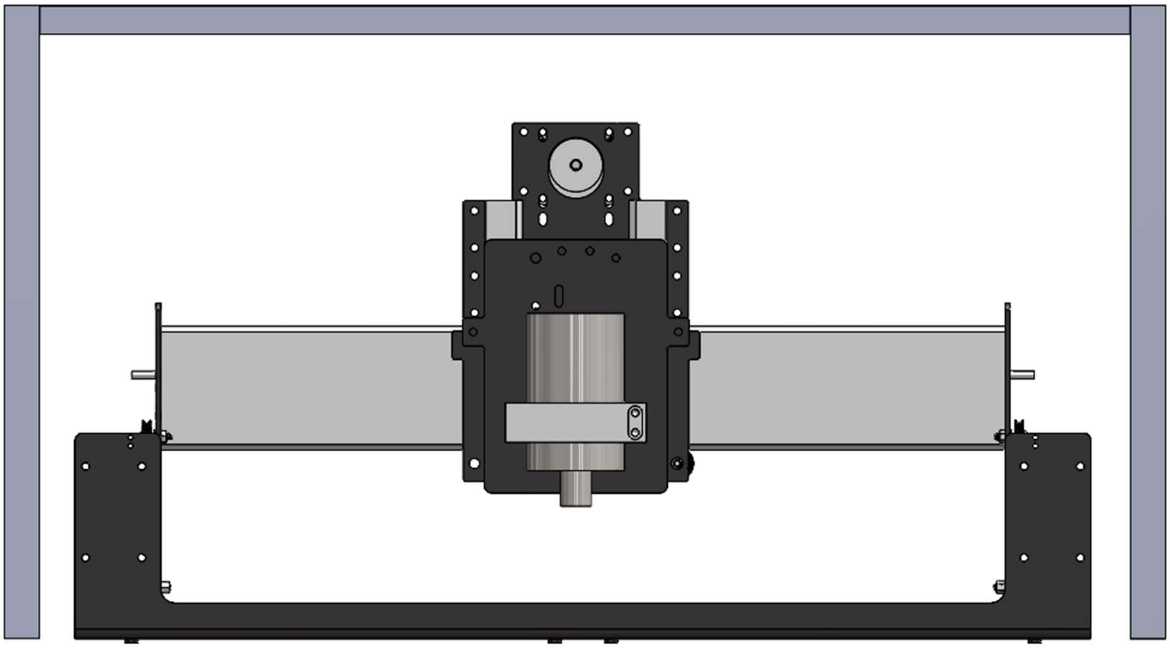

Figure F-5: *Glassless Front View of the Safeguard Frame*

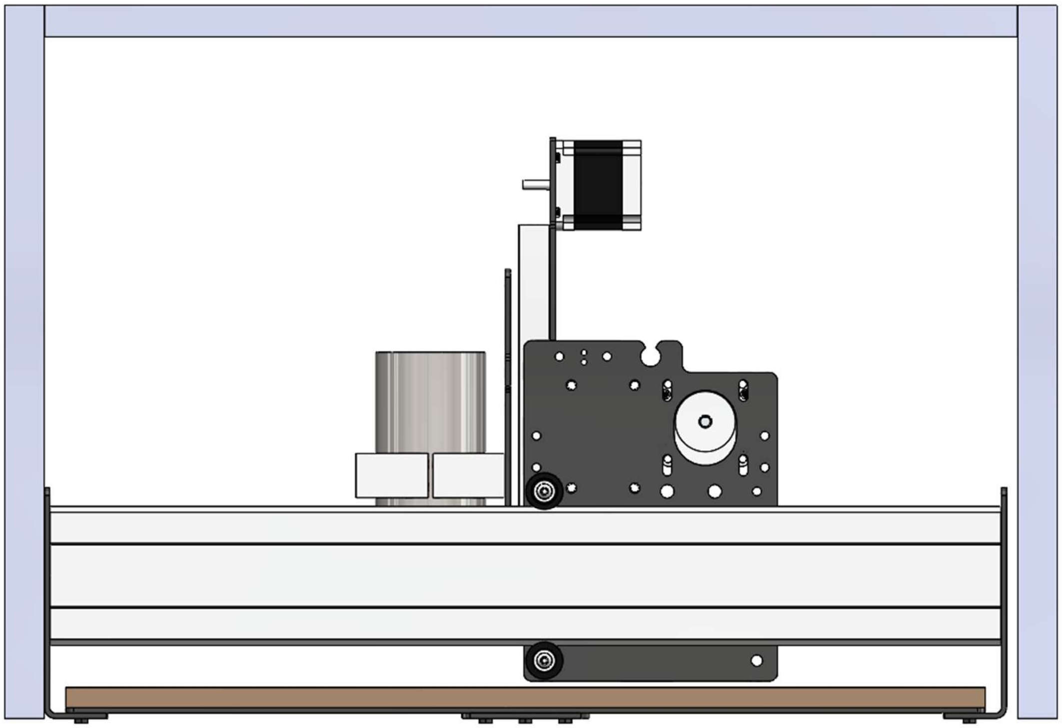

Figure F-6: *Glassless Side View of the Safeguard Frame*

References

There are no sources in the current document.