Mitigating Sub-Particle Respiratory Contamination for Ironworkers

by

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Abstract

With the increasing demand for industrial infrastructure of skyscrapers, roadways, and bridges, there is emphasis on iron workers' construction abilities. Ultimately, the development of these construction projects can prove to be difficult towards mitigating air pollutant exposure for iron workers on a sub-particle level. The working environment for iron workers cultivates a breathing ground for air toxin circulation, as the four major exposure groups of inorganic gas, dust irritants, fumes, and woodworking particles act as silent impairments to these workers' respiratory tract. Health and safety precautions like the use of non-powered air purifying respirators and powered air purifying respirators are in place, yet the occupational exposure mortality rates due to dust and air toxins overshadows the effectiveness of current products. Research indicates that these essential workers are prone to developing occupational respiratory diseases, such as, chronic obstructive pulmonary disease (COPD), asthma, lung cancer, and asbestos-related diseases by 30% (McGuane, 2018). Through understanding the occupational hazards and the sub-particle contamination, further insights can be developed such that iron workers are able to productively and safely work by reducing toxin circulation, granting accessible decontamination areas and establishing optimal monitored air quality.

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1.1 Problem Definition

Iron construction workers are essential workers that strengthen our economy and help shape our communities (Government of Ontario, 2021). Welding is an industrial process that iron workers typically use to join metals, which includes allied processes such as; gouging, cutting, grinding metal or finishing (Employment And Social Development, 2022). Typically, iron workers use two types of welding: thermal welding, and pressure welding, which often involve the use of multiple metals and chemicals which can lead to exposure to chemical agents such as fumes and gases (Employment And Social Development, 2022). These exposure points contribute to an increased level of iron workers developing COPD, Asbestos, Silicosis, etc., all due to sub-particle air pollution hazards and the constant re-encounters with these hazards (Bergdahl et al., 2004). Additionally, Respiratory Safety Guidelines (OSHA) for iron workers require respiratory protection, such as powered and non-powered respirators, to be in place to reduce contamination, yet most construction workers opt out of wearing them due to level of comfort, adaptability, durability and whether the job site requires facial personal protective equipment to be worn. Ultimately, these air pollutants become a silent toxicological effect on workers’ respiratory systems which leads to an increased risk of mortality.

1.2 Rational & Significance

1.2.1. Key Information To Be Determined

Iron workers accomplish an abundant amount of manual labour with high hazardous risk, even though physical labour policies are in place, the internal respiratory protection measures are often overlooked. To benefit this project further, it is critical to understanding the work environment framework based on the following questions:

1. What are the demographics of the primary users?
2. What type of environments does the target user usually perform a task in?
3. What are the proposed respiratory hazards that workers in the field may face?
4. Currently, what are the personal protective respiratory equipment in place?
    a. How effective is the personal protective respiratory equipment?
    b. What are some key benefits and features listed?
    c. What are the drawbacks of personal protective respiratory equipment?
5. What is the duration of time that iron workers typically work for?

1.2.2. Key Questions To Be Asked

Questions provide greater insights towards the design development, as users are able to share information that is pivotal benefit which can lead to greater design opportunities. Asking the appropriate questions is of much importance, as it can address common pain points. The following questions are:

1. What are the needs and wants of iron workers when wearing respiratory personal protective equipment (PPE) in the field?
2. Are there any ergonomic challenges towards using current respiratory personal protective equipment (PPE)?
3. What is the work cultural response towards wearing respiratory personal protective equipment (PPE)?

4. Are there any innovative respiratory personal protective equipment (PPE) aspects desired?

1.2.3. Investigation Approach

To discover this key information required and apply this knowledge towards this project, a plan must be developed that incorporates a variety of methods. The plan will follow the methods as follows:

- Literature Review
- Product Benchmarking
- User Research
    - User Interviews
    - User Observations
- Ergonomic Studies
- Semantic Analysis

Through utilizing these methods, insights can be determined on the conditions of iron workers within a construction environment. The results will help form a firm foundation into the development and design viability of this project.

1.3 **Background / History / Social Context**

1.3.1 Demographic Trends

The iron working construction field is most dominantly male by 95%, while there has been a rise in females in the field in recent years by 4.9% (Government of Ontario, 2022). There seems to be a large job projection across the fields of construction welding; whether it is welders, machine operators, industrial or electrical occupations related to construction. Most workers have obtained the minimum job requirement of a post-secondary certificate, while workers who obtained a 3 year apprenticeship or received a master's degree receive higher incomes (Government of Ontario, 2022).

1.3.2 Lifestyle Trends

Typically, most iron workers work individually with occasional aid from coworkers or supervisors that can provide insights on technical aspects of welding on the job (Government of Ontario, 2022). The lifestyle of iron workers is heavily affected by the level of comfort towards the respirator use, as most work site locations require respirator use, along with a welding helmet due to the Occupational Health and Safety Association (OHSA) policies and based on the type of welding process being conducted. However, it is common for workers to experience the health hazards associated with welding and allied processes due to exposure of fumes and gasses, heat, noise, radiation, as well as, repetitive stresses that can cause musculoskeletal injuries (MSI's), such as strains and sprains (Employment And Social Development, 2022).

1.3.3 Media Trends

Media trends often depict a singular type of construction worker, which are those who primarily work on roads and highways or residential infrastructure, however, there are a vast amount of specialities that allow construction workers to become an iron worker. Through apprenticeships and several months of training, these workers can read and interpret blueprints or welding process specifications, operate manual or semi-automatic welding and flame-cutting equipment (Statistics Canada, 2021).

1.3.3 Product Trends

Common trends within the welding industry include the usage of products, such as welding helmets, air-purifying respirators (APRs) and atmosphere-supplying respirators (ASRs) that are CSA compliant and meets ANSI Z87.1 standards (The National Institute for Occupational Safety and Health (NIOSH), 2021). Workplaces may differ in the types and selection of respirators based on respiratory hazards that are present and the welding process that is required.

CHAPTER 2: RESEARCH

Figure 2. Pixabay. (2017, December 17). *Welder Working*. Retrieved December 15, 2022, from https://pixabay.com/photos/welder-welding-work-labor-job-car-3018425/

2.1 User Research

Research is a driving force that propels the opportunity for a new design to flourish and obtain key insights that branches into various subsections of the iron working community. An investigation into users allows for the creation of a persona, which further emphasizes user's environment, product usage and disadvantages that they may possibly encounter. The methods used to undergo this investigation consist of user interviews, user observations, literature reviews and product benchmarking in relation to human factors.

2.1.1 User Profile - Persona

While it is true that iron workers typically work individually, they often converse with site supervisors and fellow workers to ensure that technical project schematics are done correctly. To understand the iron working community in a deeper scope, the categorization of users were identified as either primary, secondary or tertiary.

Persona:

Name	Collin
Age	30 years old
Gender	Iron worker 5 years in the field
Occupation	High School Diploma 3-Year Apprenticeship
Relationship	Married w/children
Location	Toronto, Ontario
Work Hours	Up to 10 hours per shift, with occasional overtime Days/Mornings
Additional Notes	
Goals	• To reduce poor air quality intake at work • Doesn't want to deal with coughs or throat irritations • Doesn't want dust filled clothes to be around children
Barriers	• Occupational hazards are somewhat unavoidable
Likes	• Not having to wear a mask often

Figure 3. Pixabay. (2012, August 12). *Man Welding Blowtorch Welder Job.* Retrieved December 16, 2022, from https://pixabay.com/photos/man-welding-blowtorch-welder-job-53903/

Table 1. User Persona

Primary Users:

The primary users are iron workers and welders, as these workers produce a wide range of tasks that are most similar. These workers are highly exposed to air toxins for over 10 hours a day, where the most common respiratory symptom in exposed workers was cough (24.5%) (Saraei et al., 2018).

Secondary Users:

Secondary users' risk for harmful respiratory toxin intake is limited, as they have a set amount of exposure to harmful dusts. Where this depends on when they are needed for work, most of these workers only need to be exposed to air toxins for 2-3 hours a day. These workers include;

- Carpenter
- Fumigator
- Painter
- Millwright Worker
- Construction Supervisor

- Civil Engineer
- Concrete Finisher
- Plumber

Tertiary Users:

Tertiary users have limited exposure with harmful air particles, as they primarily work indoors by working on administrative paperwork. When these workers are required to be surrounded by air toxins, it is for no more than 2 hours. The tertiary users include:

- Construction Site Surveyor
- Electrician
- Safety Manager
- Roofer
- Pipefitter
- Construction Inspector

Demographics:

Iron workers are predominantly male by 95%, and female workers by 4.9% (Government of Ontario, 2022). In this occupation, the ethnicity of workers are commonly Caucasusin, while Hispanics and African Americans are among the other ethnicities present. Typically, workers are 40-year olds with an average income of $50,501, where 31% are located in Toronto, Ontario. Most male workers accumulate an average of $51,123, while females accumulate $39,689 (Government of Ontario, 2022). Workers who have obtained a 3 year apprenticeship or trades diploma receive $54,306 in earnings, while workers who receive a post-secondary certificate $50,501. Workers with no certificate, diploma or apprenticeship earn $47,224 (Government of Ontario, 2022). Approximately, 95% of workers are employed, while 5% of iron workers are unemployed (Government of Ontario, 2022).

User Behaviour

Collin is a 30 year old male working in the construction worker-field for over 5 years after obtaining his apprenticeship certificate 3 years ago (See Figure 3). He is a father of two children and is currently married and a full-time worker. Currently, he has the opportunity to work with Lebovic Enterprises Limited for approximately 2 years as an ironworker. Collin usually works a 10-12 hour shift in the early mornings, where he starts work at 5:00 AM and typically ends at 4:00 PM, where he then picks up his children from school. Additionally, he has years of familiarity with following iron working procedure and safety policies according to the OSHA and how maintenance of a respirator typically works.

2.1.2 User Current Practice

To better understand the depth of the iron working environment in relation to respiratory health, further studies were conducted in order to receive information on the work cultural outlook of current products, drawbacks and practices in use.

Method:

To determine this information, user research was conducted through the form of user interviews, and observations.

Routine Tasks, Procedures and Attitudes

While on site, Collin would be required to read welding process specifications, operate a manual flame cutting equipment, and operate metal shaping machines throughout the day (Statistics Canada, 2021). Most times, Collin would be required to repair worn parts of metal products by welding on extra layers, while also operating brazing and soldering equipment (Statistics Canada, 2021). Prior to welding, Collin must put on an air-purifying respirator or a powered respirator under his welding helmet depending on the level of air toxins caused by the type of welding and its duration. Towards the completion of his shift, Collin must factor in time to clean and maintain his air-purifying respirator or a powered respirator by thoroughly cleaning the cartridges, valves and straps with warm water and soap. More specifically, a detergent or soap and warm water could be used to clean the surface of the exterior filter cartridge prior to disinfection, where Collin would carefully avoid contact with the filter media by using a clean, soft cloth dampened with warm water approximately 49°C (120°F) (National Center for Immunization and Respiratory Diseases (NCIRD), 2020).

Non-Routine Tasks, Procedures and Attitudes

Oftentimes, Collin would feel as though his respiratory protection is not being maintained, as he finds that he would need to take off his respirator to hold clear conversations, even when fumes from welding have not disbursed yet. Additionally, Collin would find it difficult to remember the procedure for properly cleaning his respirator, as there are various components to detach and reattach. Most times, Collin feels more comfortable wearing a thick fabric cloth over his face and mouth, as it is more comfortable than the silicone straps of his respirator. There would be times when Collin would weld small metal tubes quickly and not have on a respirator, mask or welding helmet, as he feels he is more comfortable without them. It is also hard for Collin to afford a powered respirator welding helmet, as he has a wife and kids to attend to and spending over $2,000 is out of his price range.

Expert Interviews / Surveys / Discussion boards

Through a 1:1 interview with an advisor who works within the construction field as an iron worker, further information was determined towards the common situations users are exposed to, how products are used, and the work cultural practices of respiratory personal protective equipment (PPE) usage.

The initial interview with the advisor was beneficial towards generating a basic concept of the scenarios, procedures, thoughts and feelings that iron workers typically face when dealing with welding and their respiratory health. By facilitating this interview, visual representation of a user empathy map was developed in order to tangibly view the overarching themes present within the workers' lives.

Moving forward, the general questions asked during each interview ranged from:

1. What type of respiratory personal protective equipment (PPE) do you wear, if any?
    i. How would you rate the personal protective equipment (PPE) effectiveness?
    ii. Why have you chosen or not chosen to wear respiratory personal protective equipment (PPE)?

    iii. Do your fellow workers wear the same level of personal protective equipment (PPE)?

2. How would you rate the level of communication when wearing respiratory personal protective equipment (PPE)?
3. How often have you experienced respiratory irritation? (I.e. Sneezing, sniffling, coughing, etc.)?
4. Are there any drawbacks when wearing personal protective equipment (PPE)?

Table 2. User Empathy Map

The conducted interview provided key insights into how iron workers' typical procedures, thoughts and feelings that are done when welding and in relation to their respiratory health. Most research interview findings reiterated academic literature research previously explored on the subject. The key findings were categorized by employer and employee procedures, respiratory health observations, and general usability. Key findings that were determined included the following:

Employer & Employee Procedures

- Employers must provide worker medical evaluations and respirator fit testing, as well as maintenance storage and cleaning of respirator training
    - Employer must provide workers with an appropriate respirator to protect health respiratory protection must be selected based on the hazard that will be exposed
- Training must be provided on respiratory hazards and proper respirator use
- Employer must use several methods to reduce exposure to air toxins
    - Including engineering controls such as local exhaust ventilation, work practice controls such as using wet cutting techniques and administrative controls such as minimizing the number of workers exposed to the hazard
    - The user seal check is performed to ensure the respirator is sealed tightly to the face
- Respirator Considerations must include;
    - Type and weight of respirator to be used
    - Duration and frequency of use
    - Expected physical work effort
    - Whether additional personal protective equipment (PPE) is to be worn
    - Temperature and humidity extremes
    - A copy of the written program and the medical evaluation portion of the standard

Respiratory Health Observations

- Workers that wear N95 mask and goggles, often have to take off their mask and glasses at times to clean off glasses and take breaks, which leads to heavy coughs and sneezing
- Not every respirator will protect against every hazard so it's important for employer to select the right one

- Inclusion of respirator, goggles, and accessories is an asset, yet it can become costly to provide these equipments, as most are sold separately
- 58.2% of exposed groups loosely wear protective masks and are are greater risk for respiratory symptoms (Saraei et al, 2018)
    - Various types of cancers can develop, whether it may be urinary, lung or larynx when improper use of respirators are in place
- Some respirators provide a 2-stage filtration process, further maximizing its effectiveness

General Usability

- Easy build up of contaminants, fog and other substances that can obstruct vision in the welding helmet visor
- Poor ventilation and build-up of air toxins can reduce workers desire to work efficiently
- Iron workers may use welding helmets and respirators which may muffle the sound or communications
- Some respirators and welding helmets do not prevent a build up of heat

2.1.3 User Observation – Activity Mapping

To obtain further insights on target users’ experiences throughout the day, a user observation was required in order to validate previous findings further. Considering the health code regulations, policies and training involved to conduct basic welding, in-person welding could not be utilized, however the use of user-video observations were observed by the advisor and elaborated on. The observational goals were to determine:

- How users put on personal protective equipment (PPE)
- How users react to personal protective equipment (PPE)
- How users work/communicate with personal protective equipment (PPE)

- What work cultural practices do users undergo when using personal protective equipment (PPE)
- How users remove personal protective equipment (PPE)

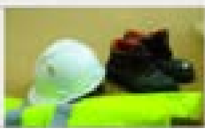
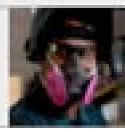
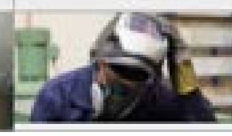
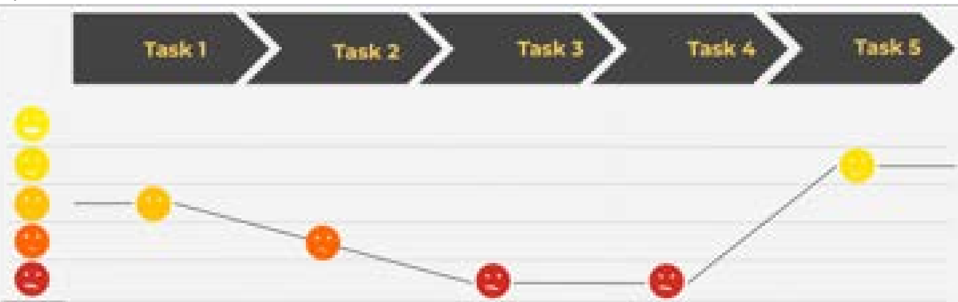
	Task 1	Task 2	Task 3	Task 4	Task 5
User Goal	**Preparation**	**Reviewing & Securing PPE**	**Communication on Site**	**Assess Comfort**	**Unequip PPE**
User Actions	• Receiving insights on daily tasks from supervisor • Reluctantly goes to pick up PPE	• Checking on PPE's cleanliness • Placing PPE on in order that is displayed by supervisor	• Attempting to communicate with supervisors and peers but having difficulty	• Redoing training/fitting since workers can outgrow their equipment	• Workers are done welding, they are able to take off PPE • PPE cleaning can be done
User Thoughts	• "Is this mask enough protection?" • "I hope this PPE actually works."	• "I think I'm putting this on right." • "Why are there so many layers to adjust?"	• "Why is it hard to hear and talk using this?" • "Should I take off PPE to be heard clearly?"	• "This PPE is feeling unbalanced." • "Should I just ignore it slipping off?"	• "I can finally breathe!" • "I'm so glad to have this off!"
Storyboard					

Table 3. User Journey Map



	Task 1	Task 2	Task 3	Task 4	Task 5
User Goals	Working in their construction site with optimal respiratory PPE and safety measures in place.	Checking out the PPE, clean equipment, and secure PPE accurately.	Actually using the respiratory PPE while welding and communicating with coworkers.	Comfortably use respiratory PPE. Ensuring it is properly cleaned, provides well communication.	Ending a shift and having to properly take off PPE. Feeling relief when PPE is off.
Problems/ Challenges	Remembering instructions and understanding how to properly put on respiratory PPE.	Workers may be pressed for time and rush the cleaning or securing process.	Ensuring that communication is clear and understandable through the PPE.	Navigating how to use and enhance respiratory PPE can be cumbersome and tedious.	Lots of equipment is used and needs to be replaced quickly.
Ideas/ Takeaways	Procedure and instructions could be easier to understand and follow.	To alleviate some degree of misunderstanding videos and tutorials can be played while on site.	Using respiratory PPE like respirators could make communication more difficult while on site.	The amount of money and time it takes to train staff on how to accurately use PPE is taxing.	Lots of equipment is involved, more time spent cleaning and ensuring PPE is on correctly.

Table 4. User Activity Map

To elaborate further, the user journey map and user activity map depict the basic tasks done within the welding industry, such as; how users put on personal protective equipment (PPE), how users react to personal protective equipment (PPE), how users work/communicate with personal protective equipment (PPE), what work cultural practices do users undergo when using personal protective equipment (PPE) and how users remove personal protective equipment (PPE). Each map outlines how users must inspect their personal protective equipment (PPE) prior to use, with additional considerations into the category and duration of welding being in place. Additionally, some workers may rush the cleaning process and place the personal protective equipment (PPE) without appropriate inspection. Further insights show how users may feel easily frustrated by the lack of clear communication when wearing the personal protective equipment (PPE) and attempting to verbalize work schematic inquiries with supervisors or coworkers. Additionally, some iron workers adopted the practice of improper use of wearing no facial covering or use thick fabric 'masks' for greater comfort. As a final process, workers must appropriately remove their respirators and maintain them through cleansing or disinfecting methods, such as, wearing nitrile gloves to protect their hands and using warm water and detergent with a mild pH neutral (pH 6-8) and start wiping in a mechanical wiping action (National Center for Immunization and Respiratory Diseases (NCIRD), 2020).

2.1.4 User Observation – Human Factors of Existing Products

Human factors within design is a critical step towards design advancement, as every interaction, gesture or emotion enhances the quality of a product and user relation. Understanding the key aspects of current products is beneficial towards determining user needs and wants for future designs. A list of key pieces of medical equipment towards iron worker safety should go as follows:

- Welding Helmet
- Welding Hood
- Respirator
    - Air Purifying

  - Powered Air-Purifying Respirator (PAPR)
  - Filtering Facepiece
  - Elastomeric Half Facepiece Respirator
- Welding Gloves
- Welding Torch
- Lightweight and Cool Flame-Resistant Cotton Shirt
- Tool Kit

Each of these items are required to be on hand with the worker at all times for safety purposes, especially when welding. The types of respirators being used on shift are heavily dependent on the welding condition that is assigned, however welding gloves, helmet and torch are mandatory to use on site (Statistics Canada, 2021).

2.1.5 User Observation – Safety and Health of Existing Products

Millions of workers are required to wear respirators in various workplaces throughout the United States, this same policy is applied in Canada as well (United States Department of Labour, 2022). Respirators protect workers against insufficient oxygen environments, harmful dusts, smokes, gasses, and sprays, where these hazards may cause cancer, lung impairment, diseases, or death (United States Department of Labour, 2022). This is why employers are required to develop and implement a written respiratory protection program with required worksite-specific procedures and elements for required respirator use (United States Department of Labour, 2022).

The program must be administered by a suitably trained program administrator, as well as certain program elements may be required for voluntary use to prevent potential hazards associated with the use of the respirator (United States Department of Labour, 2022). Additionally, an employer may provide respirators at the request of employees or permit employees to use their own respirators, if the employer determines that the respirator use will not in itself create a hazard (United States Department of Labour, 2022).

2.2 Product Research

Research is a driving force that propels the opportunity for a new design to flourish and obtain key insights that branches into various subsections of the iron working community. An investigation into users allows for the creation of a persona, which further emphasizes user's environment, product usage and disadvantages that they may possibly encounter. The methods used to undergo this investigation consist of user interviews, user observations, literature reviews and product benchmarking in relation to human factors.

2.2.1 Benchmarking – Benefits and Features of Existing Products

Based on the previous insights provided by the advisor, a deeper understanding towards the range of products that iron workers use was determined. With this information, six diverse respirators were chosen to be cross referenced and benchmarked for key benefits and features. These products range from powered to non powered respirators, where usability, protection and unique functionality was outlined. A short list was compiled to represent the key benefits and features of current products on the market. This list was cultivated by the previously established research from 1:1 interviews and user observations.

- Secure Air Filtration Power
- Clean Air Delivery Rate (volume)
- Compatibility With Other Products
- Secure Connectivity To Person
- Embedded Filtration Cartridge
- Fan System Settings

Product	Product Image	Benefits	Features
 3M™ Full Facepiece Reusable Respirator	Figure 3. 3M™ Full Facepiece Reusable Respirator - Retrieved from 3M™ Secure Click™ Full Facepiece Reusable Respirator FF-801, Small, 4/Case | 3M Canada	- A silicone facepiece that helps provide a durable and a comfortable fit - A secure fit on the face - Can be used with a passive or electronic clip-on welding lens	- Head mounted - Cool-flow valve - Comfortable straps - The double-flange face seal - Adjustable straps
 3M™ Half Facepiece Disposable Respirator	Figure 4. 3M™ Half Facepiece Disposable Respirator - Retrieved from https://www.3m.com/3M/en_US/p/d/v000093582/	- NIOSH approved against certain organic vapours and particulates - It can be used for a variety of applications, including spray painting - Comes fully assembled with cartridge	- Compactable - Simplistic cartridge replacement - Easily accessible with a wide range of products
 3M™ Versaflo™ Helmet	Figure 5. 3M™ Half Facepiece Disposable Respirator - Retrieved from 3M™ Versaflo™ M-Series Helmet Assembly | 3M Canada	- Premium Visor and Flame Resistant Shroud M-407 help provide respiratory and limited head and eye protection	- Lightweight - Easy visor replacement
 3M™ Particulate Respirator 8577	Figure 6. 3M™ Particulate Respirator 8577r - Retrieved from https://www.3mcanada.ca/3M/en_CA/p/d/v000057503/	- A disposable particulate respirator designed to help provide reliable respiratory protection against certain oil and non-oil based particles	- Compactable - Easily adjustable straps - Lightweight - Easily accessible with a wide range of products
 Air Stream Headgear Mounted Power Air Purifying Respirator	Figure 7. Air Stream Headgear Mounted Power Air Purifying Respirator - Retrieved from https://www.3mcanada.ca/3M/en_CA/p/d/v000093620/	- Headgear-Mounted Powered Air Purifying Respirator System, AS-400LBC - A comfortable, lightweight powered air purifying respirator system helps provide high efficiency respiratory protection against particles	- Head-mounted - Hardhat embedded with visor - Easy assembly and cleaning
 Versaflo Painter's Supplied Air Respirator	Figure 8. Versaflo Painter's Supplied Air Respirator - Retrieved from https://www.3mcanada.ca/3M/en_CA/p/d/v000153484/	- Modular design and convertibility of major components - M-400 Series Helmets are designed to be used with certain 3M™ Breathing Tubes and Powered Air Purifying (PAPR) or Supplied Air (SA) units to form a respiratory system	- Belt mounted - Clear visual supports within visor - Loose fitting facepieces

Table 5. Product Benefits and Features Table

2.2.2 Benchmarking – Functionality of Existing Products

Upon review of the various respirators that iron workers utilize, it was evident that each feature would overlap and maintain a common theme of lightweightness, form fitting, feasible usage and effectiveness. More specifically, identifying the key benefits that users desire and need within current respirator design will help reduce major pain points that currently exist. Considering that, it is clear to see how users prefer a respirator that incorporates; A cool flow valve for enhanced breathing and a speech diaphragm mounted at the front of the mask to offer unimpeded speech transmission. Additionally, the use of a low-resistance positive-pressure exhalation valve allows for normal breathing when used in positive pressure mode which can be beneficial for light welding. The proper placement of gaskets, headband/straps, and face piece holder will result in greater ease of comfort for the user.

Although Table 4 primarily goes over the respirators that iron workers use, the additional protective wear of welding helmet/hood, welding gloves, welding torch, and the lightweight- cool flame-resistant cotton shirt are products that help provide a cohesive experience towards their respiratory health maintenance. Important considerations for these items include; A high durability belt, battery charger and in some cases an air-flow indicator within the helmet/hood design. The material considerations are critical for user comfort as well, since the standard material for helmets/hoods are considered to be thermoplastic material that is strengthened by special glass fiber with high heat and mechanical resistance. Kevlar heat-resistant thread is also utilized in hooded design to prevent seam failure (Statistics Canada, 2021). It is also important to note that helmet balance can affect the user’s breathing experience in a positive and negative way, if the helmet becomes imbalanced then this causes neck and shoulder pain, which in some cases can lead to shortness of breath.

2.2.3 Benchmarking – Aesthetics and Semantic Profile of Existing Products

Product formation is an essential aspect of design which should not be overlooked. As users first encounter a product, their first appeal to it would be the overall form, shape, lightweightness as well as style and how it connects with them at first glance. Building that firm connection requires a proper overview of current product style trends and applying while also advancing key aspects of the form and shape. In the respirator market, it is evident that bulky and harsh designs were made as a quick fix towards respiratory health. As time progressed, the form and shape evolved into a trend of lightweight and minimalistic design. Curvilinear organic shapes were also examined, as these forms would enhance user’s initial interaction with the design, as the organic shapes creates a positive and natural relationship with users when in use. Lines and patterns in the industry are also significant, as both elements require balance between weight & length for cohesion in design, and less confusion. Current colours of respirators include muted earth tones that range from light grey to dark black, this is a result of limiting the UV light refraction and possible UV burns that are harmful to users.

2.2.4 Benchmarking – Materials and Manufacturing of Existing Products

When researching the optimal materials and manufacturing, there is an emphasis on user comfort and the iron workers ability to efficiently produce work in a safe manner. Most common materials used within respirators consist of; Liquid silicone rubber outer mask with reflex seal, neoprene, and butyl rubber (Government of Ontario, 2022). Thermoplastic olefin is used in place of fiberglass because it has similar, if not better performance regarding UV exposure, temperature resistance, water resistance, and impact resistance. As well as cool flame-resistant cotton, and kevlar heat-resistant thread to prevent seam for iron worker clothing. Current technological material advancements include; interference suppression technology works to stop false triggering caused by light sources other than welding, thermal barrier shows significant heat reduction, and auto-darkening welding helmets carrying the EN-379 lens. Additional, advancements to materials include; a 180° flip-up mechanism of visor that can remove item when not in use, as well as fume or gas threat detection sensors that can be read through augmented reality in the visor to view thermal imaging, environmental analysis, and remote image.

2.2.5 Benchmarking – Sustainability of Existing Products

Reduction of harmful material and product waste is an ideal method towards creating a sustainable solution towards products. However, with the single-use disposable particulate respirators, such as N95 masks, the Earth remains filled with the harmful products. To combat this, iron workers should have affordable accessibility towards the reusable respirators and tools that are often used within the industry. For instance, Elastomeric half mask respirators are a type of air-purifying respirator and are reusable devices with exchangeable filter elements (cartridges or filters) that may be selected to provide the needed level of filtration (e.g., N95). The facepieces are made of synthetic or natural rubber material that allow repeated cleaning, disinfection, storage, and reuse (Government of Ontario, 2022). Additionally, solar welding helmets are an option that is now widely available. The little strip of solar panels above or below the view screen clearly distinguishes them. These do not require sunlight since they can capture light from the welding arc (Government of Ontario, 2022).

2.3 Summary of Chapter 2

Research of possible innovations were discovered throughout this chapter, as well as insightful findings towards how iron workers interact with welding tools, with emphasis on the various kinds of respirators. Additional information on workplace procedures and regulations were examined, where it was determined that employers and workers must spend a great deal of time training and testing the use of most respirators prior to use through medical evaluations, respirator test fitting, etc. However, iron workers still find respiratory personal protective equipment (PPE) obstructive through decreasing levels of communication within the noisy construction site or fog/contamination build up, lengthy respirator cleaning & maintenance procedures, etc. Evidently, most welding helmets grant more capacity for non-powered respirators, which means that costly powered respirators and purifying welding helmets are inaccessible for new workers in the industry to easily purchase. Despite this, iron workers still desire a lightweight and balanced welding helmet and respirator that provides greater comfort and benefits their ergonomics, such as; helmet centre of gravity & harness/strap contact points. Above all, this chapter outlined key aspects that can propel this thesis study by noting how iron workers on site typically wear no facial covering or use thick fabric ‘masks’ for greater comfort.

CHAPTER 3: ANALYSIS

Figure 9. Pixabay. (2019, June 29). *Worker Gas Welder Pipe*. Retrieved December 16, 2022, from https://pixabay.com/photos/worker-gas-welder-pipe-work-human-4304178/

3.1 Analysis – Needs

This chapter will analyse the scope of the needs, benefits and latent needs of users, while creating a parallel analysis towards usability and human factors that iron workers may encounter while on the field. Through reflecting on the general findings from the user research and product research, significant design development can be cultivated in order to inspire innovation towards mitigating air contamination for iron workers.

3.1.1 Needs/Benefits Not Met by Current Products

Research depicts that current respirator products can be cause for confusion among users, even after receiving proper training. Whether it may be the bulky size or shape, the lack of comfort within the straps or the unaffordability, most iron workers find it challenging to wear the current respirator designs without identifying at least one discomfort. Additionally, if the workplace respirator becomes uncomfortable or loosens over time, due to poor respirator fittings, this leads most users to sacrifice their respiratory health by solely wearing a welding helmet or hood, with no respirator mask in use.

Another design notion that is not met would be the human aesthetics towards respirators and helmets. Current designs can be seen as the typical look for respirators, however there is a lack of an ergonomic or comfortable outlook, as mentioned in 2.2.3 Benchmarking – Aesthetics and Semantic Profile of Existing Products. At first glance, respirator designs have a bulky and heavy look towards them and minimal organic shapes that visually displays the comfort it is intended to have. Although some designs have been propelled in their development of organic form and shape, there are still drawbacks, such as complexity of use, isolating design due to lack of clear communication, andhigh price point.

3.1.2 Latent Needs

Latent Needs	Benefits Statement
Ease of use	- Easier respirator set up, with simplistic training - Manageable maintenance with feasible repairs
Lightweight & balanced	- Less aches and pains when lightweightness and balance are at the centre of the design - A respirators lightweightness is important towards the overall weight of items the iron worker must wear - I.e. Welding helmet/hood, tool kit, welding torch, etc.
Inexpensive in cost for all users	- Spending over $1,000 on a powered respirator is undesirable and expensive for both the employer and employee - Having to not sacrifice good design or health maintenance
A product that feels seamless	- The respirator should be feel like second-nature to apply and remove

Table 6. Latent Needs and Benefits Statement

3.1.3 Categorization of Needs

Immediate Needs	Benefits Statement	Correlation Towards Design
Protection	- Respirator protection that reduces the inhalation of poisonous chemicals and gases	**Strong**
Comfort	- Less obstructiveness of communication and vision for greater productivity and safety	**Strong**
Adaptability	- Ability to work more efficiently when product's various components are simplified	**Strong**
Latent Needs	**Benefits Statement**	**Correlation Towards Design**
Ease of use	- Easier respirator set up, with simplistic training - Manageable maintenance with feasible repairs	**Strong**
Lightweight & balanced	- Less aches and pains when lightweightness and balance are at the centre of the design - A respirators lightweightness is important towards the overall weight of items the iron worker must wear - I.e. Welding helmet/hood, tool kit, welding torch, etc.	**Strong**
Inexpensive in cost for all users	- Spending over $1,000 on a powered respirator is undesirable and expensive for both the employer and	**Moderate**

	employee - Having to not sacrifice good design or health maintenance	
A product that feels seamless	- The respirator should be feel like second-nature to apply and remove	**Moderate**
Wants/Wishes	**Benefits Statement**	**Correlation Towards Design**
Durability	- Not having to go in for re-tests or refittings of respirator - Having durable lens with precision with vision enhancements	**Strong**
Communication clarity	- Ability to easily communicate with coworkers while productively getting work done	**Strong**
Simplistic maintenance and/or cleaning	- Being able to easily clean respirator and put components back into place without fear of misplacement or mismanagement of parts	**Moderate**

Table 7. Categorization of Needs Table

3.2 Analysis – Usability

Identifying the user pain points and points of delight is an important step towards design viability, as it provides key insights toward how users typically interact with products and where new opportunities may be. Through visualizing this process with a user journey map and user experience map, a brief glimpse into the day of an iron worker is presented.

3.2.1 Journey Mapping

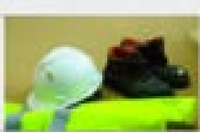
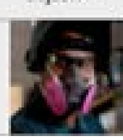
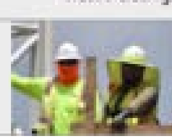
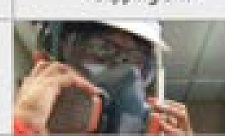
	Task 1	Task 2	Task 3	Task 4	Task 5
User Goal	**Preparation**	**Reviewing & Securing PPE**	**Communication on Site**	**Assess Comfort**	**Unequip PPE**
User Actions	• Receiving insights on daily tasks from supervisor • Reluctantly goes to pick up PPE	• Checking on PPE's cleanliness • Placing PPE on in order that is displayed by supervisor	• Attempting to communicate with supervisors and peers but having difficulty	• Redoing training/fitting since workers can outgrow their equipment	• Workers are done welding, they are able to take off PPE • PPE cleaning can be done
User Thoughts	• "Is this mask enough protection?" • "I hope this PPE actually works."	• "I think I'm putting this on right." • "Why are there so many layers to adjust?"	• "Why is it hard to hear and talk using this?" • "Should I take off PPE to be heard clearly?"	• "This PPE is feeling unbalanced." • "Should I just ignore it slipping off?"	• "I can finally breathe!" • "I'm so glad to have this off!"
Storyboard					

Table 8. User Journey Map

The user journey map outlines the average tasks done within the welding industry, such as; how users put on personal protective equipment (PPE), how users react to personal protective equipment (PPE), how users work/communicate with personal protective equipment (PPE), what work cultural practices do users undergo when using personal protective equipment (PPE) and how users remove personal protective equipment (PPE).

Task 1. Preparation & Task 2. Reviewing & Securing PPE

Originally, the user would think it is easy to secure and prep his respirator, as he has undergone training on its proper usage, maintenance, applying and removing. However, the initial placement of a respirator was daunting, as the user had to ensure each filter was properly attached and the air valves were working correctly, as well as no damages or hindrances were on the surface of the respirator. With this being the case, the user would get weary by this repetitive process, and try to place the respirator on. As the user works throughout the day, the headband straps become tight and uncomfortable, which means the user has to call over his supervisor for assistance in the matter.

Task 3. Communication

From the user journey map, it can also be noted that clear communication is sometimes difficult to achieve. This is a result of the layers of products that the users must wear in order to ensure there is some form of safety involved. However, this makes the user feel easily frustrated by the lack of clear communication when wearing the personal protective equipment (PPE) and attempting to verbalize work schematic inquiries with supervisors or coworkers.

Task 4. Assess Comfort & Task 5. Un-Equipe PPE

Throughout the day, users often wonder whether they are wearing their PPE correctly, as they may feel looseness, by this point the user either books a respirator re-fitting or continues to ignore the discomfort. Typically, users are advised to clean their respirator often and ensure that the accurate cleaning process is in place. However, this user is easily overwhelmed by the various components that are involved within a respirator, such as the filters cartridges, cool flow valve, gasket and seal, headband strap, face piece holder, inhalation valve, etc. Which results in the worker rushing the cleaning process of the personal protective equipment (PPE) without appropriate inspection.

3.2.2 User Experience

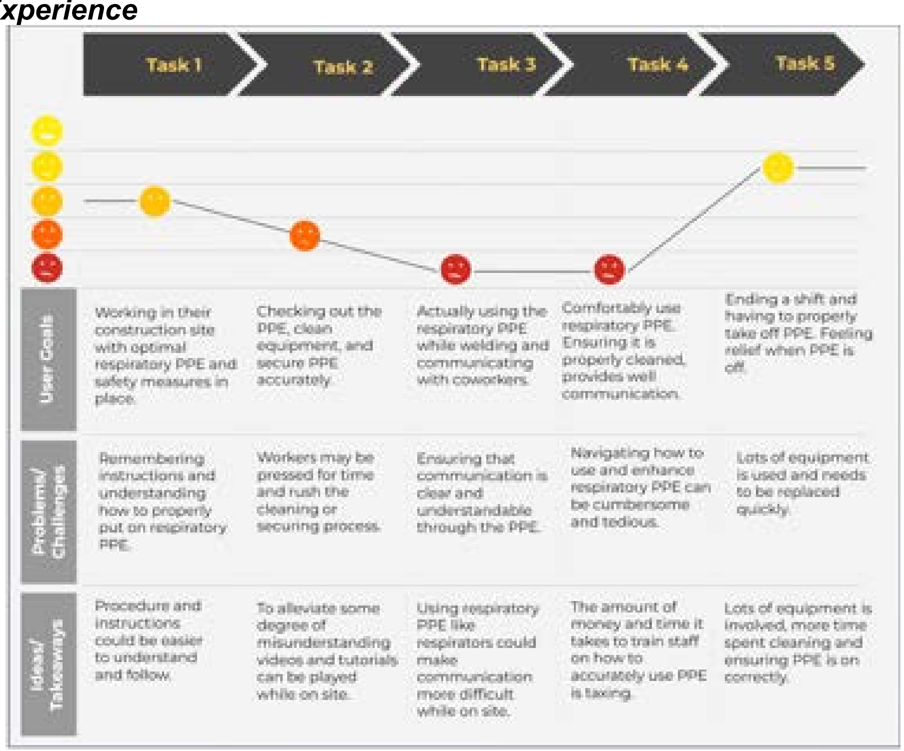


Table 9. User Experience Map

Similarly, the user experience map continues to emphasize how the worker may feel towards these challenges, while trying to attain the goal of maintaining appropriate respiratory health. Additionally, the user ideas and takeaways were analyzed to determine how the user may be feeling towards the general task.

Task 1. Preparation & Task 2. Reviewing & Securing PPE

In the user experience map (Table 8), the user seems to be optimistic about the usage of the respirator towards their health maintenance when welding. However, as they try to remember the proper procedure and instructions, they get easily confused, as some components sound and look similar, for instance the gasket and silicone seal within a respirator. Additionally, the user may mistakenly touch components that are required to be secured or rearranged. As the user tries to place on the respirator for the second time, things go much smoother, however the pressing issue of the headband strap being too tight is still predominant. While working, the user may notice obstructions , such as particle contamination on the respirator, thus, they try to clean it on their break to ensure the use is done correctly. The user would still ask his supervisor or coworkers for tips and tricks towards maintaining the respirator.

Task 3. Communication

In correspondence with the user journey map (Table 9), it is evident that the communication is still difficult to use while the respirator is one, thus the user would swiftly take it off to get his point across and have a productive conservation. However, this results in any airborne substances getting into the respiratory system of the user, which is something that the user overlooks because it is for a few minutes.

Task 4. Assess Comfort & Task 5. Un-Equipe PPE

The user would still attempt to adjust PPE to appropriate comfort levels, and would often wonder whether he is wearing his PPE correctly, as they feel looseness. Additionally, the inconvenience towards booking a respirator refitting is an option that the user overlooks, as long hours of retraining would be involved, thus the user continues to ignore the discomfort. Once again, the user feels as though the cleansing process of the respirator is a long and thorough one, thus he easily rushes the process of the thorough cleaning so it can be done in half the time. As the user gets ready to leave work, he notices his coworkers who are not welders, wear thick fabric facial coverings, and he wishes to have a comfortable and simplistic PPE like that.

3.3 Analysis – Human Factors

User ergonomics is a critical juncture in any design process, as most products incorporate touchpoints that affect how the user could interact, feel and use a given product. Understanding the ergonomics behind user interactions produces a greater outcome for a product’s benefit, where reference to 1:1 human scale diagrams, measurements can be incorporated through a physical study.

3.3.1 Product Schematic – Configuration Diagram

Literature Review

The anthropometric data of the 50th percentile female and 97th percentile male was referenced from the Tilley and Dreyfuss (1993) book; *The Measure of Man and Woman*. These dimensions were documented in this ergonomic study to depict the accurate measurements of the upper body, including the head (i.e. centre of the scalp to the bottom chin, neck length etc.), upper torso (i.e. the shoulder width, chest width and depth, waist, etc.), as well as the arms and hands (i.e. arm length, hand width, etc.).

Ergonomic Diagrams

This ergonomic study was utilized to provide key insights towards the design’s primary function, level of comfort, ease of use and whether any challenges may be present. To investigate these insights, the following interaction between the major touchpoints were documented to identify and reduce adverse experiences while increasing favourable experiences of:

- Getting user equipped/equipped with the suit (Upper body)
- Ease of use when performing tasks while wearing a facial mask, visor & helmet (Head & Arms)
- Interaction with respirator suit functions (Hand & Arms)

This study benefited the use of schematic diagrams of the 50th percentile female and 97.5th percentile male, as it provided a general understanding of comfortable product measurements. The figures below display the measurements in inches.

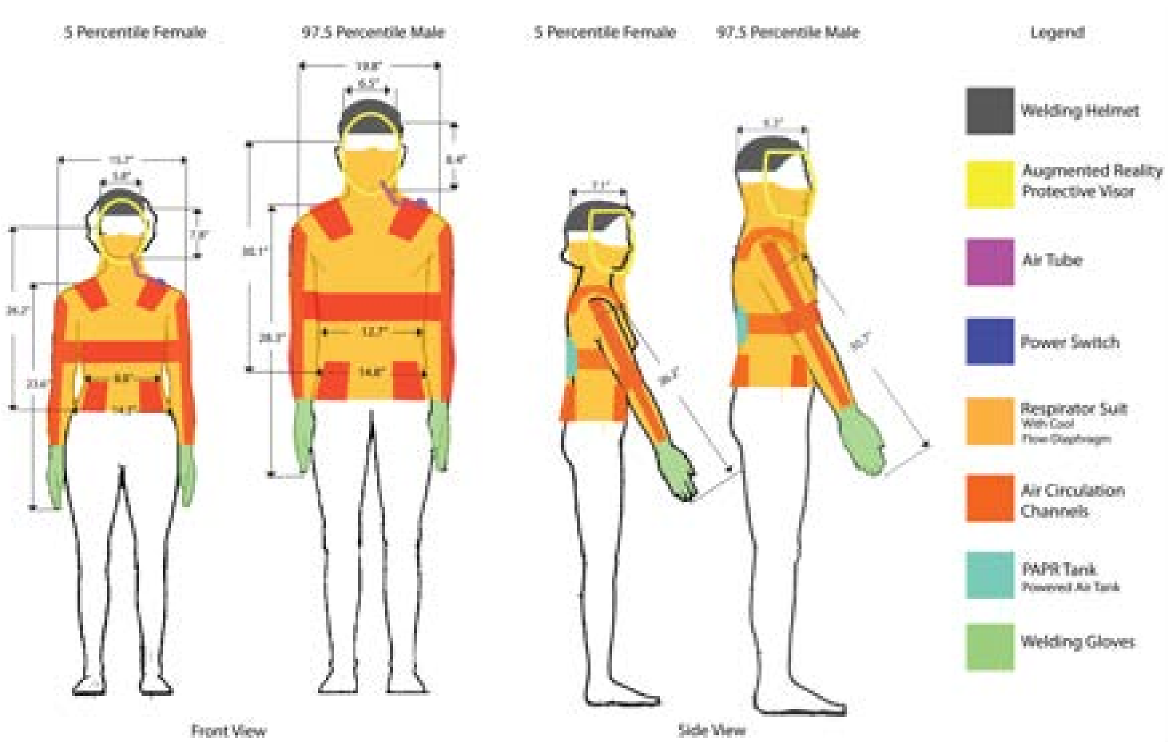


Figure 10. Product Schematic Diagram

Additionally, the schematics were used to guide a general design for both the 97.5th percentile male and the 50th percentile female, as these measurements are typically found among users within the ironworker occupation. Through these schematics, design decisions could be determined in order to best suit the users across the spectrum of the 97.5th percentile male and the 50th percentile female. Colour codes that represent the potential design details can be indicated based on the user's dimensions, which can lead to greater comfort and usability. The black colour code represents the welding helmet that both users would use, as well as the golden colour code to indicate the location of the augmented reality visor. The colour code then indicates the purple to represent the breathing tube, along with blue for the power switch. To emphasize the respirator suit it is swatched with a bright orange, while the air flow channels are a dark orange that flow back to the teal powered air supply tank and green welding gloves.

3.3.2 Ergonomic – 1:1 Human Scale Study

Target User(s)

The evaluation process considered the full scale 1:1 ergonomic buck of the respirator suit in relation to the 90th percentile male and 50th percentile female. To investigate the user experience and general usage, the following critical observations were configured:

- Getting user equipped/equipped with the suit
- Observing how users perform with the suit in use, as well as with the helmet visor (Vision clarity and efficiency while in use)
- Interaction with respirator suit functions (Ability to note the location of the power button, the visor's 180° flip switch and built-in respirator use)

Evaluation

The 1:1 human scale study with models gave insights towards ease of use, basic interactions and how the user would equip and unequip their suit. Enlightenment on irritations or obstructions of the current design was also determined through the ergonomic analysis. The figures below display how the participants would appear when using the respirator suit in a frontward position.

Respirator Suit Fully Equipped:

Figure 11a. Male Percentile Users Wearing the Respirator Suit

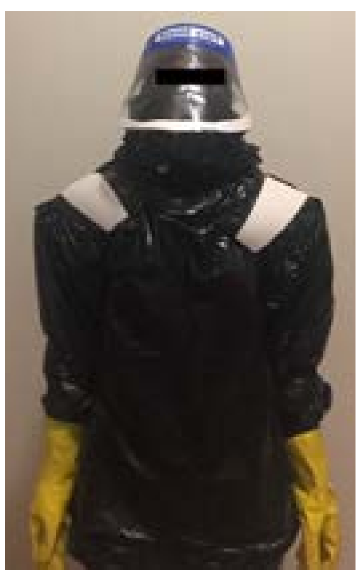


Figure 11b. Female Percentile Users Wearing the Respirator Suit

Figure 12a. Male Percentile Users Side

Figure 12b.Female Percentile Back View

Figure 11a depicts a 90th percentile male wearing the respirator suit, along with the helmet, visor, air circulation channels and gloves. It is most notable that the suit fit well on this user, however the internal mask that was built in did not reach his nose for total air coverage. While figure 11b depicts a 50th percentile female wearing the respirator suit, where the mask fits well, but the visor overarches and does not provide the full coverage required. Figure 12a shows the side view of the 90th percentile male where it is evident that the helmet and visor of the respirator suit could provide greater security and coverage for the ears and sides of the face. Figure 12b shows the 50th percentile female’s rear view, where it can be shown that the suit is too large for it to be comfortably worn when performing tasks.

Respirator Suit Interactions:

Figure 13a-b. Basic Interactions with Respirator Suit

Figure 13a displays how the 90th percentile male would interact with the power button that is located on the left side of the suit, the user is easily able to reach this button and is ergonomically correct for the hand or finger to press and activate. Figure 13b continues to show the basic interactions of the suit by demonstrating how the user could initiate the 180° visor flip; the user was naturally able to use this function of the design with little to no instruction.

Analysis

According to the Occupational Safety and Health Administration (OSHA) in the United States and Canada, a workplace should conduct a respiratory evaluation and provide appropriate respirators and respirator fit testing should the work site require it. The respirator must be put under various considerations, such as the type and weight of respirator to be used, duration and frequency of use, expected physical work effort, whether additional personal protective equipment (PPE) is to be worn, etc. (Respiratory Protection - Overview | *Occupational Safety and Health Administration*, 2011). However, prior to the OSHA developing these requirements for respirators, welding helmets were designed with little to no consideration towards benefiting respiratory health, user ergonomics and interactions. This resulted in strenuous labour due to unbalanced harnesses and weight distribution of a respirator and/or welding helmet, which affects the users, neck, back and head. Prior to the modern iterations of welding helmets, most were not developed up to safety regulations which caused some users to decide between their respiratory health protection or UV light radiation burn prevention.

The respirator suit aims to tackle these design pain points by incorporating a cohesive design which allows users to obtain both a welding helmet and a built in compact respirator which provides air purification. Nonetheless, this design's ergonomics was the next critical step towards the viability of the product, as ergonomics are heavily weighed in construction type occupational settings. With this in mind, the respirator suit 1:1 human scale testing of both the 90th percentile male and 50th percentile female proved to be fruitful, as key insights were given towards the onboarding of the suit (i.e. Getting user equipped/equipped with the suit), basic functionality (i.e. Mobility, vision clarity, and how users perform with the suit in use), and interaction touchpoint response with respirator suit functions.

Getting Users Equipped/Unequipped:

Initially, the users were requested to equip themselves with the respirator suit where both users were able to identify the front and the rear parts of the suit easily. Both users started equipping themselves with the torso component of the suit, then transitioned into attaching the helmet visor. As the suit was being equipped, the 90th percentile male disclosed that the seams in the right shoulder are tight and over-stretching the arm could easily exhaust the design. Despite this, the general range of motion in the torso area was breathable and the correct proportions for comfort. The 90th percentile user also noted that the slight gaps within the visor near the neck and ears area may cause irritation or exposure to UV light burns or radiation, which is an area that should be addressed. Additionally, the female 50th percentile user disclosed that general design allowed her to move freely, yet the size must be reconsidered as it was too large and at times could become obstructive. Both the percentile users were able to swiftly equip and unequip themselves with the suit, as it followed a simplistic two-step onboarding process, yet considerations should be made into securing the mask component of the suit, as it would often become displaced.

Basic Functionality:

Most notably, the mobility aspects for both users were loose and free, yet the 90th percentile user noted concerns over basic stretching of the arm or excessive motion which can easily cause material breakage in the right arm. The visor helmet component was an area in discussion to adjust, as the 50th percentile female may find it difficult to properly view her surroundings when the visor overarches and obstructs vision by causing glares against refracted light sources. Both users were able to mimic basic welding tasks of using a torch, adjusting posture and communicating with the mask on. Typically, ironworkers lean or slightly bend over a project when using a welding torch in order to ensure precision, however, since the respirator suit design equips augmented reality precision, both users were asked to slightly bend with a powertool (to mimic a torch) in hand and then stand upright with the powertool in hand. The 90th percentile user disclosed that the slight bend granted greater comfort and precision in the short term, as the users height created discomfort in the mid back and neck when bending in the long term. While the 50th percentile female found that standing straight to do a task granted greater comfort, as it was near the user's eye level and height already, so bending was not required.

Interaction Touchpoint Responsiveness:

A critical stage in the ergonomic study was the interaction touchpoint responsive, having the users locate and use each feature within the design will inform how they will typically interact with the product and allow for positive responsiveness. The users were first required to press the power button for the PAPR (Powered Air Purifying Respirator) unit in order to determine if the button dimensions were effective for both users. Each user was able to instinctively identify where the power button was located and had no trouble using their hands or fingers to activate the function. When users were told to use the visor's 180° flip function, both the 90th percentile male and 50th percentile female were able to use one hand to lift up the visor. When it came to the discoveries from the built-in respirator mask, it proved to be quite difficult for the 90th percentile male to gain full coverage, as the nose was not fully covered by the component. Also, the mask would shift on occasion when users would make sudden movements, which means greater security and fittedness is required. This is a significant aspect within the design, which means further modifications must be made to ensure that the mask covers and remains secured when in use for long periods of time.

LIMITATIONS & CONCLUSION:

Some limitations that were identified during the ergonomic study include:

- The oversized torso of the respirator suit did not account for other user’s dimensions
- The material choice for the 1:1 model did not represent the potential material that will be used to create the final model
- The material could be less intrusive and provide a more true-fit towards each user
- Built-in mask should incorporate gender and ethnic facial characteristics to apply within its fabrication

Overall, the 1:1 ergonomic study proved to be effective in determining design functionality while understanding the level of comfort or discomfort that may be present when in use. Additionally, the operation of equipping and unequipping the suit seamlessly was analysed, where key insights were given towards primary hindrances that the design currently needs to resolve.

Some Ergonomic Issues That Are Still Not Yet Resolved:

The one-size-fits-all approach should not be applied to the development of protective wear, as the safety of workers and their ability to work efficiently is of paramount importance (Kolisi & M'Rithaa, 2016). Although further development is required towards having a respirator suit for both male and female users, the current design shows promise towards having a cohesive design for gender specific options. Through this study, it is evident that males have more muscle mass than females that needs to be accounted for within the arm and shoulder proportions of the design.

Alternative Possibilities For The Future:

Based on the current study, the alternative possibilities for the future include:

- Refinement of the 1:1 scale model along with appropriate material representation
- Developing a secondary ergonomic buck to provide greater understandings and comparisons among the genders
- Creating further observational trials that prompt the user to try various other physical tasks (i.e. lifting of products, excessive movement, etc.) to test apparel strength

This study helped determine the current design limitations and where it needs to expand, considering these results, further research into the male and female body specifications towards clothing design must be taken into account. Additionally, knowledge towards the various facial features among the genders is critical towards reaching an optimal mask fitting for both users.

3.4 Analysis – Aesthetics & Semantic Profile

Ideally, curvilinear organic forms should be explored to enhance the user's initial aspect of the design, as well as incorporation of organic shapes create a positive relationship with users. Additional material considerations include; lightweight and minimalistic materials that are approved by OSHA regulations and are sustainable and easily washable.

Figure 14. Aesthetics and Semantics XY Matrix

Pre-existing products have been placed in a XY Matrix semantic that classifies the basic form and shape, most forms were in the oval range, while the remainder were fitted within the circular and half-circular quadrants. This matrix outlines the basic characteristics of current respiratory protective products and the growing trend to alter bulky designs into minimalistic, lightweight and organic forms. With this in mind, further exploration on aesthetics will be conducted in order to fully depict the user's wants and needs towards ergonomic comfort.

3.5 Analysis – Sustainability: Safety, Health and Environment

Considering that iron workers face a vast amount of occupational hazards which range from harmful air toxins, UV radiation, burns, etc., the protection measures against these hazards require high-density materials with a lightweight balance and longevity of use. Currently, there are no sustainable initiatives for personal protective wear towards iron workers other than welding practices that can reduce carbon dioxide emissions (Government of Ontario, 2022). However, the protective equipment for iron workers must meet the expectations of the Occupational Safety and Health Administration (OSHA). Thus, a literature review on the sustainability aspects towards materials and manufacturing, as well as health and safety of current protective wear for iron workers.

Materials

When researching the optimal materials and manufacturing, there is an emphasis on user wearable comfort and the iron workers ability to efficiently produce work in a safe manner. Most common materials used within respirators consist of; Liquid silicone rubber outer mask with reflex seal, neoprene, and butyl rubber (Government of Ontario, 2022). Thermoplastic olefin is used in place of fiberglass because it has similar, if not better performance regarding UV exposure, temperature resistance, water resistance, and impact resistance (Government of Ontario, 2022). Typically, helmets are made from polycarbonate plastics that protect from radiation, burns or impact (Lowney, 2010). As well as cool flame-resistant wool/cotton, and kevlar heat-resistant thread to prevent seam for iron worker clothing. Current technological material advancements include; interference suppression technology works to stop false triggering caused by light sources other than welding, thermal barrier shows significant heat reduction, and auto-darkening welding helmets carrying the EN-379 lens (Government of Ontario, 2022). Additional, advancements to materials include; a 180° flip-up mechanism of visor that can remove item when not in use, as well as fume or gas threat detection sensors that can be read through augmented reality in the visor to view thermal imaging, environmental analysis, and remote image (Lowney, 2010).

Manufacturing

Depending on the equipment required for a certain welding task, the manufacturing treatment process will be quite different as there are various levels of protection required. More specifically, flame resistant cotton has become a popular, inexpensive, lightweight and breathable apparel choice of material, as it provides the ideal combination of protection, cost and washability (Lowney, 2010). FR fabrics are treated with a chemical that "off gasses" when it comes in contact with flames, molten metal or other intense heat sources. The off-gassing process eliminates oxygen from the area that would be required to cause combustion. (Lowney, 2010). Flame retardant and leather grain processes may vary depending on the manufacturer, with high quality treatment standards in place to ensure that chemicals are applied consistently to garments for safety assurance (Lowney, 2010). Advanced synthetic materials, such as flame-inherent fabric is comprised of a patented blend of oxidized acrylic fibers and modern strengthening fibers, which has been proven to withstand catastrophic heat exposure including iron production (Lowney, 2010). This proprietary compound is added to the base material, increasing its ability to shed sparks, spatter and other flaming or molten materials, making it applicable for welding (Lowney, 2010).

Health

Reduction of harmful material and product waste is an ideal method towards creating a sustainable solution towards products. However, with the single-use disposable particulate respirators, such as N95 masks, the Earth remains filled with the harmful products. To combat this, iron workers should have affordable accessibility towards the reusable respirators and tools that are often used within the industry (Government of Ontario, 2022). For instance, Elastomeric half mask respirators are a type of air-purifying respirator and are reusable devices with exchangeable filter elements (cartridges or filters) that may be selected to provide the needed level of filtration (e.g., N95). The facepieces are made of synthetic or natural rubber material that allow repeated cleaning, disinfection, storage, and reuse (Government of Ontario, 2022).

Safety

The emphasis on the iron workers’ safety is displayed through the procedural requirements that personal protective wear must incorporate. Based on the Government of Canada’s Occupational Health and Safety guidelines, iron workers' health must be the top priority of employers. Helmets should be made of material that complies with ANSI Z49.1., as well as filter lenses and cover plates prescribed in ANSI Z87.1. (Canadian Centre for Occupational Health & Safety, 2017). Additionally, workers must wear approved safety glasses with side shields (or goggles) under their helmet, with side shields to protect against flying metal, slag chips, grinding fragments, etc. (Canadian Centre for Occupational Health & Safety, 2017). Most notably, the filter lens shade must be at least ANSI Z49.1 according to the Lens Shade Selector Chart (Canadian Centre for Occupational Health & Safety, 2017). Additionally, high-density yet lightweight flame-resistant material has become an essential protective wear, however most iron workers are cautious towards the colour of their apparel. This is a result of the colour treatment and how each colour may interact with the UV lights and radiation, as hues like black or navy blue in flame-resistant cotton attract heat, while reducing light reflection when welding (Lowney, 2010). Most popular colours include grey, tan, burgundy and in some occasions yellow and orange which creates a cooler and breathable fabric when welding.

3.6 Analysis – Innovation Opportunity

3.6.1 Needs Analysis Diagram

Figure 15. Prioritization Grid of User Needs

Understanding the user's needs is pivotal towards developing a viable solution, thus by using a prioritization grid of the essential personal protective equipment (PPE), insights can be gathered on significant safety characteristics. The personal protective equipment (PPE) is represented in yellow and the corresponding safety characteristics were marked in orange to indicate the overlying health benefits that users need and desire while welding.

Needs Statement

With the review of previous research insights from advisors, user observation/interviews and literature reviews, the needs of iron workers include:

Needs	Benefits and Underlying Needs	Level of importance		
Basic Needs				
Air Purification	Proper air filtration when welding grants users with reassurance towards personal safety. Ultimately, this helps: - Increase health and safety which leads to less sub-particle contamination - Build reliance on air purifying tools when welding - Strong rapport between the respirator use longevity/interaction in correspondence to user			***High***

Appropriate Equipment	**Personal protective equipment (PPE)** can be bulky and obstructive while working overtime while it should be light and manageable.
	Typical welding safety equipment includes:
	- Welding helmet/hood
	- Heavy-light welding shirt/apron composed of flame resistant cotton/leather
	    - Partial or Full-body protection
	- Breathable welding gloves
	- Respirator Mask
	    - Non-powered respirator masks
	    - Powered respirator masks
	- Overall, each welding safety equipment should provide an enhanced ability for users to comfortably work, a large amount of consideration must be made into materials, as each component should be **flame-resistant**
				High

Ease of Use & Communication	The equipment should provide feasible control for fast-paced environment use. Communication can often become muffled which can cause frustration, miscommunication and lack of efficiency within the workplace due to certain respirator clarity.			***High***
Product Interchangeability	Most products that have interchangeability are restricted by their product family, this means that respirator requirements must be carefully considered if users desire to use welding helmets.		***Moderate***	
Level of Ergonomics	**Having comfortable equipment** promotes greater work ethic, which means appropriate consideration of weight distribution of the welding helmet and respirator's centre of gravity is critical towards satisfaction .			***High***
General Safety	Protection against air toxins, UV radiation, burns and sparks are significant towards the health and wellbeing of user.			***High***
Affordability	New workers can be daunted or off-put by the price of current respirators, as better quality equipment can become difficult to purchase.	***Slight***		
Work Cultural Procedures	Workers have a tendency to remove facial protection or wear thick-fabric masks (Not approved by OSHA) to ensure that communication can be clear, however this results in a lack of safety since air particles have access to the body.	***Slight***		
Feasibility of Equipment Procedures	Most respirators require multiple test fittings throughout the year or refittings, as the straps within air purifying respirators can become undone. Additionally, the procedures by which users are able to understand how to maintain, sanitize and use each component of respirators can be long and tedious.		***Moderate***	

Table 10. Underlying Benefits & Needs Table

The underlying benefits and needs table (Table 9) analyzes the personal protective equipment (PPE) and the corresponding safety characteristics within the prioritization grid of user needs (Figure 15). Both provide similar insights towards the welding community requirements, where the high level of needs are air purification, appropriate equipment, ease of use and communication, as well as ergonomics and safety. Both information sources of the underlying benefits and needs table (Table 9) and the prioritization grid of user needs (Figure 15) disclose that the product interchangeability and feasibility of equipment procedures have become moderate needs of the users. Affordability and work-cultural procedures towards personal protective equipment (PPE) are of slight importance.

3.6.2 Desirability, Feasibility & Viability

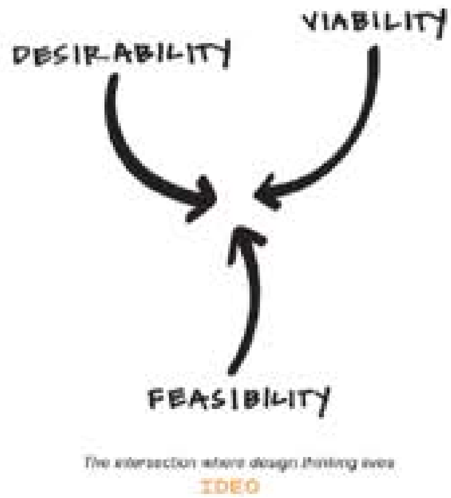


Figure 16. IDEO Model for Design Thinking - Retrieved from https://designthinking.ideo.com

Determining the essentials of a product's desirability, feasibility and viability is critical towards marketable success. With this notion in mind, constructing strong desirability of a design enhances the product's level of interest, while allowing feasibility will ensure that users are able to comfortably interact will produce strong viability. Incorporating the desirability, feasibility and viability from IDEO's Model (Figure 16) into the design solution of this thesis is essential for product commercial success.

Desirability

The iron working community is a field that is required for infrastructural success of commercial construction, additionally, there are many hobists of the community that enjoy using the interchangeable skill of welding. Professional iron workers often follow the Occupational Health and Safety Administration (OSHA)'s regulations towards respirator use, however finding the appropriate personal protective equipment (PPE) with a balance between ergonomics, function, and durability can be time-consuming and costly. With an introduction to a new product that allows for ergonomic comfort, interchangeability and safety towards the respiratory system, there is opportunity for innovation within current welding personal protective equipment (PPE).

Feasibility

Current personal protective equipment (PPE) for iron workers include; welding helmets/hoods, respirator masks, flame-resistant apron/apparel and gloves that have been developed towards comfort through ergonomic considerations. Despite this, iron workers may sacrifice certain personal protective equipment (PPE) based on cost, ease of use, effectiveness or compatibility with other products. Developing an opportunity to mitigate various personal protective equipment (PPE) while enhancing cost, ease of use, effectiveness through potential smart technologies will grant work-cultural benefits.

Viability

Current welding personal protective equipment (PPE) that are in place are chosen based on reliability and conventionalism. Products such as; welding helmets/hoods, respirator masks, flame-resistant apron/apparel and gloves are specifically chosen for safety and durability, by enhancing these key aspects of personal protective equipment (PPE) with the use of smart technology for welding enhancements, this will provide greater convenience and build strong rapports within the iron working community.

3.7 Summary of Chapter 3 – Defining Design Brief

With the appropriate consideration of the research from Chapter 2 and the analysis of Chapter 3, deeper understanding of user needs, product limitations and possible areas for innovation for welding personal protective equipment (PPE) were discovered. Using these insights, a design brief can be determined to support the design development phase. With consideration of the Occupational Safety and Health Administration (OSHA)'s Respiratory Safety Guidelines, an innovative one-stop personal protective equipment (PPE) solution for iron workers should be cultivated. Where this solution should be specifically designed for the mitigation of sub-particle respiratory hazards, while maintaining a level of comfort, adaptability and durability for users.

CHAPTER 4: DESIGN DEVELOPMENT

Figure 17. *InWay. (2019, August 4). Bulgarian Sparks Work Cuts - Free photo on Pixabay. https://pixabay.com/photos/bulgarian-sparks-work-cuts-metal-4384342/*

4.1 Initial Idea Generation

Considering the insights obtained from Chapter 2: Research and Chapter 3: Analysis, greater design considerations can commence into the following phases of; ideation, concept exploration, concept strategy, along with refinement and validation.

4.1.1 Aesthetics Approach & Semantic Profile

Figure 18. Inspiration Board

With the information provided from existing products, an inspiration board was cultivated to further guide the aesthetics and semantic approach towards the design. Key aspects that inform the design include:

- Curvilinear shapes
- Organic forms
- Balanced lines
- Equal patterns

4.1.2 Mind Mapping

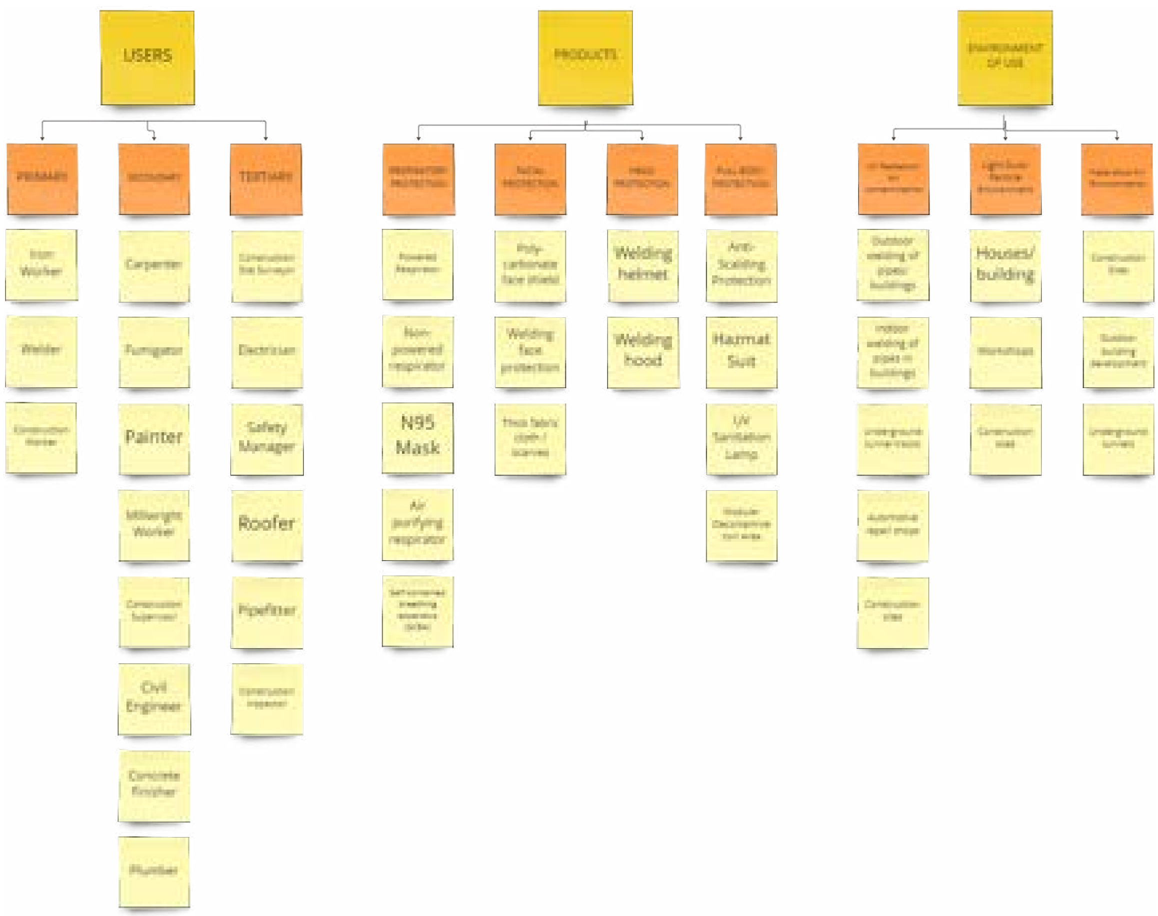


Figure 19. Mind Mapping

Figure 20. Section of Affinity Mapping

Brainstorming and categorization are significant towards the development of this thesis, as new and different aspects of the design arose and posed stronger questions that the design could potentially answer. With the use of mind mapping, the various users were identified and categorized in order to understand the primary, secondary and tertiary user standpoint of current respiratory impairments within the construction work environment (see Figure 2). Further considerations were researched based on two recurring notions that users seemed to embellish the most, which was overall safety towards respiratory health and vision clarity (see Figure 3. Section of Affinity Mapping). These general findings benefitted the design, as comparisons and drawbacks were analyzed and opportunities towards understanding the user's gains and pains was developed further.

4.1.3 Ideation Sketches

Through undergoing the aesthetics approach and semantic profile, coupled with the use of mind mapping, rough solutions were ideated in order to fulfill the users' needs and wants. To start the design phase, six idea variations were developed with the aim of tackling different directions. These directions included; portable air decontamination, air ventilation, respiratory purification as well as other key factors such as; communication and vision enhancement.

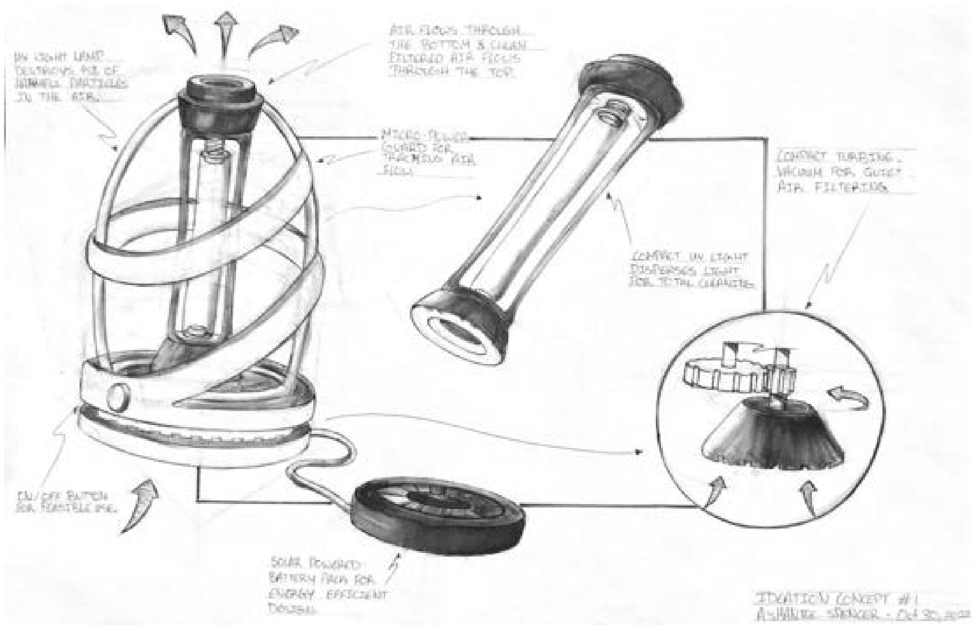


Figure 21. Ideation Sketch 1- UV Sanitation Lamp

Ideation one tackles the issue of air sanitation within the typical environments that welders may reside in while on the job. The key aspect of this design was its compatibility with HVAC systems to cover small room air sanitation within the welding site or break rooms that may have air toxin exposure.

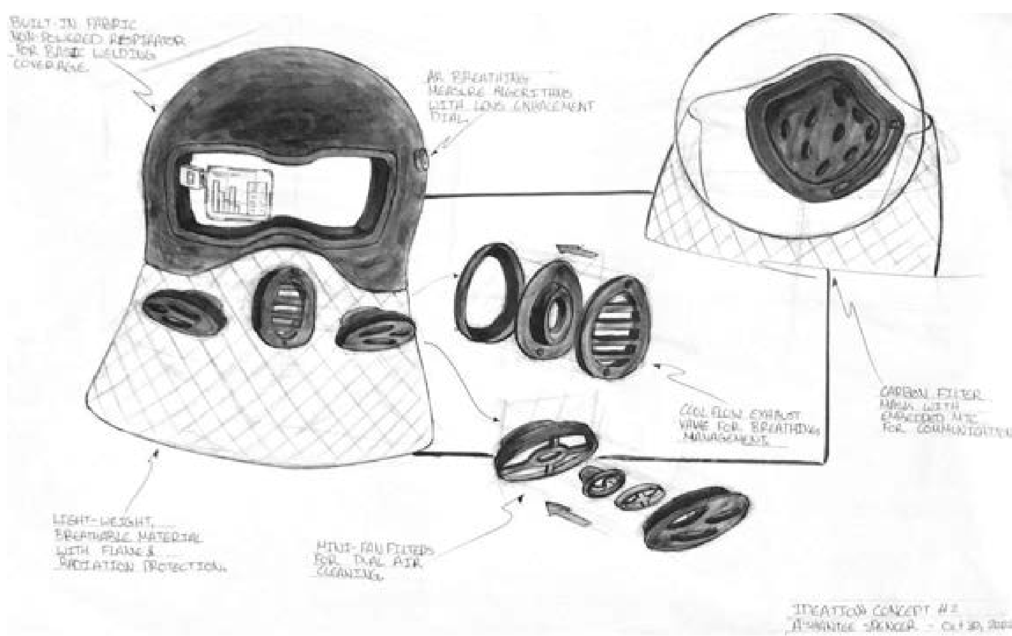


Figure 22. Ideation Sketch 2- Hooded Respirator WIth Augmented Reality

As for ideation two, its primary function was to introduce augmented reality enhancements to propel the user's understanding of their air quality instead of users having to carry an air flow gauge controller on their person. Additionally, users would be provided welding and respiratory coverage with the hooded design aspect, as filters and portable fans would be incorporated within the internal hood.

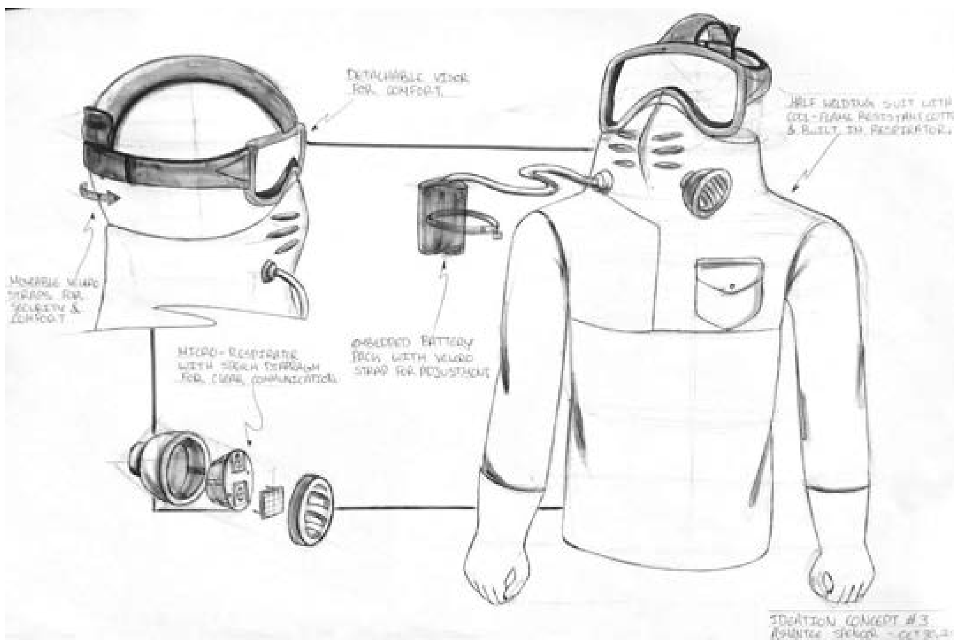


Figure 23. Ideation Sketch 3- Respirator Suit

The third idea was derived from an observational opportunity, where some welders on a construction site were seen with a thick fabric covering over their nose and mouth. To replicate this idea, a respirator suit was ideated with a simple pull-up design which can be easily adopted with the work environment, as the culture seems to be a subconscious trend with form and function.

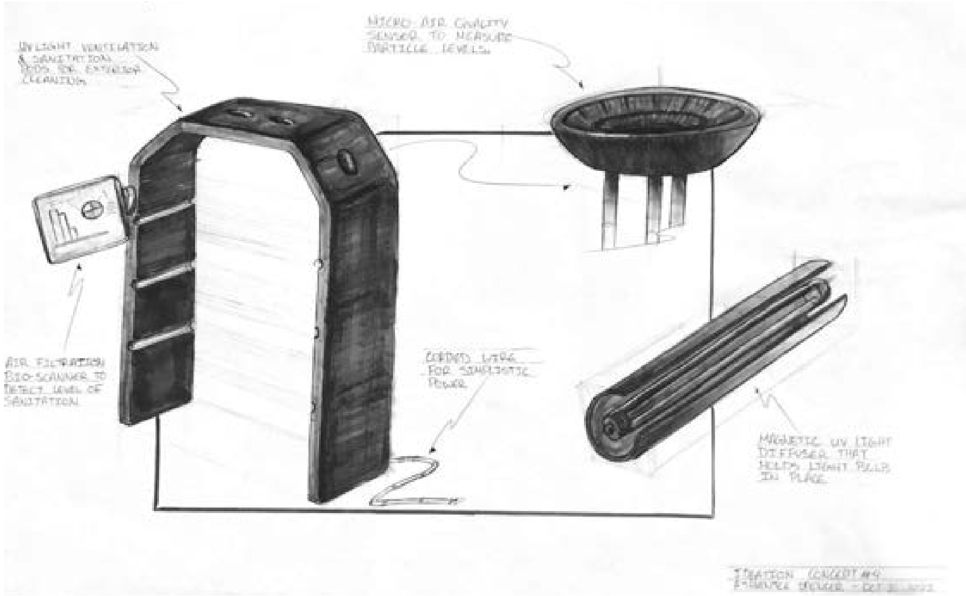


Figure 24. Ideation Sketch 4- UV Decontamination Pod

Ideation four focuses on decontamination for welders, as it is noted that these workers would clock in and out of work with air toxic particles on their clothing. To troubleshoot this, the design of a decontamination pod with UV sanitation lighting was developed in order to mitigate respiratory contamination through clothing.

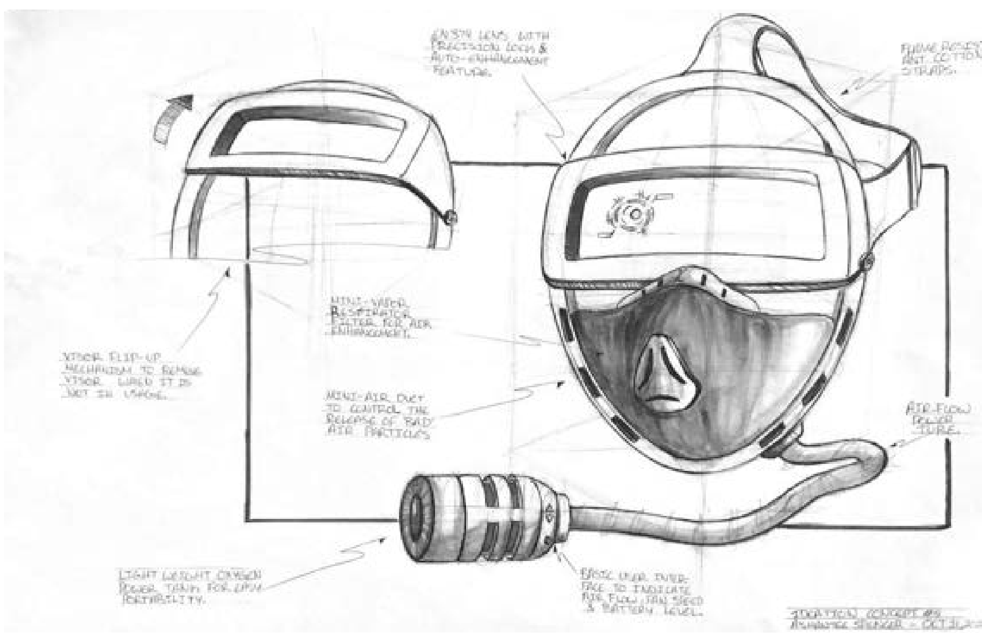


Figure 25. Ideation Sketch 5- PAPR Mask WIth Augmented Reality

The fifth ideation is centred around portability and respiratory purification, as a powered air purifying respirator (PAPR) would allow for users to have access to clean air and work efficiently at the same time through the augmented reality welding features. Having introduced augmented reality provides workers with the opportunity to create more accurate cuts, bends and metal manipulation with less human error and quicker distribution.

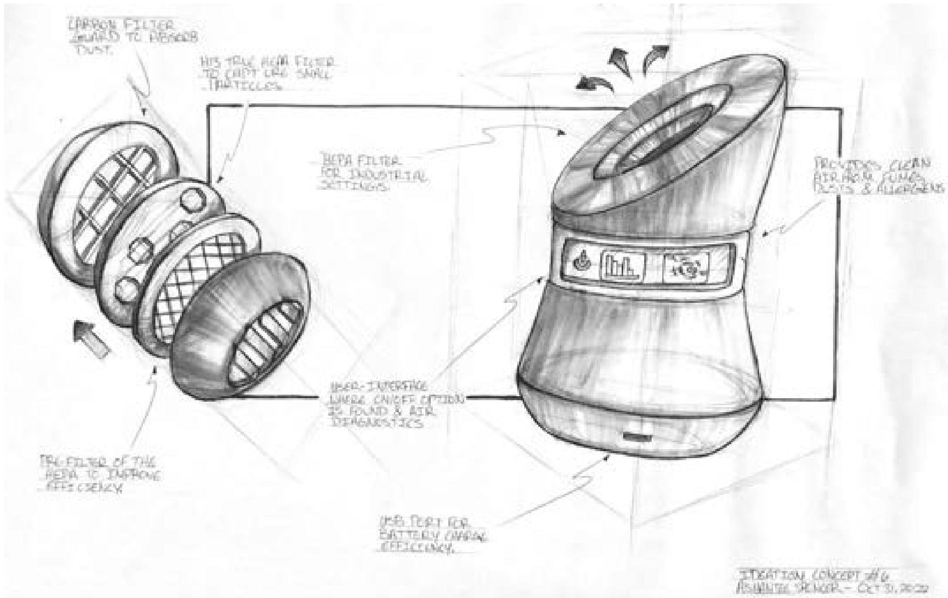


Figure 26. Ideation Sketch 6- Compact Dual Air Ventilation Pod

The sixth and final ideation compiles air sanitation through dual air ventilation and compatibility. This pod design allows for users to have the ability to work or take breaks with clean air surrounding them, which ultimately promotes workers safety and efficiency. With the digital touch-screen assist, users may control how much air they want purified and regulate the air flow channels.

4.2 Concept Exploration

With the initial ideation phase in mind, further design decisions through development can be utilized to provide viability. For the concept exploration phase, each concept required its own distinct direction and opportunities of benefit for iron workers in the field.

4.2.1 Concept One

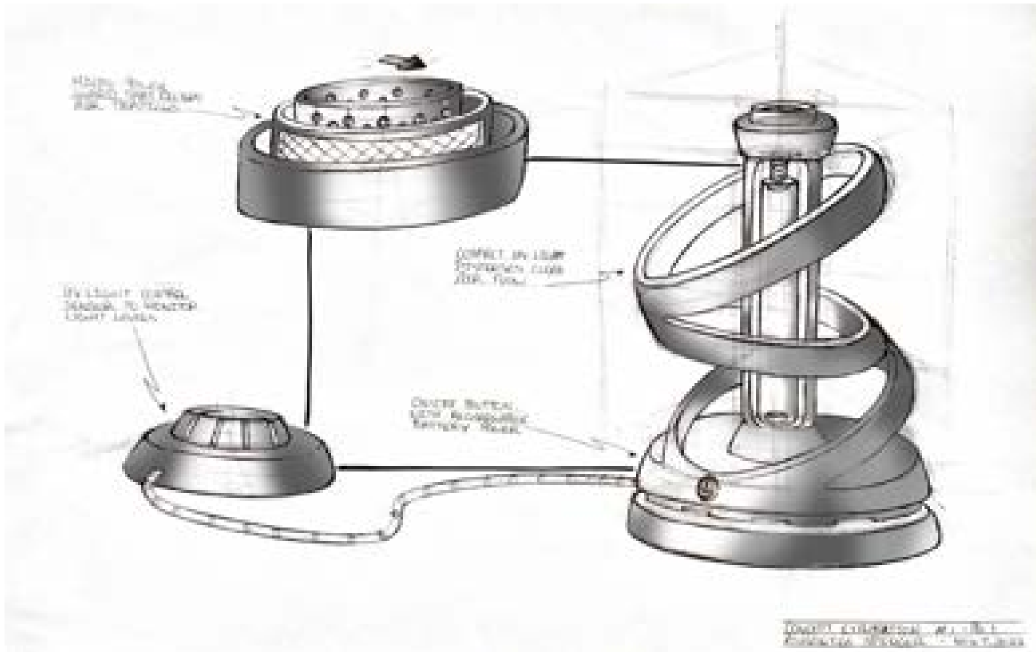


Figure 27. Concept One - 1

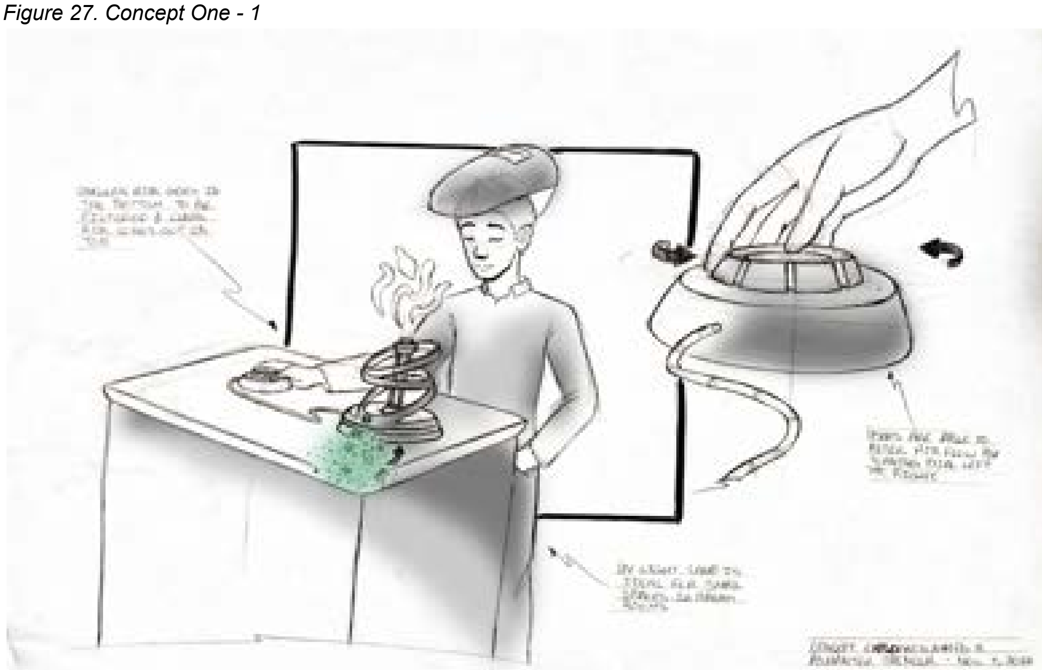


Figure 28. Concept One - 2

Concept one adapts the principle aspects of the ideations one and six, as it provides air sanitation and clean ventilation within the environment that ironworkers reside in. More specifically, it would utilize microscopic power guards to enhance its compatible HVAC system and efficiently filter clean air within small rooms or outdoor areas that may have air toxin exposure. Users are also able to control the level of air dispersion with a dial touch point interaction.

4.2.2 Concept Two

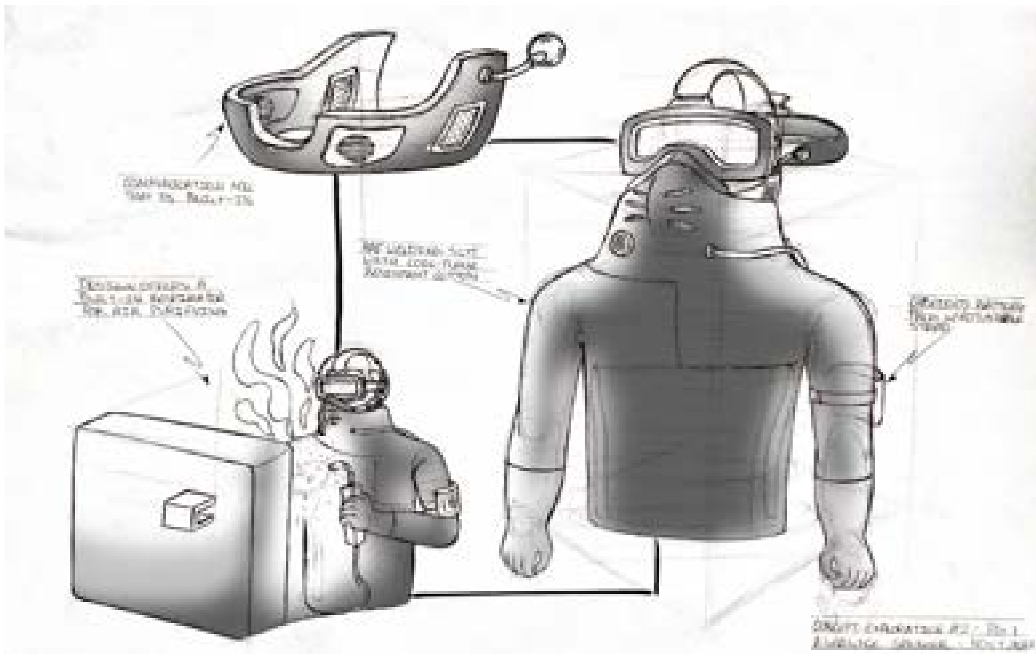


Figure 29. Concept Two - 1

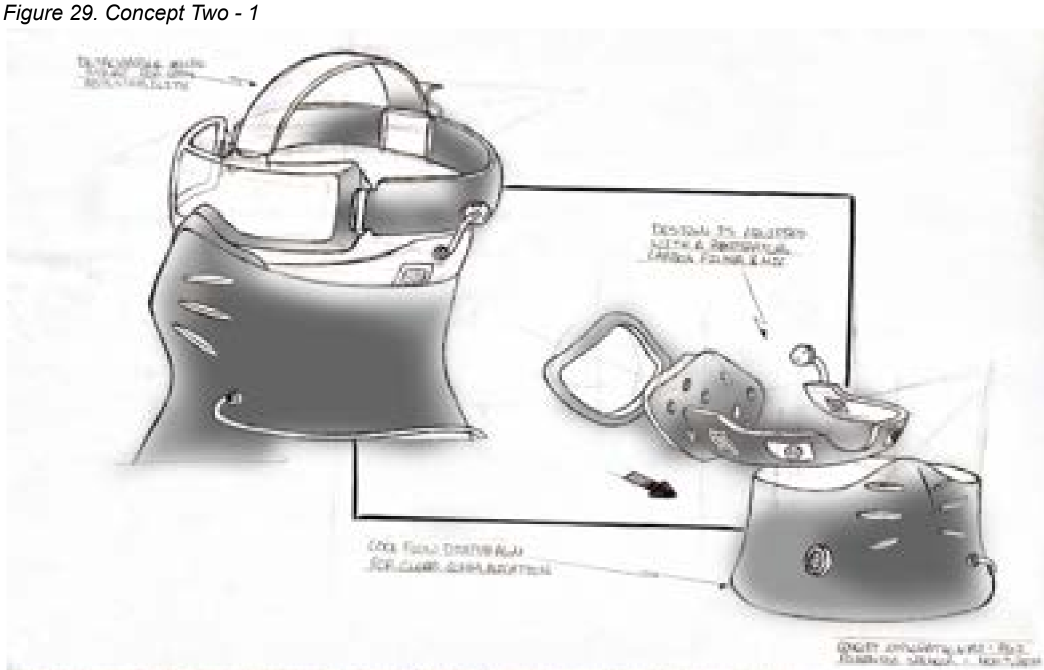


Figure 30. Concept Two - 2

Concept two is redeveloped from the third ideation, where it replicates a common construction workplace trend of workers wearing a thick fabric covering over their nose and mouth. The design was then translated into a respirator suit with a simplistic pull-up design which provides air filtration, safety and comfortability, as additional components, such as; welding goggles, gloves and heat resistant cloth, etc. that are required in the workplace were incorporated.

4.2.3 Concept Three

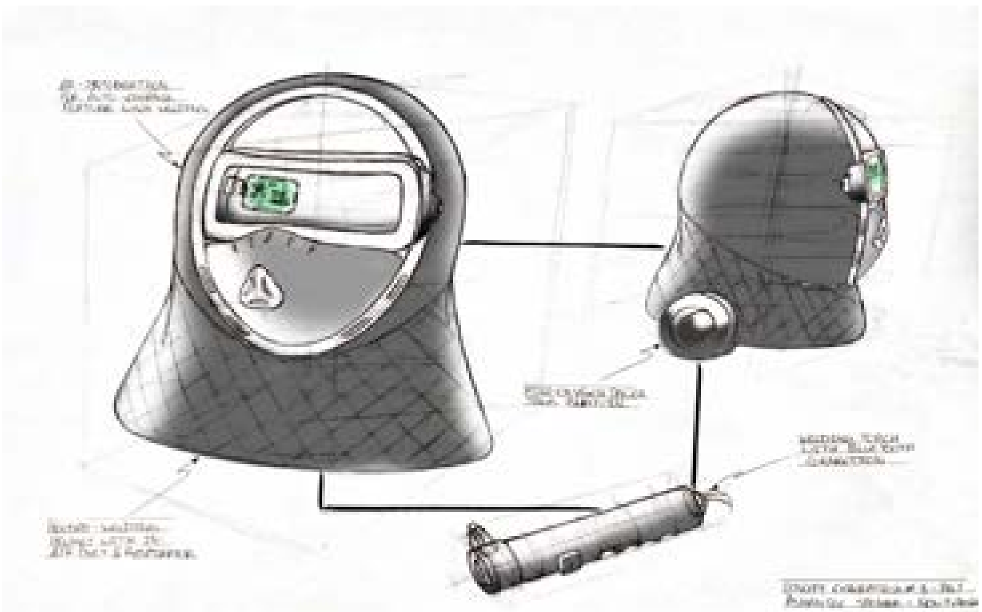


Figure 31. Concept Three - 1

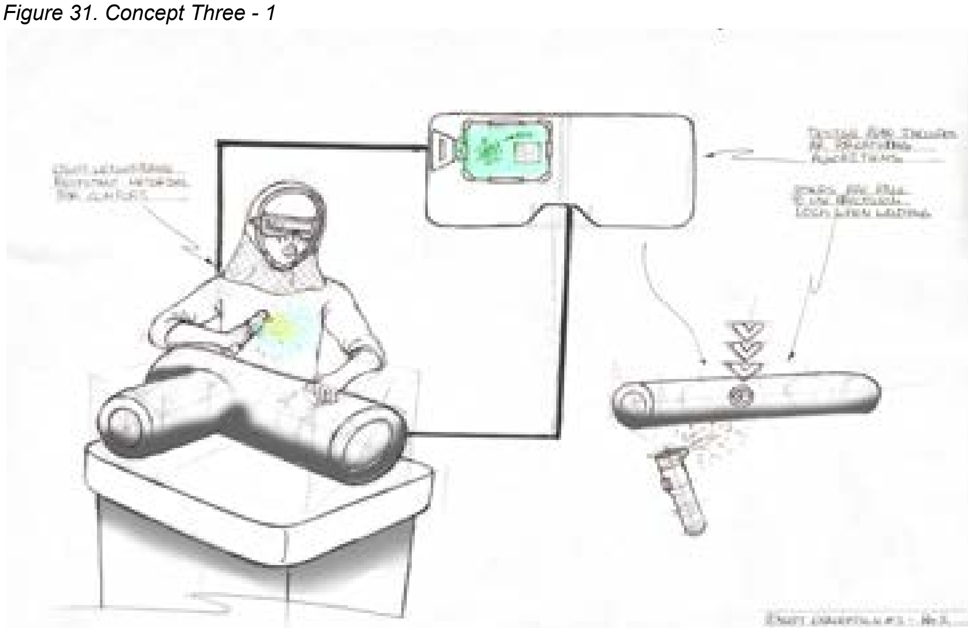


Figure 32. Concept Three - 2

Concept three combines ideation two and five through its primary function of introducing augmented reality enhancements when users weld by understanding air quality and the use of welding features, such as precision lock and metal manipulation considerations, etc. This concept allows users to have a hooded-like heat resistant protection while embedding a mask-like respirator to regulate clean air flow.

4.3 Concept Strategy

Upon further deliberation, design decisions were required in order to partially solve the problem definition, thus the notion was carried to continue developing this thesis project towards concept one (see Figure 10) which centres around HVAC sanitation through UV lighting and concept two (see Figure 12), the AR respirator suit. Where the respirator suit design should further implement the augmented reality features found within concept three (see Figure 14), as both concepts have similar principles towards respiratory coverage and feasible usability.

4.3.1 Concept Direction & Product Schematic One

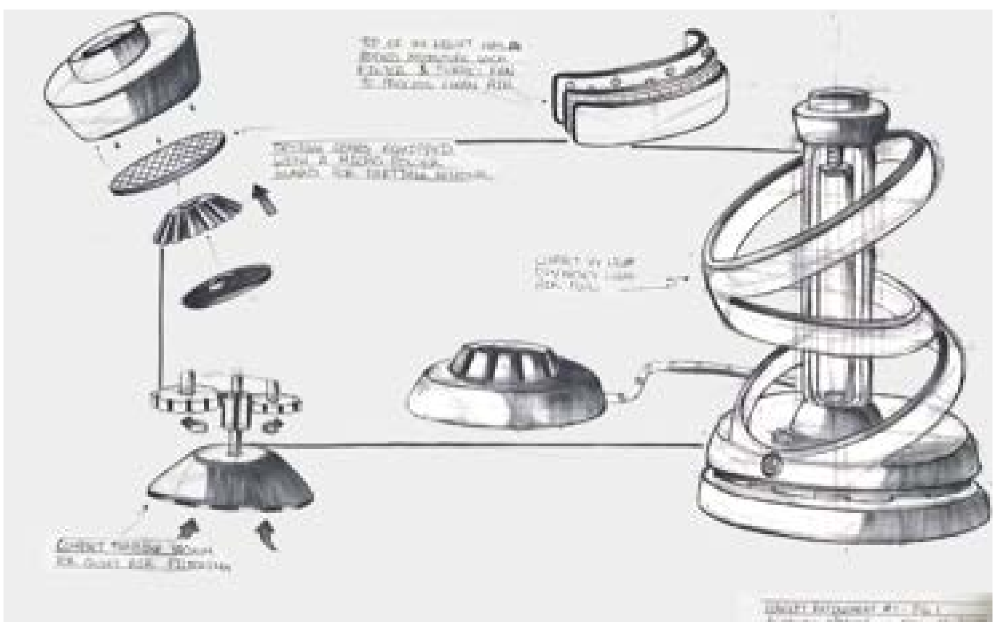


Figure 33. Concept One - 1

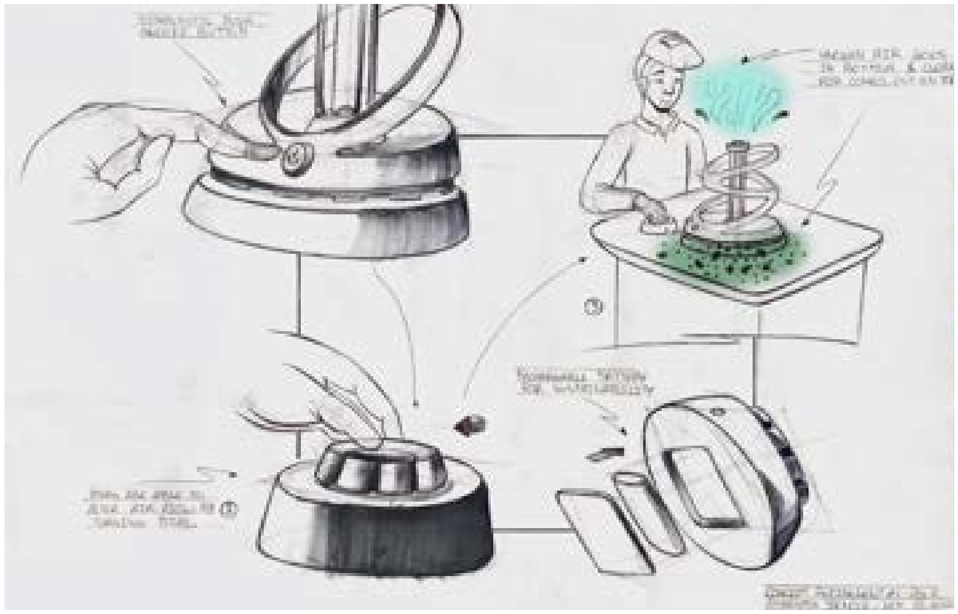


Figure 34. Concept One- 2

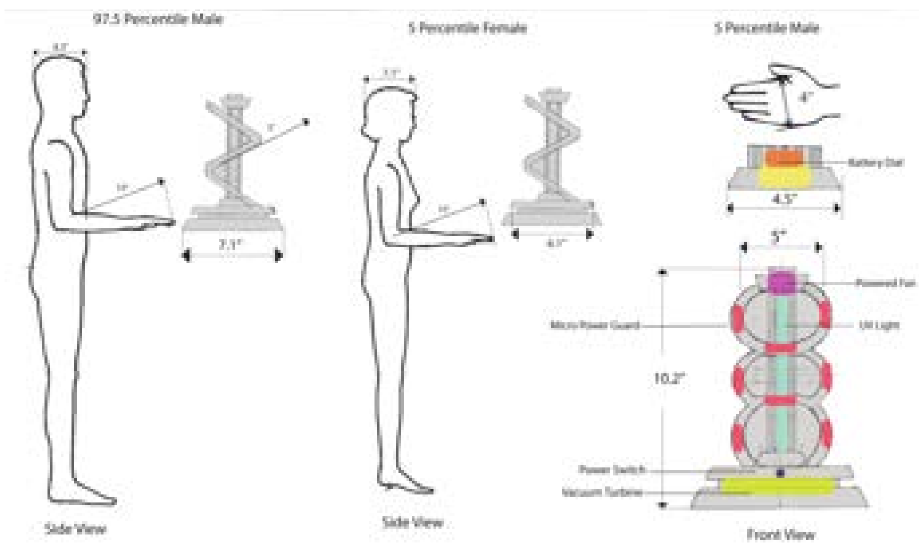


Figure 35. Concept One- Product Schematic

Concept direction one was selected for development by considering HVAC sanitation considerations within a welding environment and cultivating UV lighting for air filtration. This design is geared towards air particle optimization through its compact turbine fan, moisture filter lock systems for efficient clean air, as well as the UV light bulb for the destruction of hazardous air particles. A preparatory product schematic was created to identify the prerequisite dimensions for ergonomics and grants a general placement of components. More specifically, the schematic identifies user touchpoints and corresponds them towards a human scale.

4.3.2 Concept Direction & Product Schematic Two

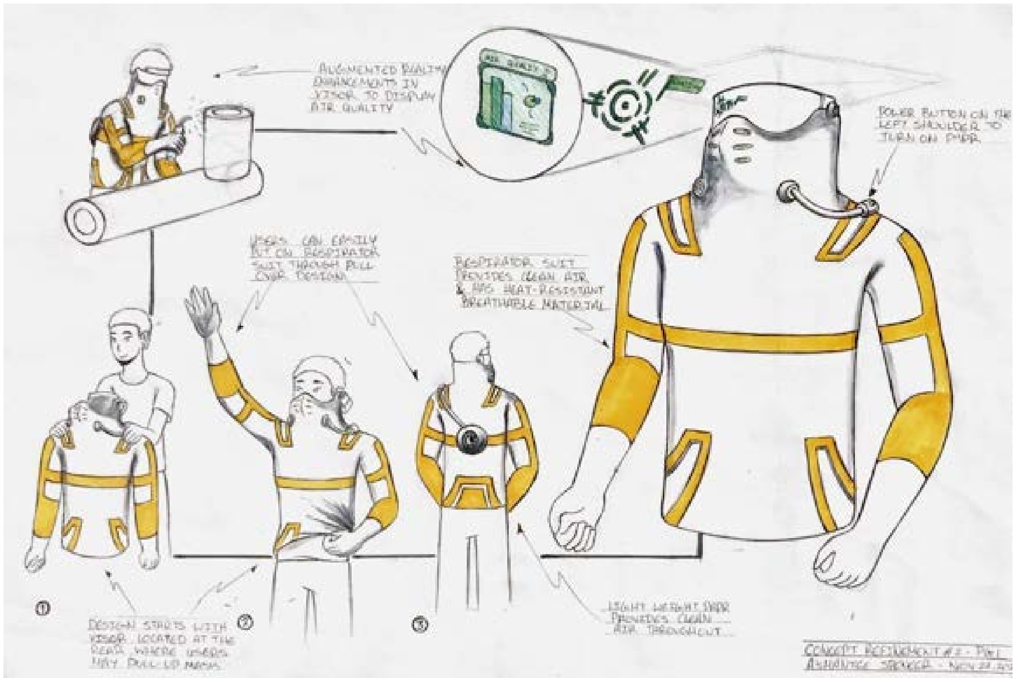


Figure 36. Concept Two- 1

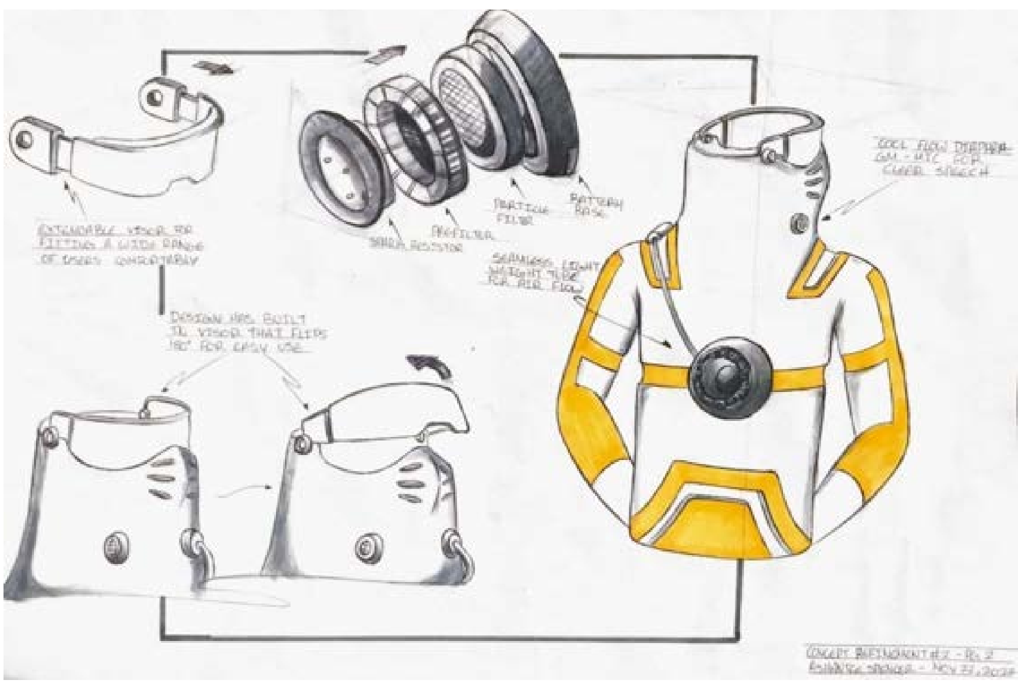


Figure 37. Concept Two- 2

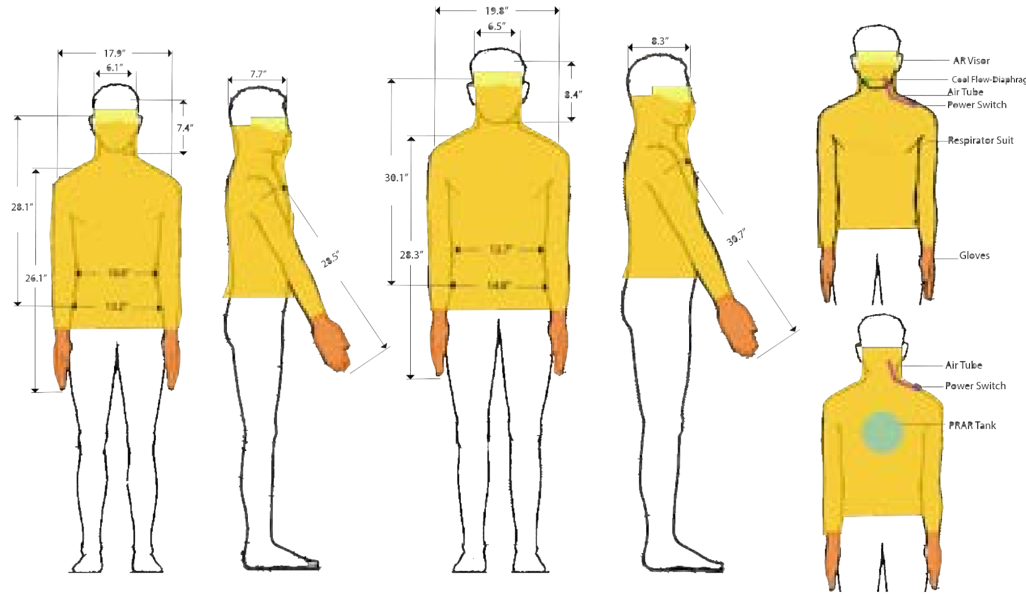


Figure 38. Concept Two- Product Schematic 1

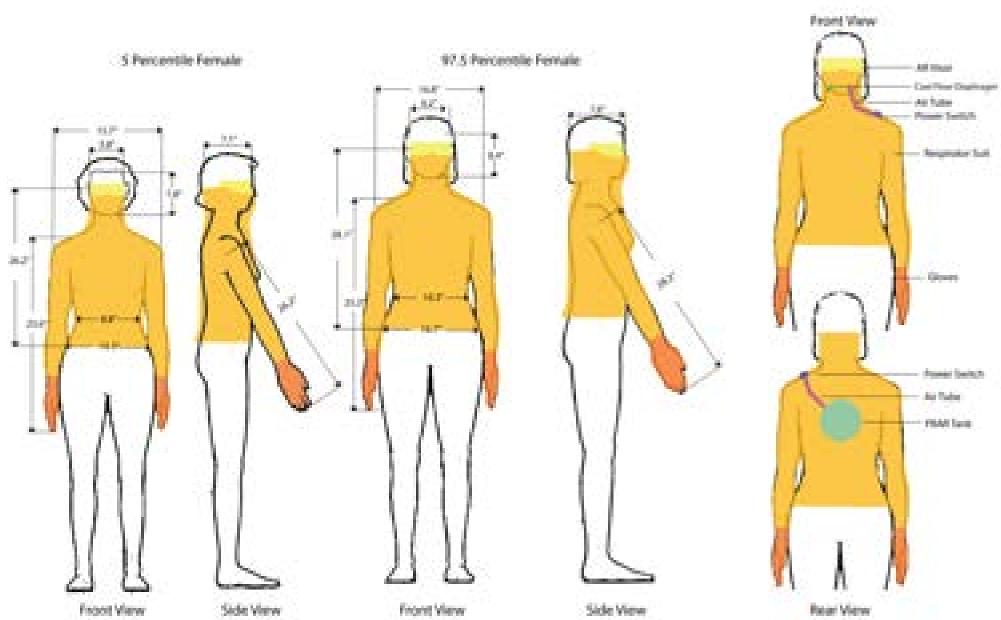


Figure 39. Concept Two- Product Schematic 2

Concept direction two takes measures to mitigate hazardous air particles by equipping workers with augmented reality enhancements to propel the user’s understanding of their air quality instead of users having to carry an air flow gauge controller on their person. Additionally, users would be provided welding and respiratory coverage with the built-in particle mask, with a portable respiratory purification device of a powered air purifying respirator (PAPR). Users also have an opportunity to adjust or retract their goggles to suit their preferences, which is established further through the ergonomic considerations in the product schematic. The product schematic identifies how users can comfortably wear the suit design, including mask, gloves and visor dimensioning on the male and female users.

4.4 Concept Refinement & Validation

Based on the feedback that was provided, concept direction two was developed further, as it provided innovative aspects that revolved around human-centred design towards the industrial and health industry.

4.4.1 Design Refinement

Figure 40. Concept Refinement 1

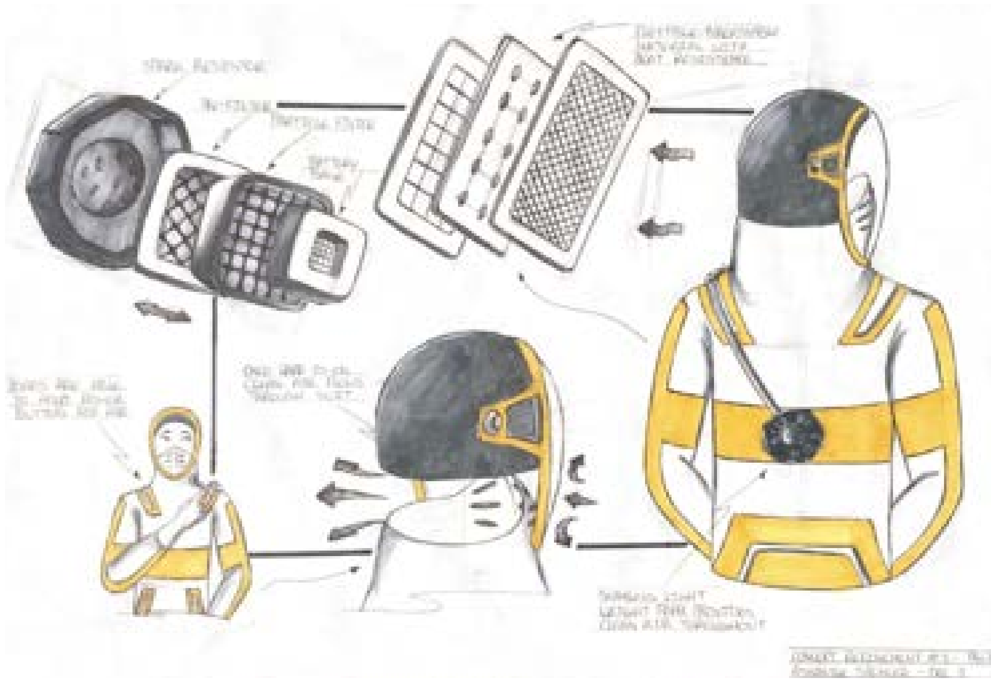


Figure 41. Concept Refinement 2

This refined concept two amplifies the notion of mitigating hazardous air particles through a compact powered air purifying respirator and curvilinear helmet and visor for greater comfort. The 180° retractable visor that’s embedded within the helmet provides users with accessibility to lock and adjust the placement of the visor when welding. Additionally, more emphasis towards the powered air purifying respirator (PAPR) component placement was developed as well as the suit’s breathable material considerations. The suit’s general aesthetics were revised to silhouette the typical construction worker apparel through vibrant strips of golden-reflective colour. The user interaction was considered through the placement of the user-interface and how it would be projected through the visor.

4.4.2 Detail Development

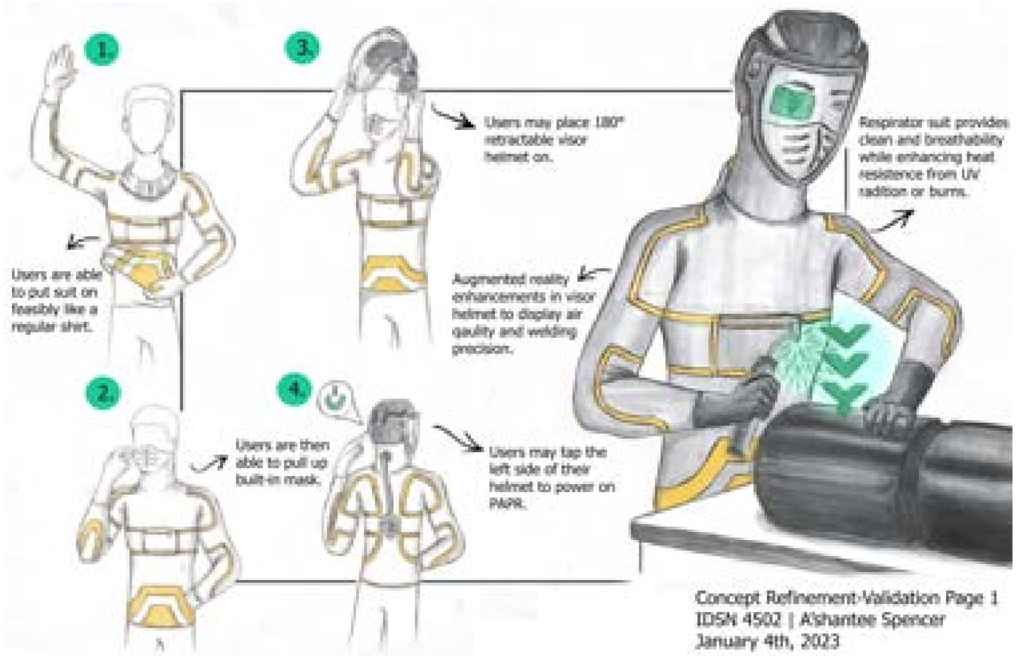


Figure 42. Concept Detail Development 1

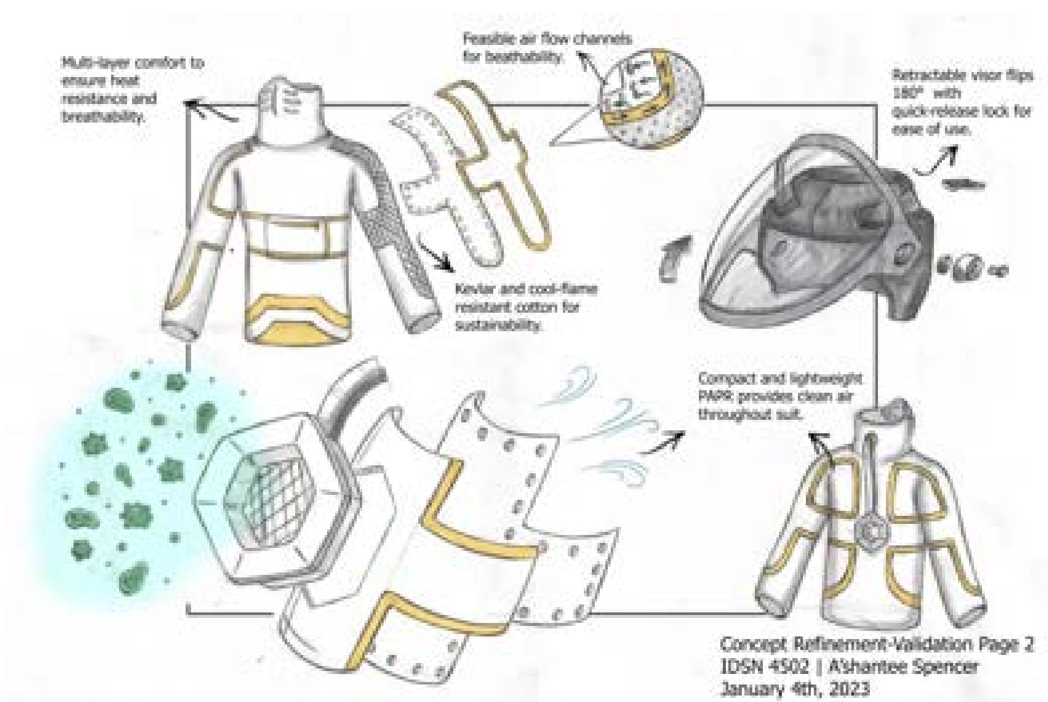


Figure 43. Concept Detail Development 2

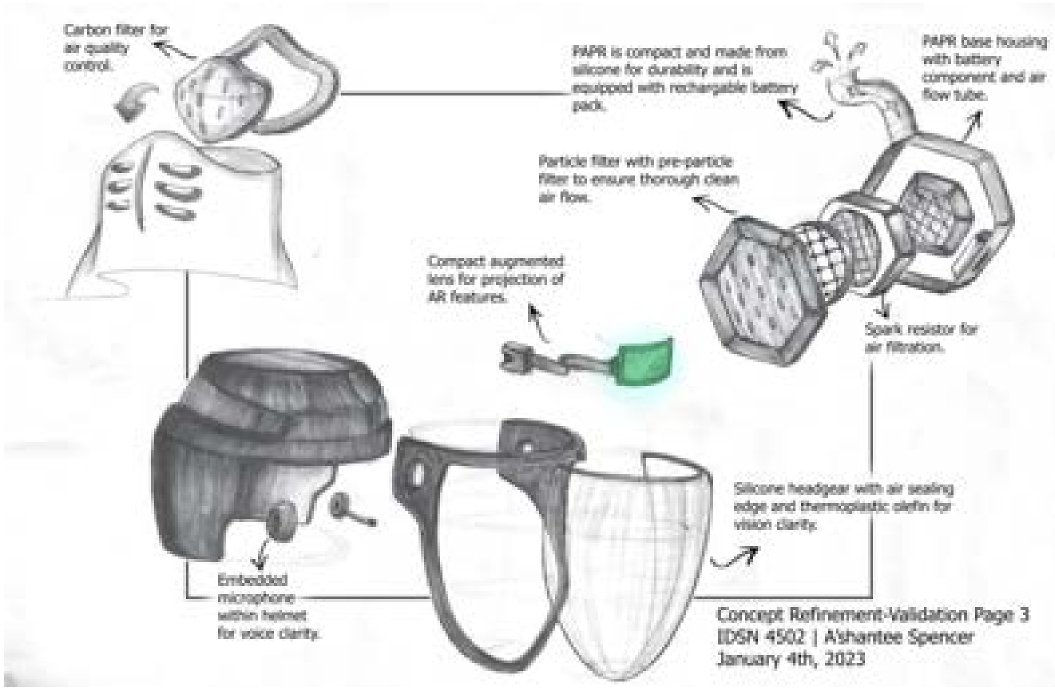


Figure 44. Concept Detail Development 3

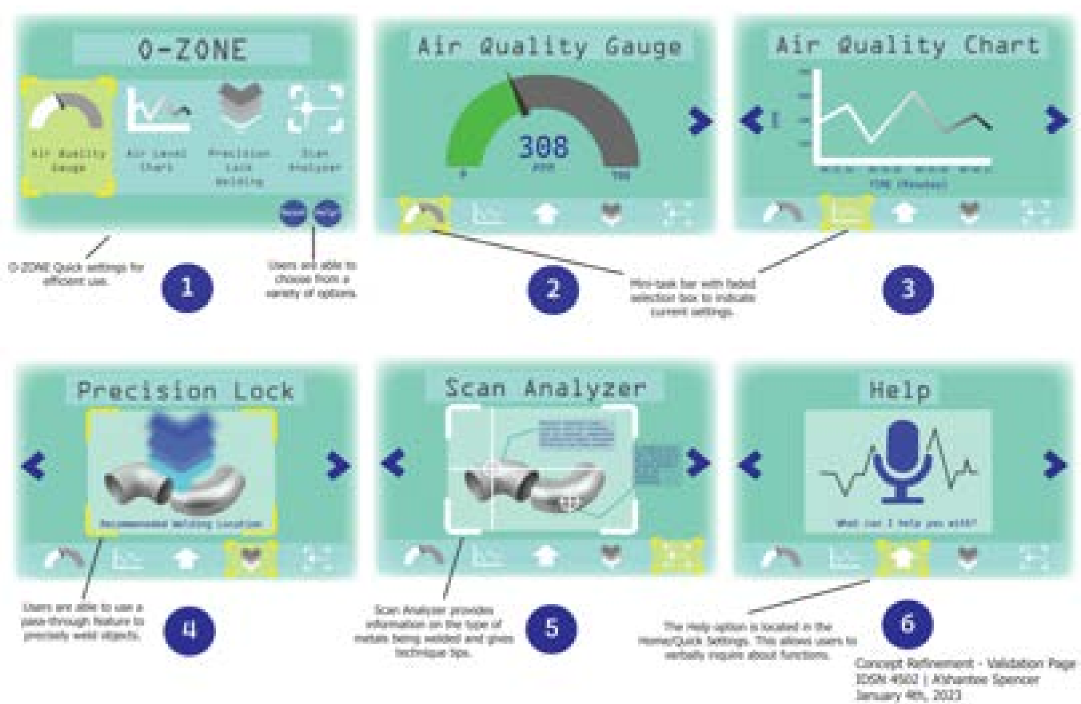


Figure 45. Concept Detail Development 4

The concept detail development consists of a revised suit design, where the vibrant strips of golden-reflective colour was reduced to a thinner line, such that it does not overpower the general design. The suit also incorporated a pouch zipper in the middle area of the suit for placement of tools and for aesthetic continuity. Further detail went into material considerations and tolerances for the suit with the use of Kevlar cool-flame resistant cotton as a general source material. Further deliberations were made based on the placement of key features of the suit design, such as; the carbon filter positioning within the fabric mask, as well as the microscopic augmented-reality projector within the visor, and the primary components required for the powered air purifying respirator (PAPR). Additionally, a basic wireframe of the user-experience and interaction of the augmented-reality features were developed. These features range from respiratory insights and welding performance enhancements, including; Air Quality Gauge, Air Quality Chart, Welding Precision Lock, and Material Scan Analyzer.

4.4.3 Refined Product Schematic & Key Ergonomics

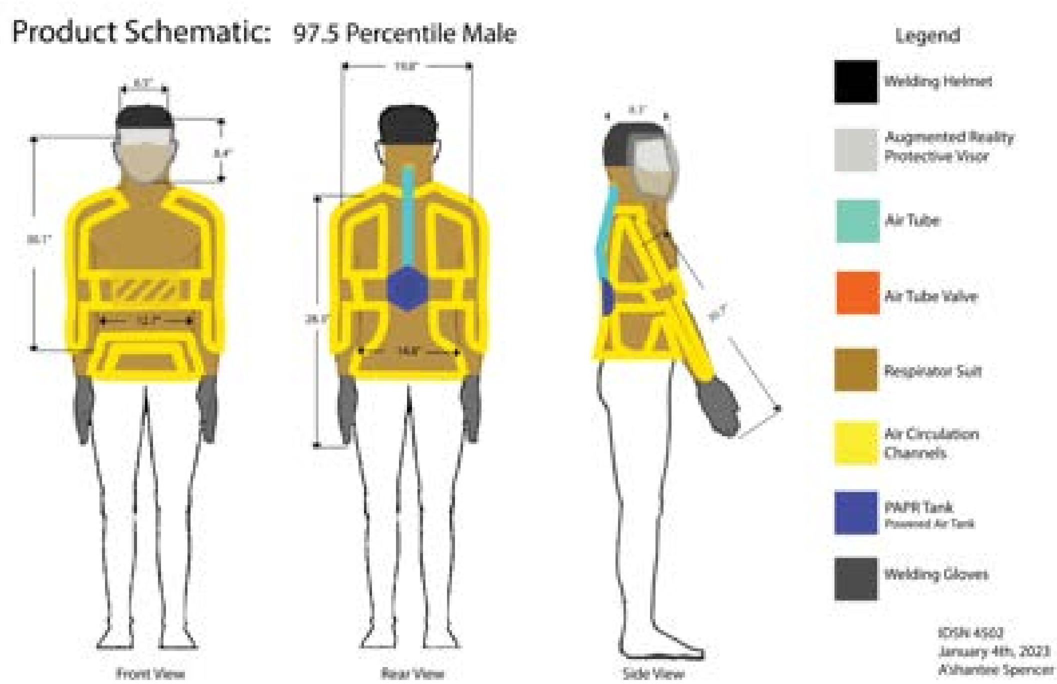


Figure 46. Concept Product Schematic

The refined product schematic and key ergonomics (Figure 44) provides insights on material flats, tolerances and how each component of the suit design can comfortably interact with the user. For instance, the waist length of the 97.5 percentile male is considered to be 12.7", which indicates that the breathable cool-flame cotton material should account for 0.25” of compression, since iron workers have a tendency to bend their back and waist area for accurate welding operations. Revisions that were established includes; the inclusion of a helmet and full-face visor, where the visor encloses the built-in fabric face mask.

4.5 Concept Realization

To solidify the suit design, iterations were made based on shape language intent, industry colour codes and standards. Innovations of the helmet, visor, mask and gloves were then finalized based on industry advisors’ feedback of a simplistic yet futuristic and functional apparel trend. The suit incorporates subtle variations of line weights between the vibrant strips of golden-reflective colour to draw attention to worker safety.

4.5.1 Design Finalization

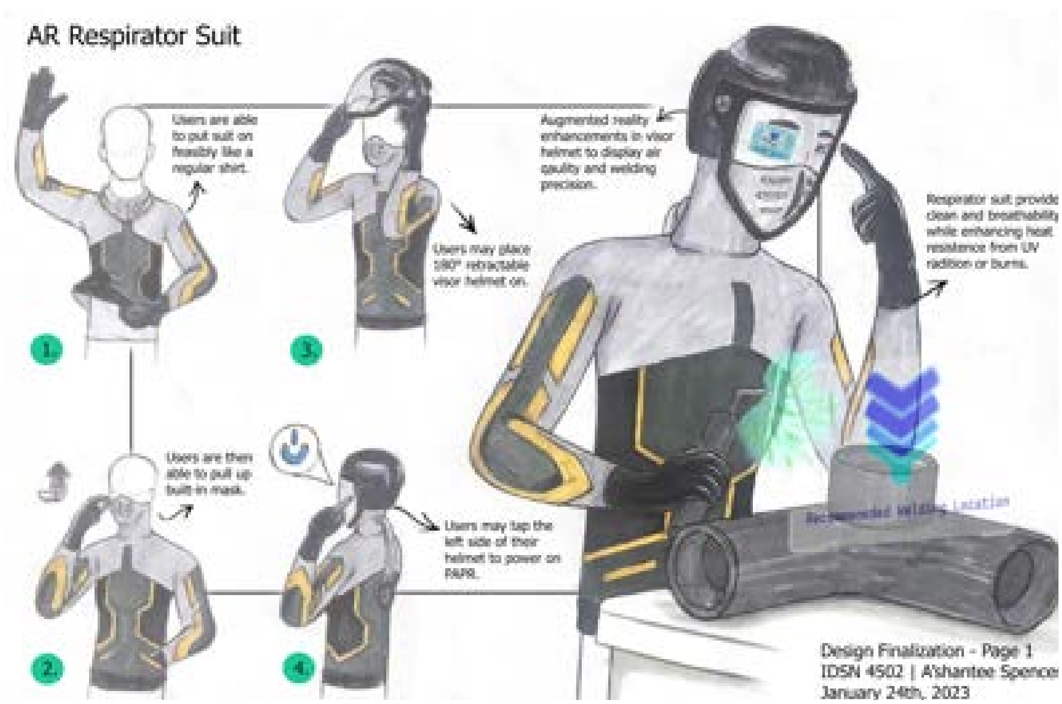


Figure 47. Concept Finalization 1

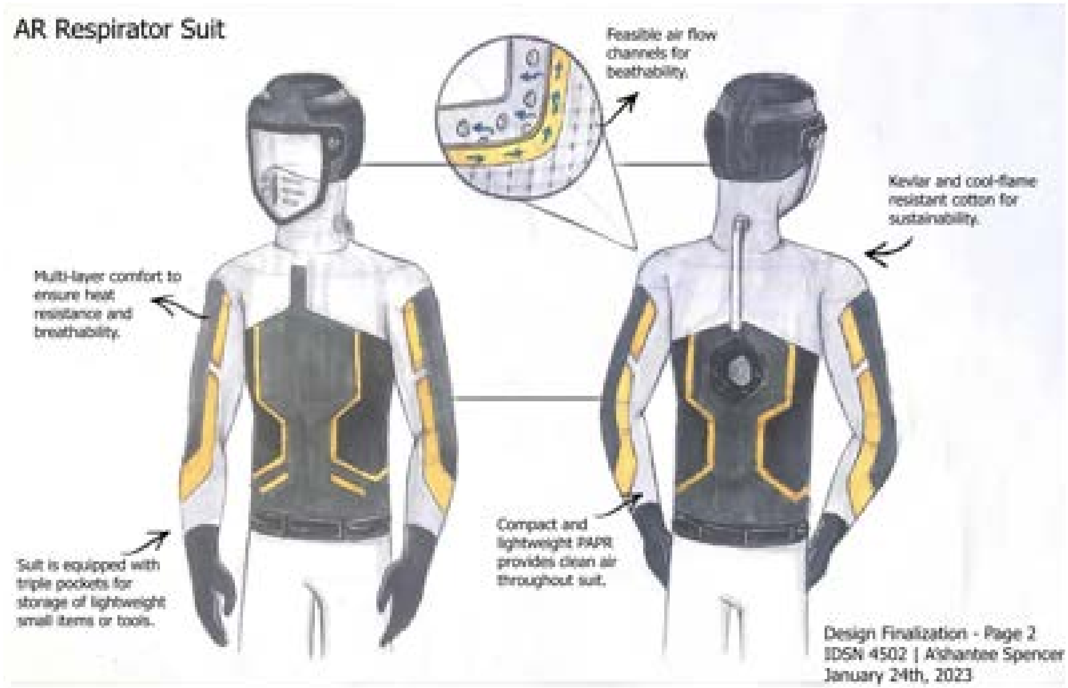


Figure 48. Concept Finalization 2

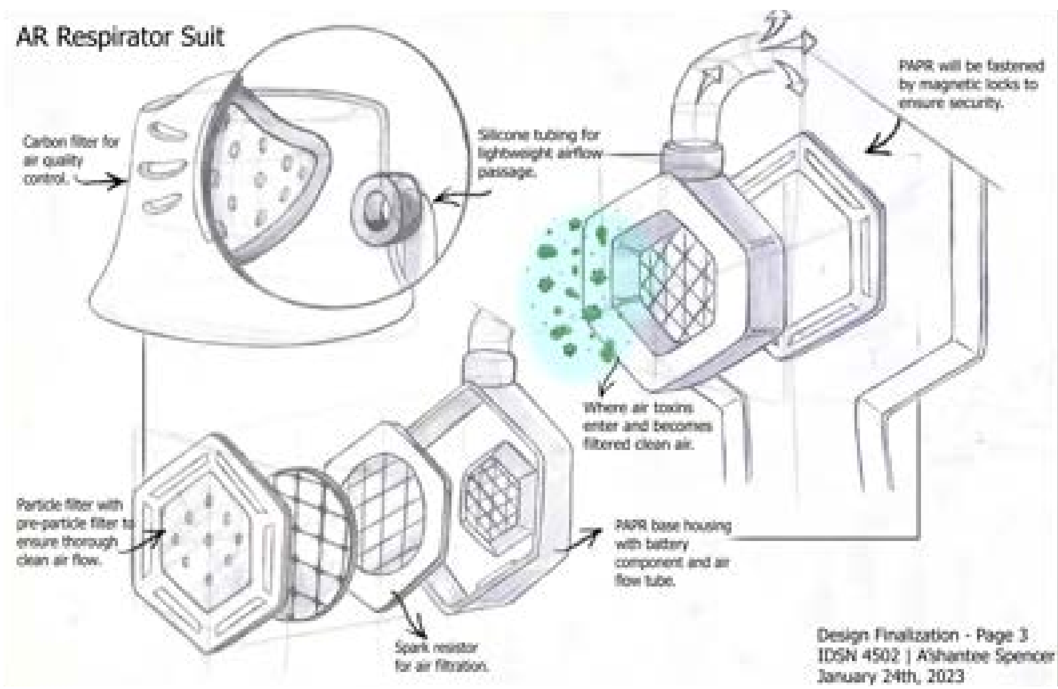


Figure 49. Concept Finalization 3

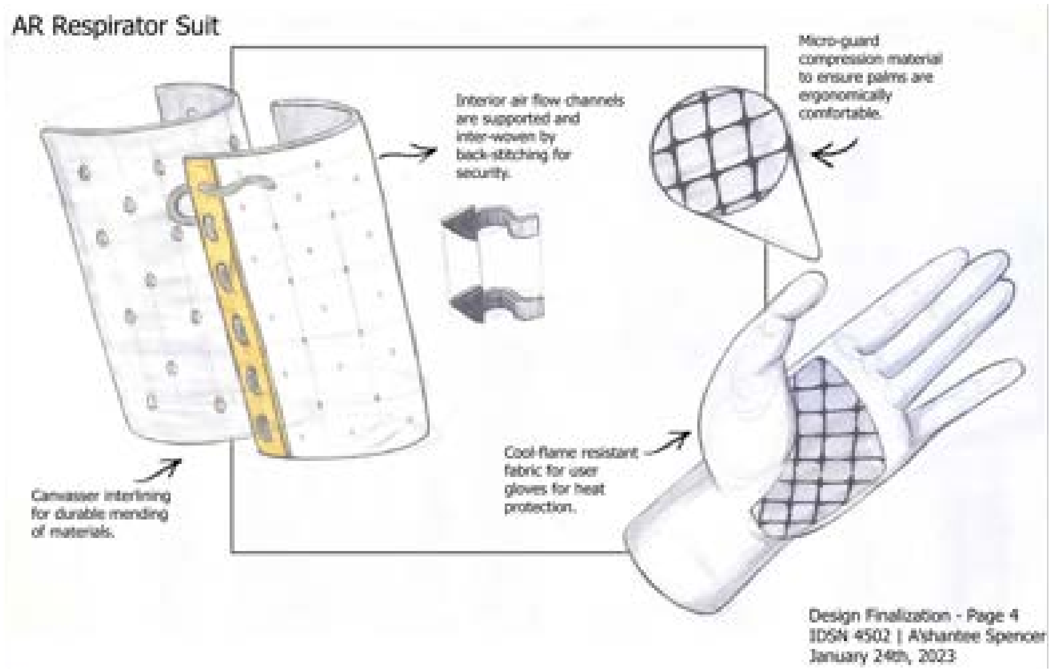


Figure 50. Concept Finalization 4

Figure 51. Concept Finalization 5

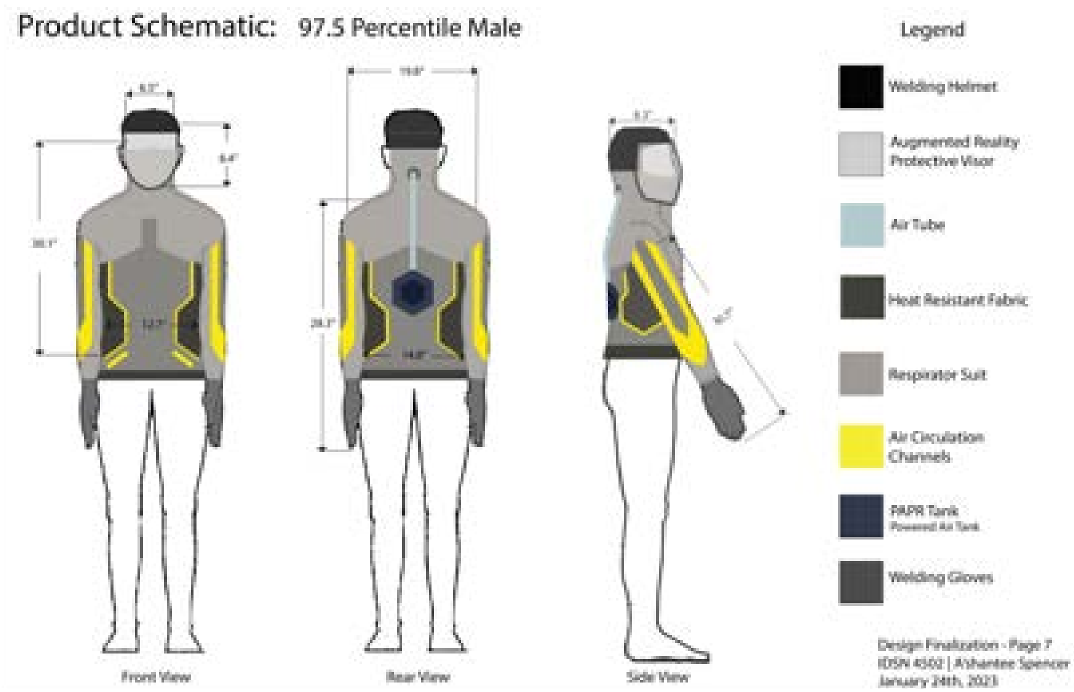


Figure 52. Concept Product Schematic

The conceptualized final design aims to demonstrate the suit's comfort, efficiency and usability for iron workers based on informed industry standards. The respirator suit's material is composed of 100% cotton flame-resistant, breathable-thickened material, where the gloves, pouch and pocket components are made up of flame-resistant leather and micro-compression material for general durability. With consideration of previous industry insights towards how workers often use thickened fabric masks in place of respirators, the respirator suit mimics that work-cultural trend with the 100% cotton flame-resistant, breathable-thickened built-in mask. The general suit's shape language embodies that of the powered air purifying respirator (PAPR)'s hexagonal form through the outline of the strips of golden-reflective colour. These strips of golden-reflective colour represent the air circulation channels throughout the suit, as well as endorses the safety of workers through its vibrancy. The overall respirator suit's dark shades of grey is reflective of the iron worker industry standards, where darker colours prevent light refraction when welding. The suit's helmet and visor act as protection against UV radiation and sparks, with additional coverage towards the back of the neck with the hooded part of the helmet.

4.5.2 Physical Study Models

Figure 53. Physical Model Study 1: Front View

Figure 54. Physical Model Study 2: Side View

Figure 55. Physical Model Study 3: Rear View

Figure 56. Physical Model Study 4: Visor Close-up

The revised physical model study was influenced by the concept product schematic (Figure 50) patterns of the suit’s design, where polished ergonomics were applied. The model provided an accurate display of how the respirator suit would fit on the users, however, it was noted that slight revisions were required for the sleeve and bust area tightness, such that users are able to freely work within the suit. These design considerations are critical towards basic functionality of the suit, as tightness can lead to strain in the muscles when performing welding tasks, as well as a lack of breathability and comfort.

4.6 Design Resolution

Upon the completion of the physical model (Figure 53-56), a minor revision was made towards the suit aesthetics, where the strips of the golden-reflective colour were conjoined to promote uniformity. The suit’s material consists of 100% cotton flame-resistant fabric, with a thickened breathable material. To promote durability, the personal protective equipment (PPE) of the gloves, pouch and pocket are made up of flame-resistant leather and micro-compression material. Consideration into branding was developed, as the previous product name of AR Respirator Suit was rebranded as the A.I.R. Suit, which stands for *Augmented Reality Iron Worker Respirator* Suit. With consideration of the Occupational Safety and Health Administration (OSHA)'s Respiratory Safety Guidelines the A.I.R. Suit provides a one-stop personal protective equipment (PPE) solution for iron workers. The A.I.R. Suit is designed for the mitigation of sub-particle respiratory hazards for iron workers, while maintaining a level of comfort, adaptability and durability while granting augmented reality welding enhancements.

The final design indicates the *A.I.R.* process, through displaying how iron workers are able to comfortably wear the breathable thickened suit and choose to put on or take off the built-in particle filtration mask for respiratory protection, while having access to the suit's powered air purifying respirator (PAPR) that supplies clean air throughout the suit.

These considerations were pivotal to develop prior to initiating CAD designs, as it provided insights towards the placement of each suit component, which allowed for feasible development of fastening details and material tolerances.

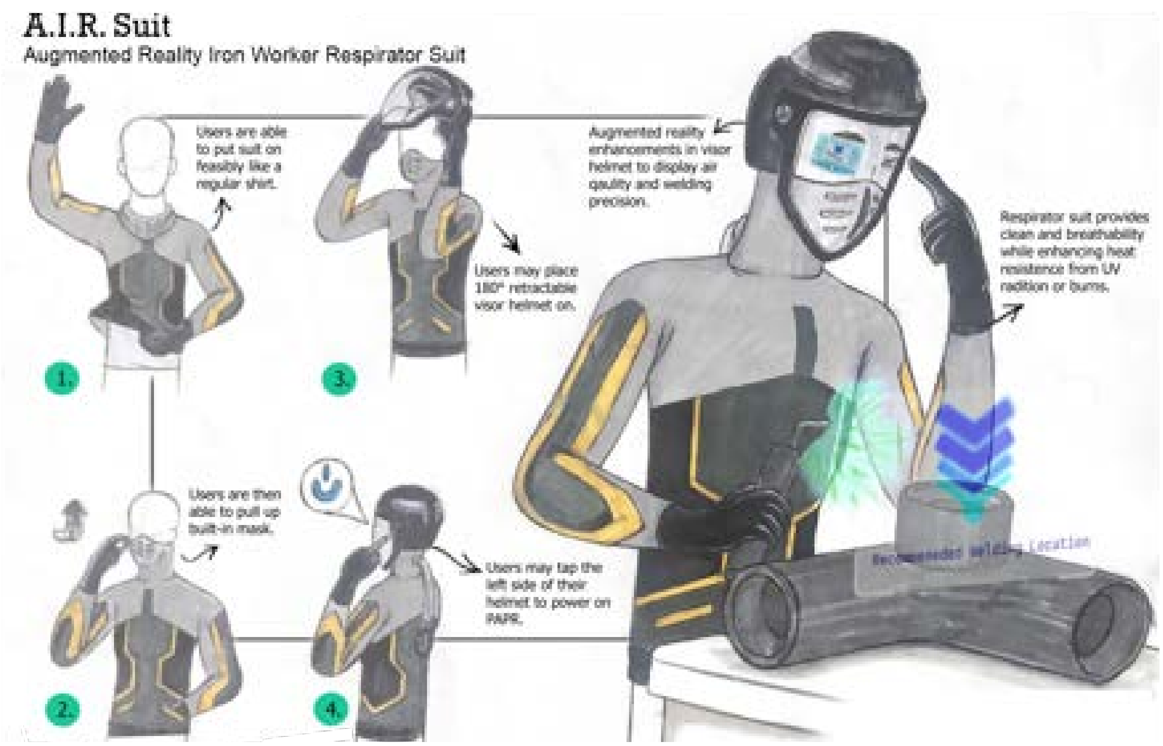


Figure 57. Final Design 1

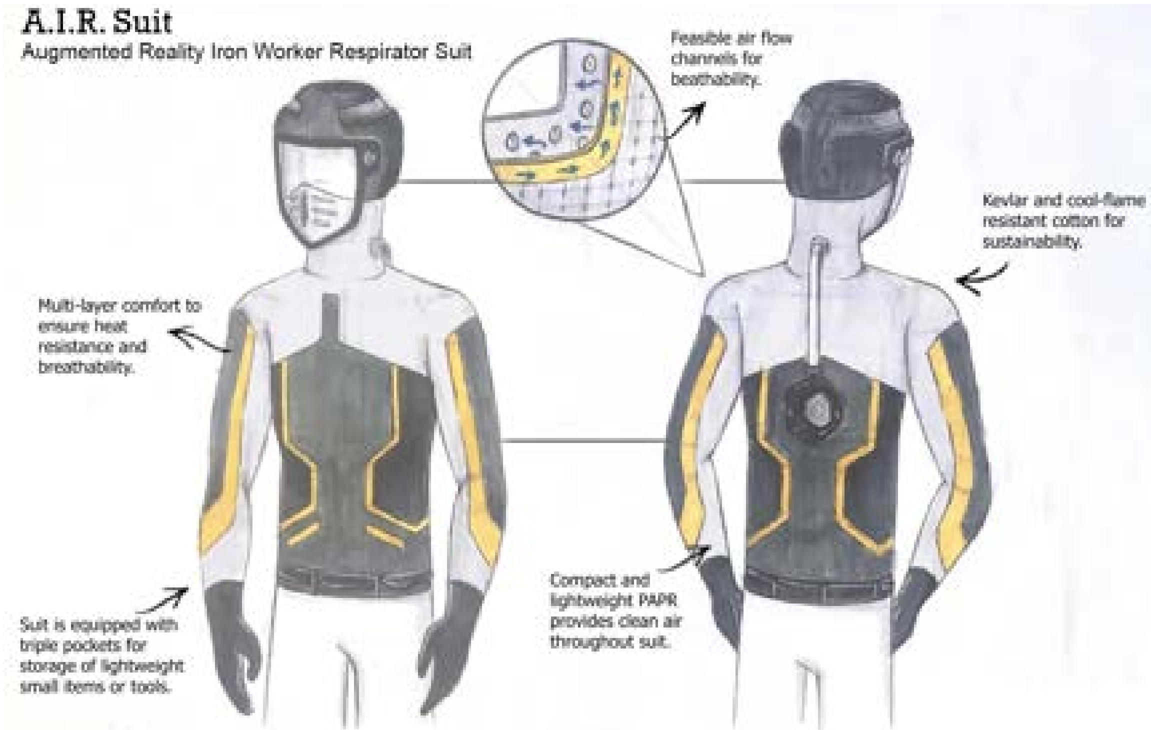


Figure 58. Final Design 2

4.7 CAD Development

The CAD development of the A.I.R. Suit began in two separate softwares of Solidworks 2022 and Gravity Sketch. The helmet, visor and powered air purifying respirator suit components were modelled in Solidworks and the remainder of the suit was modelled using the augmented reality design software of Gravity Sketch. Designing in Solidworks and Gravity Sketch provided insights towards the possible manufacturable issues that were not visible within the 2D final design. The model making process consists of surfacing and solids that supports the representation of the final design.

Figure 59. Suit Helmet - 1

Figure 60. Suit Helmet - 2

Figure 61. Suit Helmet - 3

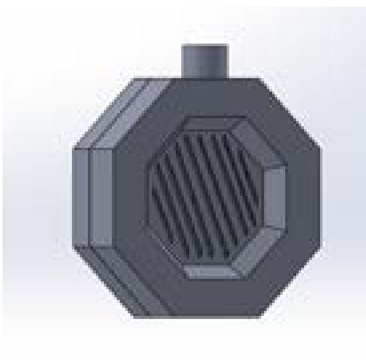


Figure 62. PAPR - 1

Figure 63. PAPR - 2

Figure 64. Suit Process - 1

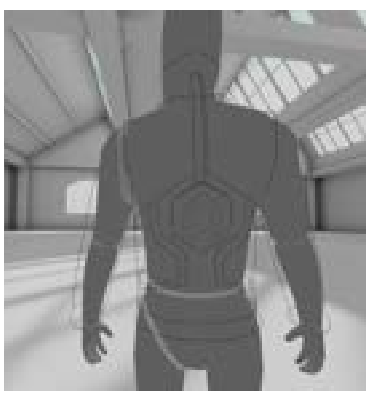


Figure 65. Suit Process - 2

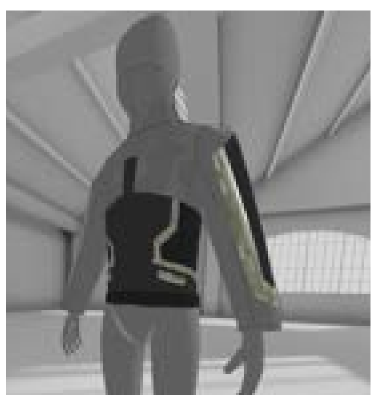


Figure 66. Suit Process - 3

Figure 67. Suit Process - 4

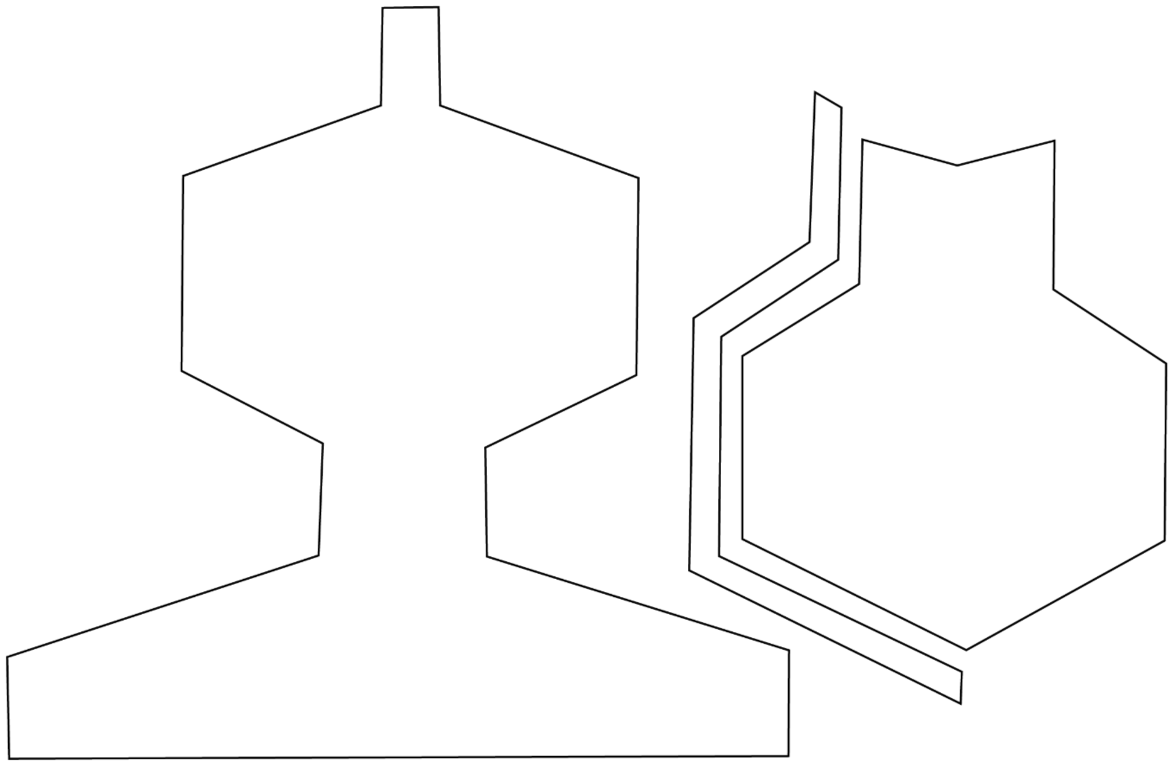


Figure 68. Suit Flat Pattern 1

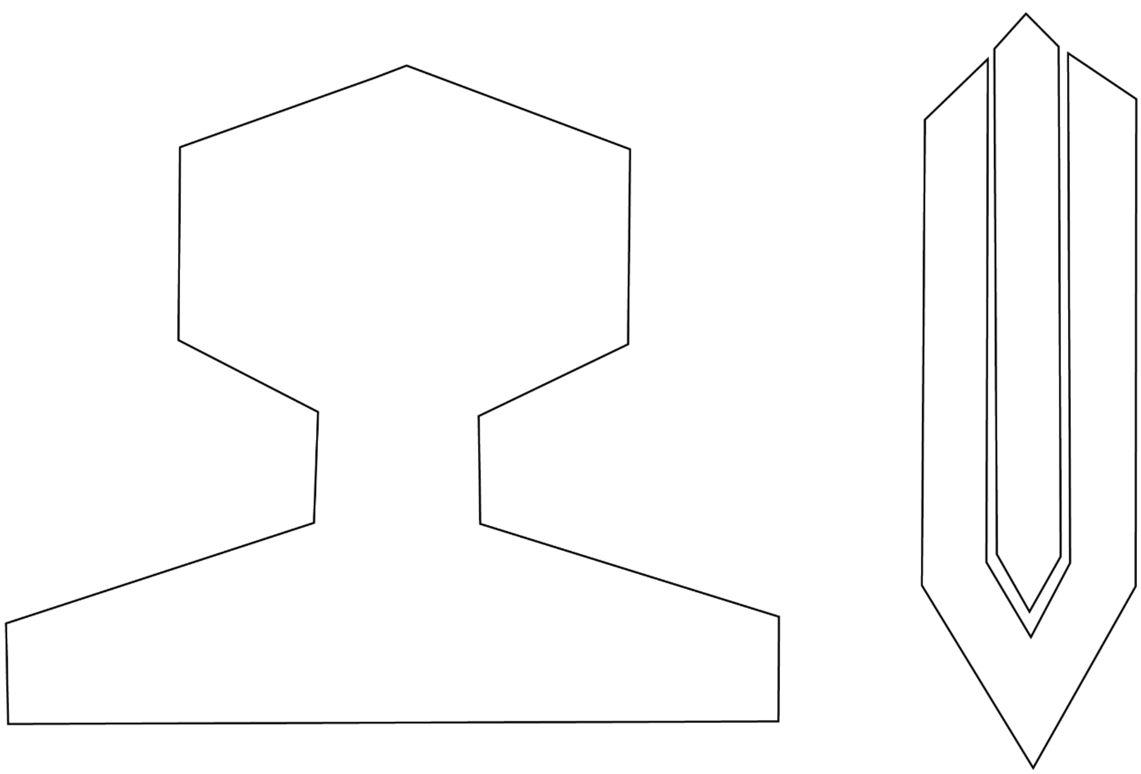


Figure 69. Suit Flat Pattern 2

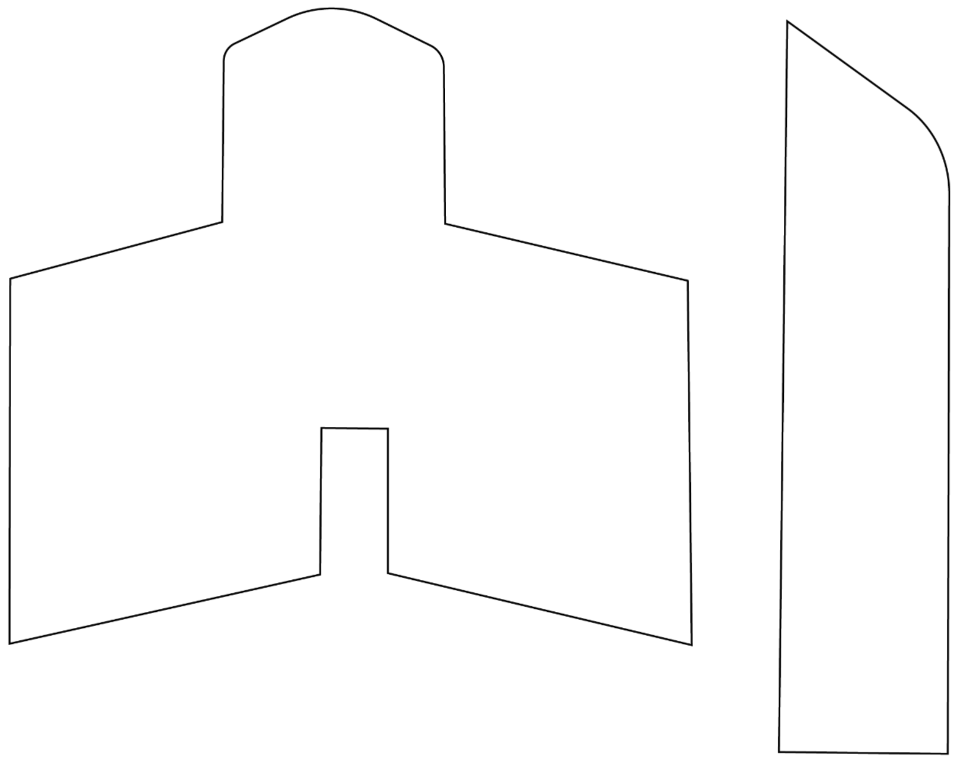


Figure 70. Suit Flat Pattern 3

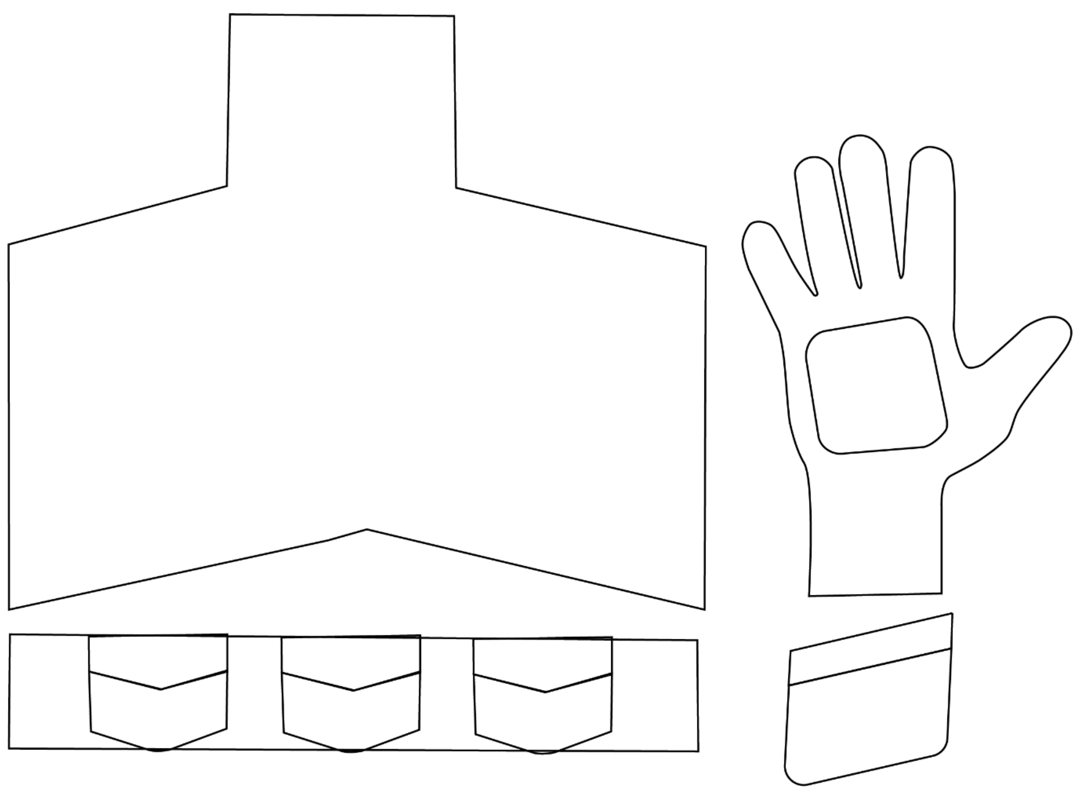


Figure 71. Suit Flat Pattern 4

4.8 Physical Model Fabrication

The physical prototype was fabricated at a 1:1 human scale in order to represent the A.I.R. Suit’s viability. The prototyping process initiated through 3D printing the helmet, visor and powered air purifying respirator (PAPR) components of the design. Once the 3D printing process was completed, the tasks of sanding and spray painting were done to each component to ensure material accuracy.


Figure 72. 3D Printed Helmet


Figure 73. 3D Printed Visor


Figure 74. PAPR Component - 1


Figure 75. PAPR Component - 2


Figure 76. 3D Printed Helmet - Spray Painted


Figure 77. 3D Printed Visor - Rear View

The apparel design prototyping began with sourcing fabric materials through local and online measures to ensure materials were appropriately represented. Afterwhich came the printing out the suit flat patterns (See Figures 68-71) in the appropriate human-scale, where it was then translated onto the fabric material and cut out. Each component of the suit was sewn together and finishing touches of the golden-reflective strips were added.

Figure 78. Suit Preliminary Layout

Figure 79. Suit Layers Partially In Place

Figure 80. Partially-Sewn Suit

Figure 81. Partially-Sewn Suit - Side View

Figure 82. PAPR Placement On Suit

Figure 83. Pre-Finalized Suit Prototype

CHAPTER 5: FINAL DESIGN

Figure 84. *MKvarda. (2016, August 18). Welder - Free photo on Pixabay. https://pixabay.com/photos/welder-metal-1598013/*

5.1 Design Summary

The *A.I.R. Suit: Augmented Reality Iron Worker Respirator Suit* consists of personal protective equipment (PPE) that ensures workers are able to efficiently and reliably work with no harm while reducing the risk of sub-particle air contamination. The design is composed of essential welding protection components, such as; a helmet, visor, suit with built-in mask, powered air purifying respirator (PAPR) and gloves, where users are able to access augmented-reality enhancements.

Iron workers help build our communities through the industrial process of welding, however, these individuals are at greater risk of developing respiratory issues due to lack of current respirator comfort, capability, affordability and durability. Research indicates that current respiratory personal protective equipment (PPE) can become obstructive to workers, as it can decrease communication, become time-consuming due to set up of respirator and increases contamination build up. Additionally, most welding personal protective equipment (PPE) (i.e. Helmets) grant more capacity for non-powered respirators rather than powered respirators which fosters a lack of personal protective equipment (PPE) interchangeability. While the effective powered respirators and purifying welding helmets are often inaccessible for new workers in the industry due to the expensive price point for each equipment. It is also known that finding a balanced ergonomically lightweight and balanced welding helmets and respirators for the workers' centre of gravity can be a challenge. These key considerations create an opportunity for an innovative personal protective equipment (PPE) for iron workers.

The A.I.R. Suit is specifically designed for feasible usability while refining the current personal protective equipment (PPE) for iron workers. Through amplifying respiratory protection, increasing welding precision and eliminating the outsourcing of multiple welding protective wear; the A.I.R. Suit is a one-stop personal protective equipment (PPE) for all iron workers.

5.2 Design Criteria Met

5.2.1 Full Bodied Interaction Design

Since the iron working field can produce long hours of labour, the A.I.R. Suit aims to enhance the experience of comfort that users have with personal protective equipment (PPE) through its lightweight and durable design. The suit provides interaction and adjustability to users with the 180° auto darkening retractable visor (Figure 85), built-in augmented reality (Figure 86), and form-fitting mask (Figure 87). The 180° auto darkening retractable visor (Figure 85) grants users the ability to interact with the suit in a natural method through adjusting the visor's positioning. To amplify the desirability of the overall suit, the welding helmet presents a built in retractable visor that enables users to secure and lock its placement. With the use of augmented reality (Figure 86), users are able to increase work productivity and precision when welding through material analyzing, precision lock and obtain reassurance towards their respiratory health through air quality gauges and environment particle level assessments. With a touch of a button, users are able to feasibly access these features within the A.I.R. Helmet and Visor components. The simplistic form-fitting mask references the N95 and non-medical mask pull up or down motion, this familiar interaction is also replicated when workers wear thicken fabric masks that workers have a tendency to wear.

Figure 85. 180º Auto-Darkening Retractable Visor

Figure 86. Built-In Augmented Reality

Figure 87. Form-Fitting Mask

5.2.2 Material, Processes and Technology

To promote the A.I.R. Suit's efficiency, the optimal material considerations that support worker health, safety and comfort were chosen based on the Canadian Centre for Occupational Health & Safety and Occupational Safety and Health Administration (OSHA). The A.I.R. Suit's fabric is comprised of cool flame-resistant 100% cotton, leather, and kevlar heat-resistant thread to reduce exposure of welding burns or sparks. The A.I.R. Suit embodies innovation through each aspect of its durable protective materials, such as; the 100% flame-resistant (FR) cotton based fabric that is interwoven within the suit, mask and gloves (Figure 88). This FR cotton based fabric is strengthened by synthetic heat-resistant leather and thread. The apparel fabric colour treatment is intertwined in grey to dark grey shades as this provides a cooler and breathable fabric when welding. The visor component is composed of thermoplastic olefin for greater performance against UV exposure, temperature resistance, water resistance, and impact resistance (Government of Ontario, 2022). The FR fabric is a patented blend of oxidized acrylic fibers and modern strengthening fibers, which has been proven to withstand extreme heat exposure including iron production (Lowney, 2010). Additionally, the visor incorporates current auto-darkening welding technology through carrying the EN-379 lens (Government of Ontario, 2022). The suit's helmet is made from polycarbonate plastics that protect from radiation, burns or impact (Lowney, 2010). Additionally, the built-in augmented reality features (Figure 89) are made possible through the technological innovations of a microscopic projector (Figure 90).


Figure 88. A.I.R. Material Close-Up


Figure 89. Augmented Reality Features


Figure 90. Microscopic Projector

5.2.3 Design Implementation

The A.I.R. Suit follows the guidelines of the Canadian Centre for Occupational Health & Safety and Occupational Safety and Health Administration (OSHA) existing manufacturing processes. The viability and feasibility of the A.I.R. Suit implements pre existing sustainable operations that allow for the design to be manufacturable.

Bill Of Materials					
No.	**Component**	**Material**	**Manufacturing**	**QTY**	**Est. Cost**
Personal Protective Equipment					
1	Helmet	Polycarbonate	Injection Molded	1	$5.00 /lbs
2	Visor Frame	Polycarbonate	Injection Molded	1	$5.00 /lbs
3	Visor Screen	Thermoplastic Olefin	Tempered Glass	1	$3.50 /sqft
4	3x3 Pivot Joints	ABS	Injection Molded	2	$3.99 /each
5	Built-in Mask	100% Flame-Resistant Breathable Cotton	Various	17.7 x 27.9 x 2.4 cm	$16.99
6	Top Torso + Sleeves	100% Flame-Resistant Breathable Cotton	Various	152 x 91 cm	$25.00
7	Mid-Chest Vest	100% Flame-Resistant Breathable Wool	Various	70 x 60 cm	$20.00

8	Side Coverage	100% Flame-Resistant Breathable Leather	Various	50 x 50 cm	$20.00
9	Golden-Reflective Strips	Polyethylene Tere, Polyvinyl Chloride	Polymerization of Ethylene Glycol	1" x 15 ft	$15.99
10	Pouch Belt	100% Flame-Resistant Leather	Various	15 x 20 cm	$10.00
11	Gloves	100% Flame-Resistant Leather/Neoprene	Various	10 x 15 cm	$12.99
Technology					
12	PAPR Front Housing	ABS	Injection Molded	1	$3.00 /lbs
13	PAPR Back Housing	ABS	Injection Molded	2	$3.00 /lbs
14	Breathing Tube	Neoprene	Polymerization	5.6 x 30.7 x 29 cm	$100
15	Compact Fan	Various	Various	1	$200
16	Front Fan Enclosure	ABS	Injection Molded	1	$3.00 /lbs
17	Back Fan Enclosure	ABS	Injection Molded	1	$3.00 /lbs
18	HE Filter	Polypropylene and Fibreglass fibres	Various	1	$50
19	Carbon Filter	Various Carbon Granules	Various	1	$150
20	Particle Filtration Filter	Polypropylene and Fibreglass fibres	Various	1	$100
21	Lithium Ion Powered Battery	Various	Various	1	$300
22	Microscopic Augmented Reality Projector	Various	Various	1	$500
23	Projector Enclosure	ABS	Injection Molded	1	$3.00 /lbs
24	Power Nodes/LEDs	Various	Various	1	$100

Table 11. Bill of Materials

5.3 Final CAD Rendering

Figure 91. Final CAD Action View

Figure 92. Final CAD Render - 1

Figure 93. Final CAD Render - 2

Figure 94. Final CAD Render - 3

5.4 Physical Model

Figure 95. Physical Model - 1

Figure 96. Physical Model - 2

Figure 97. Physical Model - 3

Figure 98. Physical Model - 4

5.5 Technical Drawings

The following technical drawing (Figure 99) depicts the 1:1 scale dimensions for the A.I.R. Suit. Due to the level of geometric detailing, each polygon on the suit must be represented as shown below (Figure 99) to ensure accurate dimensions are documented. Primary dimensions of the A.I.R. Suit's helmet, visor, and Powered Air Purifying Respirator (PAPR) are displayed, while brief dimensions are provided for the suit's gloves, pouches, upper torso, sleeves and waist are provided.

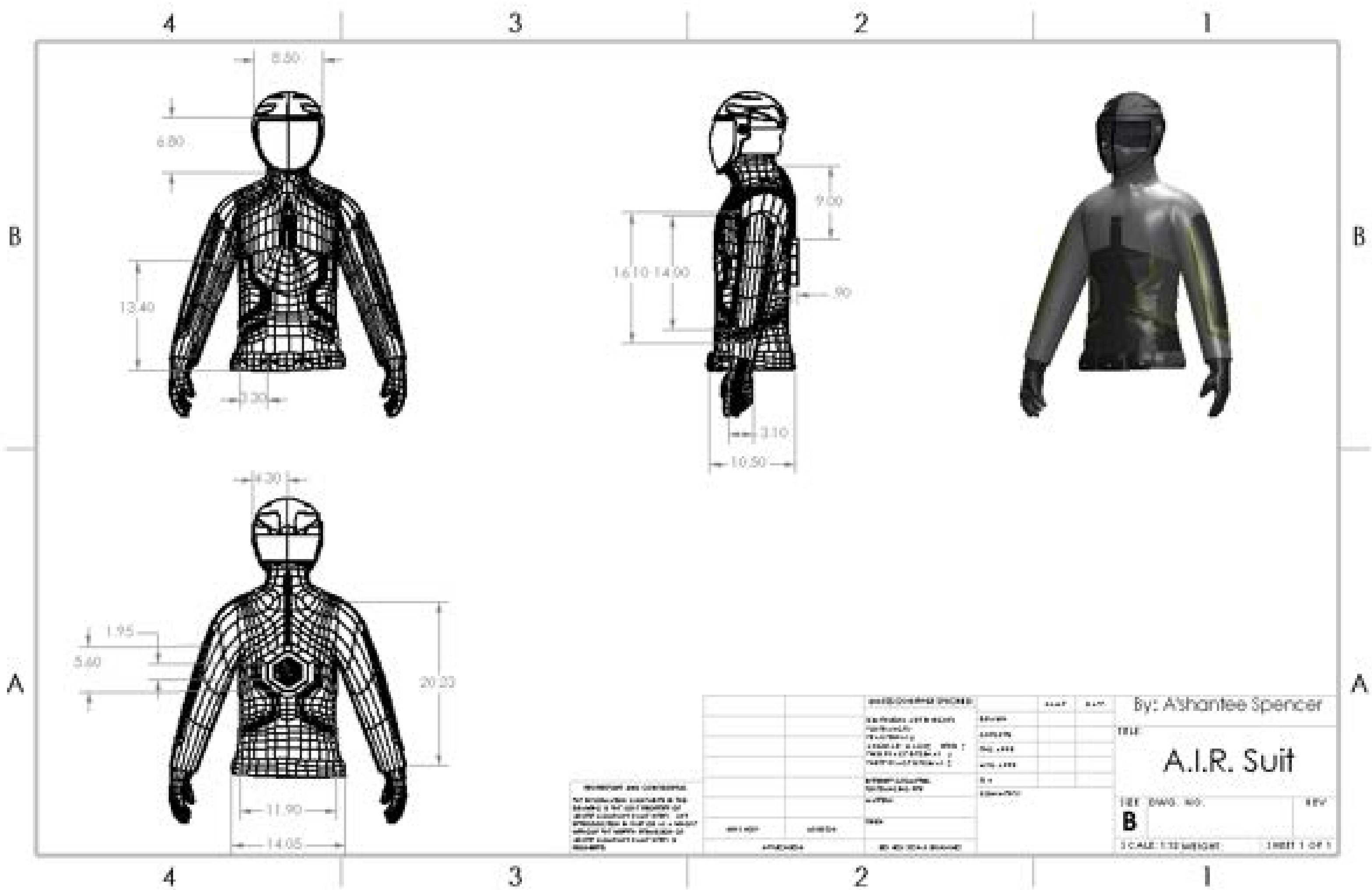


Figure 99. A.I.R. Suit Technical Drawings

*This Product is Shown in 1:1 Scale
*Technical Drawing Shown in INCHES

5.6 Sustainability

Majority of iron workers' personal protective equipment calls for a thorough manufacturing process which must meet the standards of Canada's Occupational Health and Safety guidelines. This means that the helmets, visors/lenses, gloves and apparel must be durable and reusable for iron workers to use on a regular basis. However, due to the strict regulations of Canada's Occupational Health and Safety guidelines, many of the personal protective equipment are not biodegradable or compostable for the sake of product quality and longevity. If certain areas of protective equipment were sustainable, a possible business model that can indicate the personal protective equipment cycle could be as follows; where apparel supplies receive an order for leather welding gloves, the apparel supplies construct and ship the gloves to a welding corporation. Where that cooperation would use the gloves for two years, the welding cooperation sends back the biodegrading gloves as per warranty, the apparel supplier receives the biodegradable leather gloves and uses these raw materials to make newer gloves.

With these considerations, it is evident that finding a balance towards sustainability and durability must be incorporated to both protect from respiratory hazards, UV radiation, sparks/flames (Canadian Centre for Occupational Health & Safety, 2017), while being renewable in order to sustain the environment. By optimizing the current personal protective equipment for iron workers which includes; welding apparel, helmets, visors, lenses, and gloves, there can be potential for user comfort as well as reusable and renewable aspects for the environment. The sustainability aspect of the A.I.R. Suit can be evaluated further by ensuring that each piece of personal protective equipment can be reused for a long duration, while providing strength and biodegradable components which can help the planet.

CHAPTER 6: CONCLUSION

Figure 100. The A.I.R. Suit

The iron worker community provides infrastructure benefits through the industrial process of welding. Over time, these workers face excessive exposure rates of air toxin groups of inorganic gas dust, gases, fumes, and woodworking particles. Although personal protective equipment (PPE) is required for workers to wear, finding the correct welding and respiratory equipment can be time-consuming, as consideration towards product interchangeability, compatibility, safety effectiveness and ergonomics must be in place. The A.I.R. Suit: *Augmented Reality Iron Worker Respirator* Suit takes accountability for each health and safety consideration through mitigating sub-particle respiratory contamination and improving work-efficiency through augmented reality. The A.I.R. Suit goes beyond the industry standards in order to ensure usability, durability and comfort by becoming a one-stop personal protective equipment (PPE).

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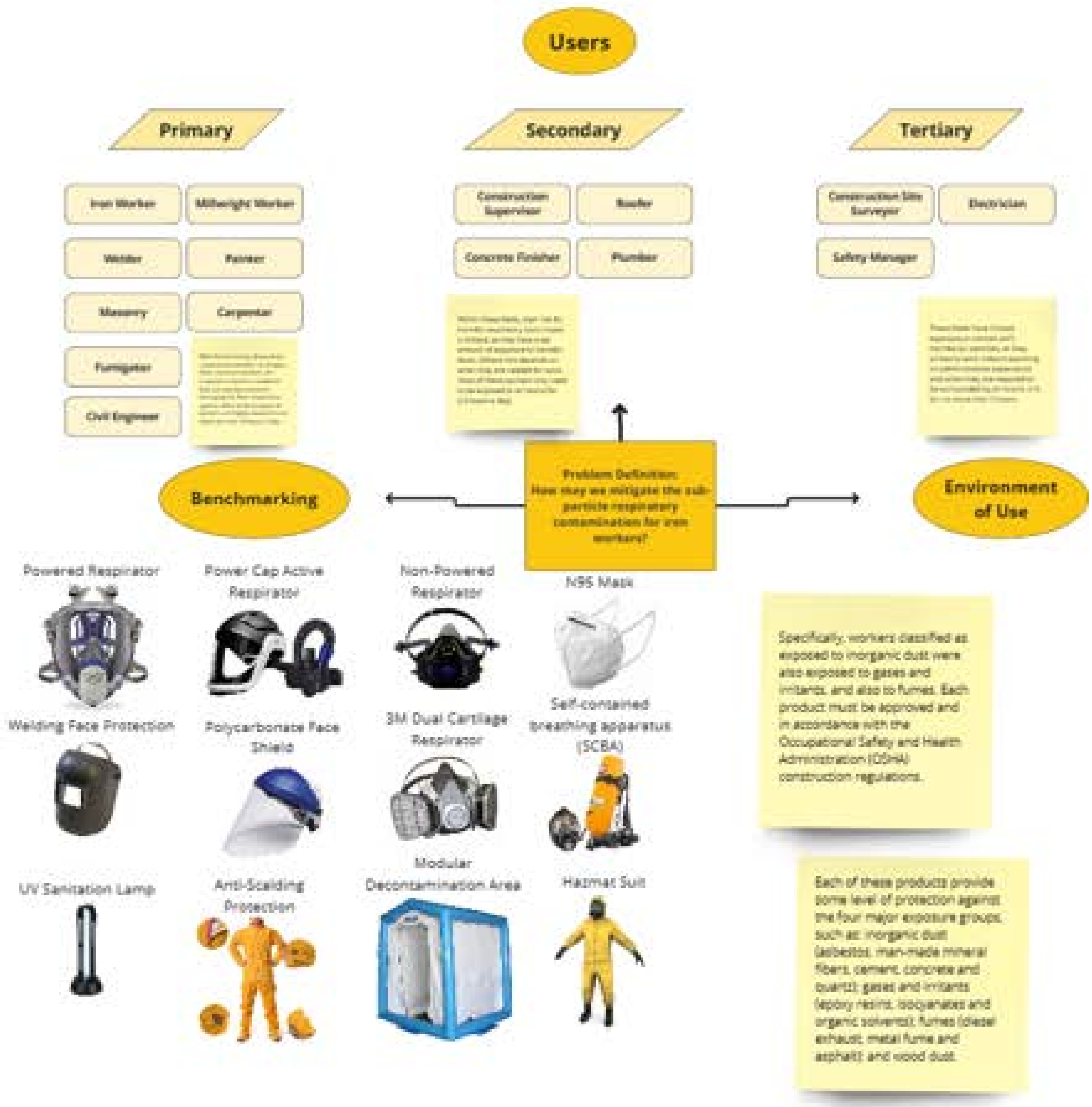
Appendix A – Discovery



Product	Benchmarked Products	Environment of Use
Anti-Scalding Protection 	Product Overview: • [illegible] • [illegible] Challenges: • [illegible] • [illegible]	Scenarios: Thermal discomfort when working after a period of time • [illegible] Challenges: • [illegible] • [illegible]
Power Cap Active Respirator 	Product Overview: • [illegible] • [illegible] • [illegible] Challenges: • [illegible] • [illegible]	Scenarios: Visibility is disoriented due to fog • [illegible] • [illegible] Challenges: • [illegible] • [illegible]
Non-Powered Respirator 	Product Overview: • [illegible] • [illegible] Challenges: • [illegible] • [illegible]	Scenarios: Training of when and how to use non-powered respirators • [illegible] • [illegible] Challenges: • [illegible]
N95 Mask 	Product Overview: • [illegible] Challenges: • [illegible] • [illegible]	Scenarios: When N95 masks can be in use • [illegible] • [illegible] Challenges: • [illegible]
Welding Face Protection 	Product Overview: • [illegible] • [illegible] Challenges: • [illegible] • [illegible]	Scenarios: Workers' eyes can easily become blurred due to transparent screen • [illegible] • [illegible] Challenges: • [illegible]

Appendix B – Contextual Research (User)

Interview Expert:

By 'A'shantee Spencer'

Topic area currently being considered: Sub-particle respiratory effects on iron workers

Name of Interviewee: Madison K.

Background of interviewee (relevant to this topic): Madison is a veteran of the construction worker-field. She has had the opportunity to work with Lebovic Enterprises Limited for over 5 years as a construction advisor/administrative secretary and construction worker. Additionally, she has familiarity with iron working and overall respiratory effects towards construction.

"I am currently in the discovery phase of selecting an area of interest.
This area is: sub-particle respiratory effects on iron workers.

1 Top 3 challenges

What do you believe are the **top 3 challenges** or major issues facing the area today?

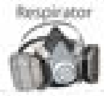
The top 3 challenges facing construction today would be the overarching threats towards workers' health, the minimal PPE that is given (to meet the Government of Canada's standards) and the low productivity due to technology limitations.

2 Top 3 trends in the past 5 years

What are the **top 3 trends** in this area over the past 5 years facing the area today?

The top 3 trends in the construction area over the past 5 years would be the rapid industrial development coupled with limited workers who are not experienced. Also, the market for this field will increase dramatically as Covid-19 precautions drift away, there will be more opportunity for development in the Steel industry. With the increasing demand for construction workers of all types, this means that more workers are required to work in conditions that can overtime become damaging for their respiratory system.

Appendix C – Field Research (Product)

Product	Environment of Use
Powered Respirator 	[illegible]
Power Cap Active Respirator 	[illegible]
Non-Powered Respirator 	[illegible]
N95 Mask 	[illegible]
Welding Face Protection 	[illegible]
Polycarbonate Face Shield 	[illegible]
3M Dual Cartilage Respirator 	[illegible]
Self-contained breathing apparatus (SCBA) 	[illegible]
UV Sanitation Lamp 	[illegible]
Anti-Scalding Protection 	[illegible]
Modular Decontamination Area 	[illegible]
Hazmat Suit 	[illegible]

Main Usability Issues

- Gains: Being able to safely work while knowing that these fumes he is surrounded by aren't penetrating his respiratory system. Also, having the confidence to work efficiently and healthily.
- Pains:
  - Not being able to keep up with constant respiratory PPE training or inconsistent design
  - Having the unconfidence to work efficiently and healthily when wearing certain PPE
  - Feeling discomfort when wearing respirators due to straps and bulkiness of designs after certain periods of time
  - Having the goggles fog up due to the mask gaps and having to pause work to cleaning or wiping goggles
- Usability & Ergonomics
  - Lots of materials/equipments to carry
  - Strenuous amounts of bending
- Efficiency
  - Preparation and cleanliness of respirator prior to use
- Interaction
  - Small adjustment buttons for airflow levels
  - Turning off/on the PAPR
- Satisfaction
  - Mastery and Control- being able to setup and properly put on respirator with little to no assistance or guidance from superiors
  - Being able to quickly adjust to using a respirator/welding helmet with little to no difficulties

FEATURES	SORT #1: CATEGORIES
Filters and Cartridges	Headgear:
One-touch positive pressure push button seal check	Headgear-Mounted Powered Air Purifying Respirator
Two dual-flow cartridges	Scotchgard™ Protector
quad flow cartridge systems	modular design and convertibility of major components
Four airflow paths	Six-strap harness
Large lens for excellent field of vision	One-touch positive pressure push button seal check
Scotchgard™ Protector	fitting facepieces and the M-400 Series Helmets
Six-strap harness	Braided headbands and an M Nose clip
Speaking diaphragm	Breathing
modular design and convertibility of major components	Two dual-flow cartridges
fitting facepieces and the M-400 Series Helmets	Four airflow paths
Breathing Tubes and Powered Air Purifying (PAPR) or Supplied Air (SA)	quad flow cartridge systems
eye and face protection standards,	Filters and Cartridges, powered air flow

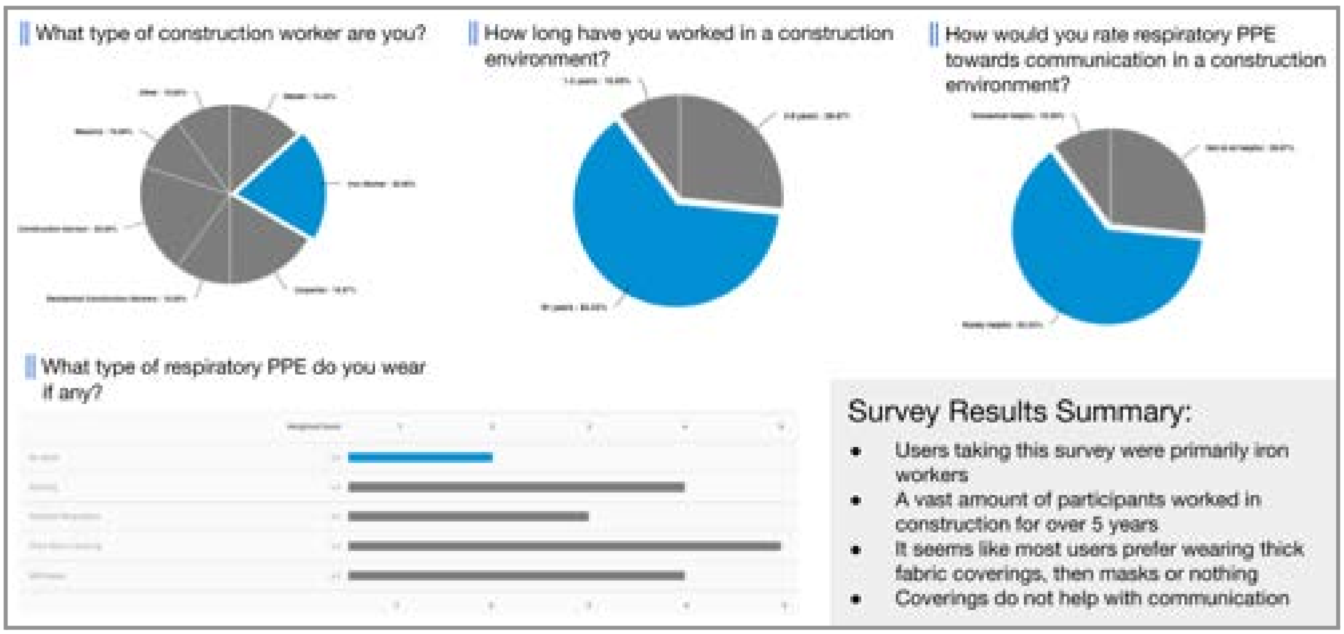
Appendix D – Results Analysis

2.1.1 User Survey

In-depth user feedback conducted to determine why users are experiencing discomfort when using respiratory PPE on construction sites, and what they like and dislike about it. A survey on Google Forms link and QR code were sent to construction workers via text messages between Oct 5-20, 2022.

Results

Results are displayed as bar pie charts Figure below



Summary: How this may inform design

- Users taking this survey were primarily iron workers
- A vast amount of participants worked in construction for over 5 years
- It seems like most users prefer wearing thick fabric coverings, then masks or nothing
- Coverings do not help with communication

2.1.2 User Interview

In-depth user feedback conducted to determine why users are experiencing discomfort when using respiratory PPE on construction sites, and what they like and dislike about it. A 1:1 interview was conducted with Madison K. by phone on Oct. 5, 2022. The interview was recorded with permission and transcribed.

Results

Preliminary questions were created (see Figure below).

An excerpt from the interview is in the Figure below (the full interview is in the Appendices)

Prelim Questions:
1. What type of construction worker are you?
2. How long have you worked in a construction environment?
3. What are the assigned tasks that you do in your field of work?
4. How long is your typical work shift?
5. Could you describe your typical work environment? (i.e. whether you work indoors or outdoors, surroundings of trees or asphalt or dust)

Primary Questions:
1. When working in a construction environment, what type of respiratory PPE do you wear, if any? How would you rate the PPE effectiveness?
2. Why have you chosen or not chosen to wear respiratory PPE?
3. In your opinion, would you say that respiratory PPE helps with communication in a construction environment? If not, how can this be improved?
4. In your line of work, how often have you experienced respiratory irritation? (i.e. Sneezing, sniffling, coughing, etc.)
5. How would you like to see the future of respiratory PPE while working on a construction site? (i.e. Level of comfort, durability or communication)
6. In your opinion, how would you rate the air quality level while on the job?
7. Are there any designated spaces for lunchtime or when workers want to remove dust?
8. Are there any final thoughts on respiratory PPE for construction workers? (i.e. Obstacles when wearing respiratory PPE, Adaptability when wearing PPE)

Interviewer:
In your opinion, how would you rate the air quality level while on the job?

Interviewee:
Personally, I haven't really thought of it, I think it depends on the weather. So if it's sunny outside and there's no wind, I would rate the air quality as normal, cause there's less dust flying in my face. But like, if it's extremely windy outside, I suppose I would rate the air quality level as poor, since the dust is like everywhere. What I'm trying to get at is that there's never really a consistent air quality while on the job, since a car could zoom by and create more dust or humidity which could bother us.

Interviewer:
Are there any designated spaces for lunchtime or when workers want to remove dust?

Interviewee:
I guess we eat in a trailer so that can count as a designated space for lunches or when we want to get away from (the) dust. But, sometimes we are so busy that we have no time to head back to the trailer so we either grab lunch from a nearby restaurant, head back to the construction site and eat there (outside). If someone has a car or truck, they are able to take breaks and eat in those too.

Interviewer:
Are there any final thoughts on respiratory PPE for construction workers? (i.e. Obstacles when wearing respiratory PPE, Adaptability when wearing PPE)

Interviewee:
Yeah, I mean unfortunately, construction dust can cause serious damage to workers' health, but once things are out of sight, it's also out of mind. As in we're so focused on the job that we try not to focus on the dust that we're breathing in. It is an issue, just not one that is talked about until someone is actually sick. I think we tend to wear thick cloth material to cover our faces more so than masks because it's more comfortable and we can actually project our voices easier. The powered respirators are good, but knowing when to change the cartilage can be tricky or just annoying.

Summary: How this may inform design

- Users feel like current designs hinder communication, but are helpful towards health and safety
- Designs have poor levels of comfort when it comes to strap adjustability
- Changing or upgrading current designs can be time consuming and costly
- Social support network being able to talk about precision, manufacturing plans on job is important

2.1.3 User Observation (preliminary)

To determine the users the way they organized their work (or progressed through their tasks), as well as their thoughts and feelings, a user observation was conducted.

The user observation employed videos available on the internet to determine the routine followed by the construction workers who use respiratory PPE. The video (information below) was transcribed.

Respiratory Protection in Construction: An Overview of Hazards & OSHA's Program Requirements
US Department of Labour
https://youtu.be/sq4ojjwaQYg
Retrieved: Oct 18, 2022

Results

An excerpt of the transcription of the video is below, along with preliminary coding.
The full transcription is available in the Appendix.

Sample Excerpt #1:

Respiratory Protection in Construction: An Overview of Hazards & OSHA's Program Requirements

- [0:27 - 0:39]
The federal Occupational Safety and Health Administration also called OSHA and state OSHA agencies require employers to have respiratory protection programs if their workers are required to wear respirators on the job
- [1:17 - 1:31]
The purpose of a respirator is to protect your health and safety gases dusts mists and fumes may be present at construction work sites; some of these can make you sick or kill you if you breathe them in.
- [1:35 - 1:53]
These gases dusts mists and fumes are referred to as respiratory hazards some respiratory hazards act quickly like carbon monoxide which can make you unconscious or kill you in minutes other respiratory hazards can take years to make you sick like asbestos which can cause lung cancer decades after you breathe it in more
- [1:57 - 2:13]
Examples of respiratory hazards and construction include lead dust and fumes from grinding welding cutting or brazing surfaces coated with lead-based paint silica dust from cutting concrete or sandblasting solvent vapors
- [2:30 - 2:55]
At your job site your employer must use several methods to reduce your exposure to them including engineering controls such as local exhaust ventilation work practice controls such as using wet cutting techniques and administrative controls such as minimizing the number of workers exposed to the hazard when you and your co-workers cannot be adequately protected from respiratory hazards

Sample Excerpt #2:

Respiratory Protection in Construction: An Overview of Hazards & OSHA's Program Requirements

- [2:59 - 3:19]
Employer must provide you with an appropriate respirator to protect your health respiratory protection must be selected based on the hazard you will be exposed to on the job not every respirator will protect you against every hazard so it's important for your employer to select the right one
- [3:13 - 3:17]
Not every respirator will protect you against every hazard so it's important for your employer to select the right
- [3:55 - 4:07]
Atmosphere supplying respirators are the only respirators that will protect you against hazardous atmospheres such as carbon monoxide and lack of oxygen selecting an appropriate respirator
- [4:32 - 4:54]
Written respiratory protection program evaluate the respiratory hazards in the workplace select and provide appropriate respirators provide worker medical evaluations and respirator fit testing provide for the maintenance storage and cleaning of respirators provide worker training about respiratory hazards and proper respirator use
- [5:50 - 6:10]
Workplaces may differ in the following ways the types and amount of respiratory hazards present the people who manage the program the policies and procedures for tasks such as respirators selection maintenance and use and other methods for controlling exposure such as using wet cutting techniques to reduce airborne dusts

CODING:

Respiratory Protection in Construction: An Overview of Hazards & OSHA's Program Requirements

- [0:27 - 0:39]
  The federal Occupational Safety and Health Administration also called OSHA and state OSHA agencies require employers to have respiratory protection programs if their workers are required to wear respirators on the job
- [1:17 - 1:31]
  The purpose of a respirator is to protect your health and safety gases dusts mists and fumes may be present at construction work sites, some of these can make you sick or kill you if you breathe them in
- [1:35 - 1:53]
  These gases dusts mists and fumes are referred to as respiratory hazards, some respiratory hazards act quickly like carbon monoxide which can make you unconscious or kill you in minutes other respiratory hazards can take years to make you sick like asbestos which can cause lung cancer decades after you breathe it in more
- [1:57 - 2:12]
  Examples of respiratory hazards and construction include lead dust and fumes from grinding welding cutting or brazing surfaces coated with lead-based paint silica dust from cutting concrete or sandblasting solvent vapors
- [2:30 - 2:55]
  At your job site your employer must use several methods to reduce your exposure to them including engineering controls such as local exhaust ventilation, work practice controls such as using wet cutting techniques and administrative controls such as minimizing the number of workers exposed to the hazard when you and your co-workers cannot be adequately protected from respiratory hazards
- [2:59 - 3:19]
  Employer must provide you with an appropriate respirator to protect your health respiratory protection must be selected based on the hazard you will be exposed to on the job not every respirator will protect you against every hazard so it's important for your employer to select the right one
- [3:13 - 3:17]
  Not every respirator will protect you against every hazard so it's important for your employer to select the right
- [3:55 - 4:07]
  Atmosphere supplying respirators are the only respirators that will protect you against hazardous atmospheres such as carbon monoxide and lack of oxygen selecting an appropriate respirator
- [4:32 - 4:54]
  Written respiratory protection program evaluate the respiratory hazards in the workplace select and provide appropriate respirators, provide worker medical evaluations and respirator fit testing provide for the maintenance storage and cleaning of respirators provide worker training about respiratory hazards and proper respirator use

Coding Themes:

Respiratory Protection in Construction: An Overview of Hazards & OSHA's Program Requirements

- Employer Respirator Responsibility
  - Safety Planning/ Training
  - Respiratory Efficiency
- Respirator Use
  - Protection
  - Adequate tooling
- Respiratory Hazards
  - Types of air toxins
  - Where air toxins are prevalent

Summary: How this may inform design

- Gains: Being able to safely work while knowing that these fumes he is surrounded by aren't penetrating his respiratory system. Also, having the confidence to work efficiently and healthily.
- Pains:
  - Not being able to keep up with constant respiratory PPE training or inconsistent design
  - Having the unconfidence to work efficiently and healthily when wearing certain PPE
  - Feeling discomfort when wearing respirators due to straps and bulkiness of designs after certain periods of time
  - Having the goggles fog up due to the mask gaps and having to pause work to cleaning or wiping goggles

Results

An excerpt of the notes are below, along with preliminary coding.

The full notes are available in the Appendix B.

Sample Excerpt #1:

Respiratory Protection in Construction: An Overview of Hazards & OSHA's Program Requirements

- [0:27 - 0:39]
  The federal Occupational Safety and Health Administration also called OSHA and state OSHA agencies require employers to have respiratory protection programs if their workers are required to wear respirators on the job
- [1:17 - 1:31]
  The purpose of a respirator is to protect your health and safety gases dusts mists and fumes may be present at construction work sites; some of these can make you sick or kill you if you breathe them in
- [1:35 - 1:53]
  These gases dusts mists and fumes are referred to as respiratory hazards some respiratory hazards act quickly like carbon monoxide which can make you unconscious or kill you in minutes other respiratory hazards can take years to make you sick like asbestos which can cause lung cancer decades after you breathe it in more
- [1:57 - 2:12]
  Examples of respiratory hazards and construction include lead dust and fumes from grinding welding cutting or brazing surfaces coated with lead-based paint silica dust from cutting concrete or sandblasting solvent vapors
- [2:30 - 2:55]
  At your job site your employer must use several methods to reduce your exposure to them including engineering controls such as local exhaust ventilation work practice controls such as using wet cutting techniques and administrative controls such as minimizing the number of workers exposed to the hazard when you and your co-workers cannot be adequately protected from respiratory hazards

Sample Excerpt #2:

Respiratory Protection in Construction: An Overview of Hazards & OSHA's Program Requirements

- [2:59 - 3:19]
  Employer must provide you with an appropriate respirator to protect your health respiratory protection must be selected based on the hazard you will be exposed to on the job not every respirator will protect you against every hazard so it's important for your employer to select the right one
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  Not every respirator will protect you against every hazard so it's important for your employer to select the right
- [3:55 - 4:07]
  Atmosphere supplying respirators are the only respirators that will protect you against hazardous atmospheres such as carbon monoxide and lack of oxygen selecting an appropriate respirator
- [4:32 - 4:54]
  Written respiratory protection program evaluate the respiratory hazards in the workplace select and provide appropriate respirators provide worker medical evaluations and respirator fit testing provide for the maintenance storage and cleaning of respirators provide worker training about respiratory hazards and proper respirator use
- [5:50 - 6:10]
  Workplaces may differ in the following ways the types and amount of respiratory hazards present the people who manage the program the policies and procedures for tasks such as respirators selection maintenance and use and other methods for controlling exposure such as using wet cutting techniques to reduce airborne dusts

Coding

More in-depth coding was then conducted.

Coding:

Respiratory Protection in Construction: An Overview of Hazards & OSHA's Program Requirements

- [0:27 - 0:38]
  The federal Occupational Safety and Health Administration also called OSHA and state OSHA agencies require employers to have respiratory protection programs if their workers are required to wear respirators on the job
- [1:17 - 1:31]
  The purpose of a respirator is to protect your health and safety gases dusts mists and fumes may be present at construction work sites, some of these can make you sick or kill you if you breathe them in
- [1:35 - 1:53]
  These gases dusts mists and fumes are referred to as respiratory hazards, some respiratory hazards act quickly like carbon monoxide which can make you unconscious or kill you in minutes other respiratory hazards can take years to make you sick like asbestos which can cause lung cancer decades after you breathe it in more
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  Examples of respiratory hazards and construction include lead dust and fumes from grinding welding cutting or brazing surfaces coated with lead based paint silica dust from cutting concrete or sandblasting solvent vapors
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  At your job site your employer must use several methods to reduce your exposure to them including engineering controls such as local exhaust ventilation, work practice controls such as using wet cutting techniques and administrative controls such as minimizing the number of workers exposed to the hazard when you and your co-workers cannot be adequately protected from respiratory hazards
- [2:59 - 3:19]
  Employer must provide you with an appropriate respirator to protect your health respiratory protection must be selected based on the hazard you will be exposed to on the job not every respirator will protect you against every hazard so it's important for your employer to select the right one
- [3:13 - 3:17]
  Not every respirator will protect you against every hazard so it's important for your employer to select the right
- [3:55 - 4:07]
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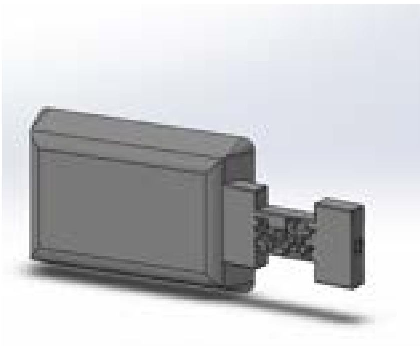
  Written respiratory protection program evaluate the respiratory hazards in the workplace select and provide appropriate respirators, provide worker medical evaluations and respirator fit testing provide for the maintenance storage and cleaning of respirators provide worker training about respiratory hazards and proper respirator use

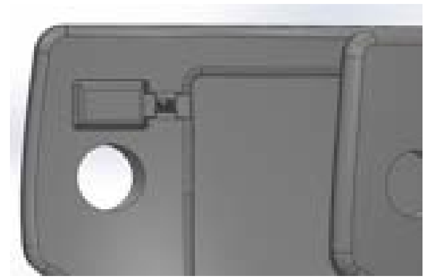
Coding Themes:

Respiratory Protection in Construction: An Overview of Hazards & OSHA's Program Requirements

- Employer Respirator Responsibility
  - Safety Planning/ Training
  - Respiratory Efficiency
- Respirator Use
  - Protection
  - Adequate tooling
- Respiratory Hazards
  - Types of air toxins
  - Where air toxins are prevalent

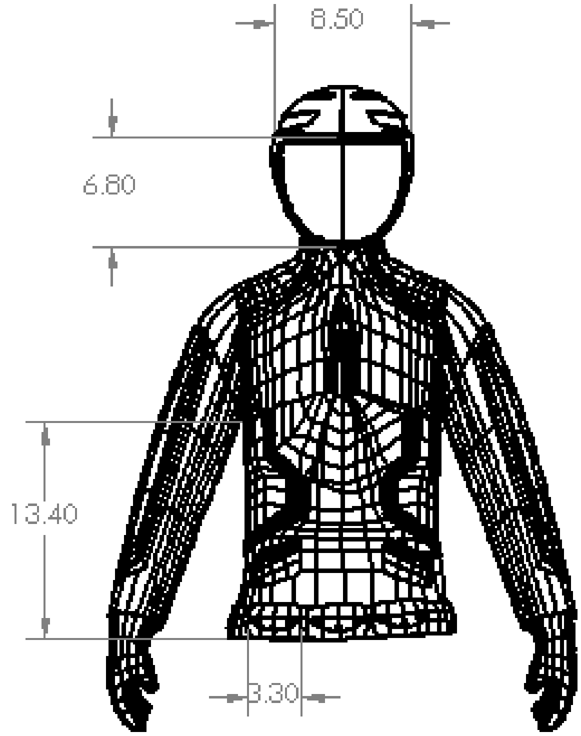
Appendix E – CAD Development

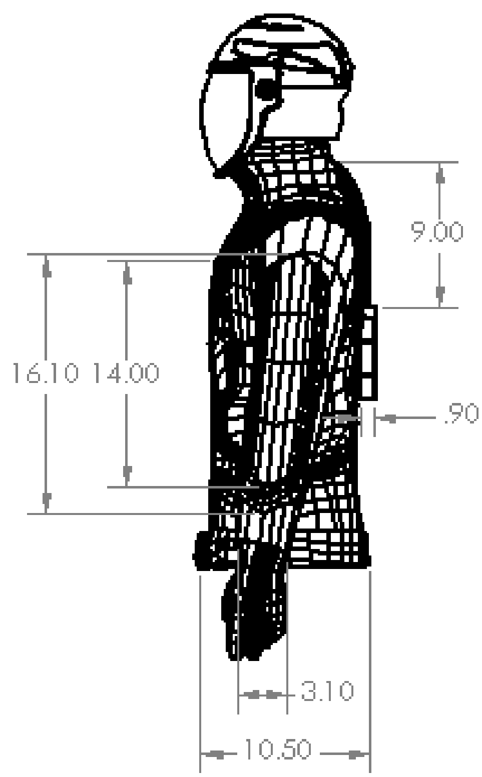




Appendix F – Physical Model Photographs

Appendix G – Technical Drawings





Appendix H – Bill of Materials Info/Data

Bill Of Materials					
No.	**Component**	**Material**	**Manufacturing**	**QTY**	**Est. Cost**
Personal Protective Equipment					
1	Helmet	Polycarbonate	Injection Molded	1	$5.00 /lbs
2	Visor Frame	Polycarbonate	Injection Molded	1	$5.00 /lbs
3	Visor Screen	Thermoplastic Olefin	Tempered Glass	1	$3.50 /sqft
4	3x3 Pivot Joints	ABS	Injection Molded	2	$3.99 /each
5	Built-in Mask	100% Flame-Resistant Breathable Cotton	Various	17.7 x 27.9 x 2.4 cm	$16.99
6	Top Torso + Sleeves	100% Flame-Resistant Breathable Cotton	Various	152 x 91 cm	$25.00
7	Mid-Chest Vest	100% Flame-Resistant Breathable Wool	Various	70 x 60 cm	$20.00
8	Side Coverage	100% Flame-Resistant Breathable Leather	Various	50 x 50 cm	$20.00
9	Golden-Reflective Strips	Polyethylene Tere, Polyvinyl Chloride	Polymerization of Ethylene Glycol	1" x 15 ft	$15.99
10	Pouch Belt	100% Flame-Resistant Leather	Various	15 x 20 cm	$10.00
11	Gloves	100% Flame-Resistant Leather/Neoprene	Various	10 x 15 cm	$12.99
Technology					
12	PAPR Front Housing	ABS	Injection Molded	1	$3.00 /lbs
13	PAPR Back Housing	ABS	Injection Molded	2	$3.00 /lbs
14	Breathing Tube	Neoprene	Polymerization	5.6 x 30.7 x 29 cm	$100
15	Compact Fan	Various	Various	1	$200
16	Front Fan Enclosure	ABS	Injection Molded	1	$3.00 /lbs
17	Back Fan Enclosure	ABS	Injection Molded	1	$3.00 /lbs
18	HE Filter	Polypropylene and Fibreglass fibres	Various	1	$50
19	Carbon Filter	Various Carbon Granules	Various	1	$150
20	Particle Filtration Filter	Polypropylene and Fibreglass fibres	Various	1	$100
21	Lithium Ion Powered Battery	Various	Various	1	$300
22	Microscopic Augmented Reality Projector	Various	Various	1	$500
23	Projector Enclosure	ABS	Injection Molded	1	$3.00 /lbs
24	Power Nodes/LEDs	Various	Various	1	$100

Appendix I – Sustainability Info/Data

Full Article

Cotton-Based Flame-Retardant Textiles: A Review

Md. Shahidul Islam and Theo. G. M. van de Ven *

Biodegradable textiles made from cellulose, the most abundant biopolymer, have gained attention from researchers, due to the ease with which cellulose can be chemically modified to introduce multifunctional groups, and because of its renewable and biodegradable nature. One of the most attractive features required for civilian and military applications of textiles is flame-retardancy. This review focuses on various methods employed for the fabrication of cellulose-based flame-retardant cotton textiles along with their developed flame-retardant properties over the last few years. The most common method is to merge N, S, P, and Si-based polymeric, non-polymeric, polymeric/non-polymeric hybrids, inorganic, and organic/inorganic hybrids with cellulose to fabricate flame-retardant cotton textiles. In these studies, cellulose was chemically bonded with the flame-retardants or in some cases, cotton textiles were coated by flame-retardants. The flame-retardant properties of the cotton textiles were investigated and determined by various methods, including the limiting oxygen index (LOI), the vertical flame test, thermal gravimetric analysis (TGA), and by cone calorimetry. This review demonstrates the potential of cellulose-based flame-retardant textiles for various applications.

Keywords: Cellulose; Cotton textile; Flame-retardancy

*Contact information: Department of Chemistry, McGill University, Montreal, QC, Canada; Quebec Centre for Advanced Materials, and Pulp and Paper Research Centre, 3420 University Street, Montreal, QC, Canada; *Corresponding author: theo.vandeven@mcgill.ca*

INTRODUCTION

The textile markets are currently dominated by synthetic polymer fibers such as polyester and nylon, and natural polymer fibers such as cotton and rayon. The cost of cotton fibers has increased due to limited arable land on which it can be grown. Cotton also requires extensive irrigation and use of pesticides. Increasing concerns regarding the environmental impact of non-biodegradable synthetic polymer fibers prepared from non-renewable sources are the driving force to find suitable alternatives. Biomass contains large quantities of cellulose, which is biodegradable and unusable as food or feed. Therefore, cellulose has become an extremely suitable candidate as a sustainable alternative to natural or synthetic polymer fibers in textile markets. It is estimated that the production of cellulosic textile fibers in 2015 was 5.2 million tons (approximately 5% of total filament products), which is projected to reach 10 million tons in 2030 (Carmichael 2014).

Textiles play a significant role in the everyday life of human beings. Textiles are primarily made of organic polymers, which are flammable in nature. The annual UK fire statistics demonstrates that most of the fire accidents that occur in houses involve upholstering furniture, bedding, and nightwear (Salmeia *et al.* 2016). The inclusion of flame-retardants can prevent or delay the appearance of a flame and can reduce the flame-spreading rate of the textile (Salmeia *et al.* 2016; Babu *et al.* 2020; Dai *et al.* 2020; Holdsworth *et al.* 2020; Thi *et al.* 2020; Xu *et al.* 2020; Yin *et al.* 2020).

The transmission of heat and oxygen can be prevented by a low heat permeable char layer, which is produced from a flame-retardant textile during burning. Non-flammable gases that are produced during the process, such as H_2O and CO_2, assist in diluting the concentration of the flammable gases and minimizing the absorption of heat energy. In principle, non-flammable gases of a flame-retardant textile can resist flames by functioning in condensed and gaseous phases simultaneously during the burning process (Horrocks *et al.* 2005; Salmeia *et al.* 2016; Yusuf 2018; Zhang *et al.* 2019a). A schematic diagram of a possible flame-retardant mechanism for a flame-retardant textile can be seen in Fig. 1.

Appendix J – Approval Forms & Plans

IDSN 4002
SENIOR LEVEL THESIS ONE

Humber ITAL / Faculty of Applied Sciences & Technology
Bachelor of Industrial Design / FALL 2022
Catherine Chong / Frederic Matovu

THESIS TOPIC APPROVAL:

Student Name:	A'shantee Spencer
Topic Title:	How may we mitigate sub-particle respiratory contamination for iron workers?

TOPIC DESCRIPTIVE SUMMARY (PRELIMINARY ABSTRACT)

With the increasing demand for industrial infrastructure of skyscrapers, roadways, and bridges, there is emphasis on iron workers' construction abilities. Ultimately, the development of these construction projects can prove to be difficult towards mitigating air pollutant exposure for iron workers on a sub-particle level. The working environment for iron workers cultivates a breathing ground for air toxin circulation, as the four major exposure groups of inorganic gas dust, gases and irritants, fumes, and woodworking particles act as silent impairments to these workers' respiratory tract. Health and safety precautions like the use of non-powered air purifying respirators and powered air purifying respirators are in place, yet the occupational exposure mortality rates due to dust and air toxins overshadows the effectiveness of current products. Research indicates that these essential workers are prone to developing occupational respiratory diseases, such as, chronic obstructive pulmonary disease (COPD), asthma, lung cancer, and asbestos-related diseases by 30%.Through understanding the occupational hazards and the sub-particle contamination, further insights can be developed such that iron workers are able to productively and safely work by reducing toxin circulation, granting accessible decontamination areas and establishing optimal monitored air quality.

Student Signature(s):	
Date:	27/09/2022

Instructor Signature(s):	
Date:	29 September 2022

17 Chong, Kappen, Thomson, Zaccolo

PANEL ON RESEARCH ETHICS

Navigating the ethics of human research

TCPS 2: CORE 2022

Certificate of Completion

This document certifies that

A'shantee Spencer

successfully completed the Course on Research Ethics based on the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2: CORE 2022)

Certificate # 0000833094 **16 July, 2022**

IDSN 4502

SENIOR LEVEL THESIS TWO

Humber ITAL / Faculty of Applied Sciences & Technology
Bachelor of Industrial Design / WINTER 2023
Catherine Chong / Fredric Matovu

CRITICAL MILESTONES: APPROVAL FOR CAD DEVELOPMENT & MODEL FABRICATION

Student Name:	A'shantee Spencer
Approved Thesis Title:	AR Respirator Suit for Iron Workers

THESIS PROJECT – DESIGN APPROVAL FORM

Design is reviewed and approved to proceed for the following:	[X]	**CAD Design and Development Phase**
Comment:	Continue design refinement in CAD development, need to iron out detailing and product's features, pay attention to surfacing, components, and assembly methods for design feasibility. Viable holistic design thinking in conjunction with considerations into sustainability aspects. CAD development must be at least 75% complete for review before approval for fabrication.	

Design is reviewed and approved to proceed for the following:	[X]	**Model Fabrication Including Rapid Prototyping / 3D Printing and Model Building Phase**
Comment:	Waiting for CAD development review (as of Feb-21). Good progress with CAD, design completed, continue detail refinement, once refined, fabrication of model can begin.	

Instructor Signature(s):	
Date:	07 March 2023

1 Chong, Kappen

Project Plan:

Appendix K – Advisor Meeting & Agreement Forms

HUMBER

Faculty of Applied Sciences & Technology

IDSN 4002 /4502

SENIOR LEVEL THESIS ONE & THESIS TWO

INFORMATION LETTER

Research Study Topic: How May We Mitigate Sub-Particle Respiratory Contamination for Ironworkers

Investigator: A'shantee Spencer / 1 (647) 809 4269 / Ashanteespencer@gmail.com

Sponsor: Humber ITAL, Faculty of Applied Sciences & Technology (IDSN 4002 & IDSN 4502)

Introduction

My name is A'shantee Spencer, I am an industrial design student at Humber ITAL, and I am inviting your participation in a research study on various problems that surround the sub-particle respiratory contamination that iron workers encounter. These problems include high-level air pollutants from asphalt fumes, concrete dust, diesel exhaust, metal fumes, wood dust, etc. These exposure points contribute to an increased level of iron workers developing respiratory diseases, such as COPD, Asbestos, Silicosis, etc., the constant re-encounters with these hazards. The results will be contributed to my Senior Level Thesis project.

Purpose of the Study

This study is being conducted as an aid in designing a sub-particle respiratory contamination device that is capable of mitigating air pollutants may result in an overall safer wellbeing and efficiency of iron workers. The product to be designed is inspired by current respiratory personal protective equipment, such as, powered and non-powered respirators that perform at a limited rate and become obstructive towards workers' communication. With your support, I strive to address the problems and limitations of current respiratory personal protective equipment and develop a greater solution. This study is primarily based on understanding ergonomics, human interaction design activities, and user experience aspects of the research area.

Procedures

If you volunteer in this study, details about your activities and/or personal respiratory health within construction will be observed and documented. Your activities will be documented by means of digital camera / video camera / digital device while working on a construction site. You will also be asked questions pertaining to your personal activities and/or personal respiratory health within construction.

Confidentiality

Every effort will be made to ensure confidentiality of any identifying information that is obtained during the study. In the case of being recorded visually, your face will be masked /blurred or hidden. The information and documentations (photographs) gathered are all subject to being used in the final presentation of the study.

Participation and Withdrawal

Your participation in this study is completely voluntary and you may interrupt or end the study and the session at any time without giving a reason or fear of being penalized.

If at any point during the session, you feel uncomfortable and wish to end your participation, please let the moderator know and they will end your participation immediately.

Humber Research Ethics Board

1

HUMBER

Faculty of Applied Sciences & Technology

Bachelor of Industrial Design / FALL 2022 & WINTER 2023

IDSN 4002 /4502

SENIOR LEVEL THESIS ONE & THESIS TWO

This research project /course has been approved by the Humber Research Ethics Board. If you have any questions about your rights as a research participant, please contact Dr. Lydia Boyko, REB Chair, 416-675-6622 ext. 79322, Lydia.Boyko@humber.ca

2

IDSN 4002 /4502

SENIOR LEVEL THESIS ONE & THESIS TWO

HUMBER

Faculty of Applied Sciences & Technology

Bachelor of Industrial Design / FALL 2022 & WINTER 2023

INFORMATION LETTER

Conditions of Participation

- ✔ I understand that I am free to withdraw from the study at any time without any consequences.
- ✔ I understand that my participation in this study is confidential. (i.e. the researcher will know but will not disclose my identity)
- ✔ My identity will be masked.
- ✔ I understand that the data from this study may be published.

☒ **I have read the information presented above and I understand this agreement. I voluntarily agree to take part in this study.**

Elsworth Walker	[signature]	11/6/2022
Participant's Name	Participant's Signature	Date

Project Information

Thank you very much for your time and help in making this study possible. If you have any queries or wish to know more about this Senior Level Thesis project, please contact me at the followings:

Phone: 1 (647) 809 4269

Email: Ashanteespencer@gmail.com

My supervisor is:

Prof. Catherine Chong, **catherine.chong@humber.ca**

IDSN 4002 /4502

SENIOR LEVEL THESIS ONE & THESIS TWO

HUMBER

Faculty of Applied Sciences & Technology

PARTICIPANT INFORMED CONSENT FORM

Research Study Topic: A'shantee Spencer

Investigator: A'shantee Spencer / 1 (647) 809 4269 / Ashanteespencer@gmail.com

Courses: IDSN 4002 & IDSN 4502 Senior Level Thesis One & Two

I, A'shantee Spencer, have carefully read the Information Letter for the project mitigating sub-particle respiratory contamination for ironworkers, led by A'shantee Spencer. A member of the research team has explained the project to me and has answered all of my questions about it. I understand that if I have additional questions about the project, I can contact A'shantee Spencer at any time during the project.

I understand that my participation is voluntary and give my consent freely in voice recording, photography and/or videotaping, with the proviso that my identity will be blurred in reports and publications.

Consent for Publication: Add a (X) mark in one of the columns for each activity

ACTIVITY		YES	NO
Publication	I give consent for publication in the Humber Library Digital Repository which is an open access portal available to the public	☑	☐
Review	I give consent for review by the Professor	☑	☐

Privacy

All data gathered is stored anonymously and kept confidential. Only the principle investigator /researcher, A'shantee Spencer and Prof. Catherine Chong or Prof. Frederick Matovu may access and analyze the data. All published data will be coded, so that visual data is not identifiable. Pseudonyms will be used to quote a participant (subject) and data would be aggregated.

I also understand that I may decline or withdraw from participation at any time, without negative consequences.

I understand that I can verify the ethical approval of this study, or raise any concerns I may have by contacting the Humber Research Ethics Board, Dr. Lydia Boyko, REB Chair, 416-675-6622 ext. 79322, **Lydia.Boyko@humber.ca** or « insert student Name /Phone Number /Email Address »

Verification of having read the Informed Consent Form:

☑ I have read the Informed Consent Form.

My signature below verifies that I have read this document and give consent to the use of the data from questionnaires and interviews in research report, publications (if any) and presentations with the proviso that my identity will not be disclosed. I have received a copy of the Information Letter, and that I agree to participate in the research project as it has been described in the Information Letter.

Elsworth Walker	[signature]	11/6/2022
Participant's Name	Participant's Signature	Date

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IDSN 4002 /4502
SENIOR LEVEL THESIS ONE & THESIS TWO

HUMBER
Faculty of Applied Sciences & Technology
Bachelor of Industrial Design / FALL 2022 & WINTER 2023

INFORMATION LETTER

Research Study Topic: How May We Mitigate Sub-Particle Respiratory Contamination for Ironworkers
Investigator: A'shantee Spencer / 1 (647) 809 4269 / Ashanteespencer@gmail.com
Sponsor: Humber ITAL, Faculty of Applied Sciences & Technology (IDSN 4002 & IDSN 4502)

Introduction
My name is A'shantee Spencer, I am an industrial design student at Humber ITAL, and I am inviting your participation in a research study on various problems that surround the sub-particle respiratory contamination that iron workers encounter. These problems include high-level air pollutants from asphalt fumes, concrete dust, diesel exhaust, metal fumes, wood dust, etc. These exposure points contribute to an increased level of iron workers developing respiratory diseases, such as COPD, Asbestos, Silicosis, etc., the constant re-encounters with these hazards. The results will be contributed to my Senior Level Thesis project.

Purpose of the Study
This study is being conducted as an aid in designing a sub-particle respiratory contamination device that is capable of mitigating air pollutants may result in an overall safer wellbeing and efficiency of iron workers. The product to be designed is inspired by current respiratory personal protective equipment, such as, powered and non-powered respirators that perform at a limited rate and become obstructive towards workers' communication. With your support, I strive to address the problems and limitations of current respiratory personal protective equipment and develop a greater solution. This study is primarily based on understanding ergonomics, human interaction design activities, and user experience aspects of the research area.

Procedures
If you volunteer in this study, details about your activities and/or personal respiratory health within construction will be observed and documented. Your activities will be documented by means of digital camera / video camera / digital device while working on a construction site. You will also be asked questions pertaining to your personal activities and/or personal respiratory health within construction.

Confidentiality
Every effort will be made to ensure confidentiality of any identifying information that is obtained during the study. In the case of being recorded visually, your face will be masked /blurred or hidden. The information and documentations (photographs) gathered are all subject to being used in the final presentation of the study.

Participation and Withdrawal
Your participation in this study is completely voluntary and you may interrupt or end the study and the session at any time without giving a reason or fear of being penalized.

If at any point during the session, you feel uncomfortable and wish to end your participation, please let the moderator know and they will end your participation immediately.

Humber Research Ethics Board

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HUMBER

Faculty of Applied Sciences & Technology

Bachelor of Industrial Design / [illegible]

IDSN 4002 /4502

SENIOR LEVEL THESIS ONE & THESIS TWO

This research project /course has been approved by the Humber Research Ethics Board. If you have any questions about your rights as a research participant, please contact Dr. Lydia Boyko, REB Chair, 416-675-6622 ext. 79322, Lydia.Boyko@humber.ca

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HUMBER
Faculty of Applied Sciences & Technology
Bachelor of Industrial Design / FALL 2022 & WINTER 2023

IDSN 4002 /4502
SENIOR LEVEL THESIS ONE & THESIS TWO

INFORMATION LETTER

Conditions of Participation

- ✔ I understand that I am free to withdraw from the study at any time without any consequences.
- ✔ I understand that my participation in this study is confidential. (i.e. the researcher will know but will not disclose my identity)
- ✔ My identity will be masked.
- ✔ I understand that the data from this study may be published.

☐ **I have read the information presented above and I understand this agreement. I voluntarily agree to take part in this study.**

Colin Campbell | [signature] | Nov 06/22

Participant's Name | Participant's Signature | Date

Project Information

Thank you very much for your time and help in making this study possible. If you have any queries or wish to know more about this Senior Level Thesis project, please contact me at the followings:

Phone: 1 (647) 809 4269

Email: Ashanteespencer@gmail.com

My supervisor is:

Prof. Catherine Chong, **catherine.chong@humber.ca**

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HUMBER

Faculty of Applied Sciences & Technology

Bachelor of Industrial Design

IDSN 4002 /4502

SENIOR LEVEL THESIS ONE & THESIS TWO

PARTICIPANT INFORMED CONSENT FORM

Research Study Topic: A'shantee Spencer

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[illegible]		NOV 05/22
Participant's Name	Participant's Signature	Date

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FTA - 4 RESEARCH PLAN / ADVISOR INITIATIVES

Date: Tuesday, October 18th, 2022

Student Name:	A'shantee Spencer
Topic / Problem Definition:	How may we mitigate sub-particle respiratory contamination for ironworkers?

Introduction

The purpose of this research plan is to determine a thorough timeline for conducting literature reviews, secondary research, advisor interviews and user observation studies. By understanding product strengths and weaknesses, product benchmarking and current solutions in the market will be evaluated to discover discrepancies. Overall, this plan will enable accurate design preparation for further insights towards concept ideation, refinement and finalisation for a solution towards mitigating respiratory contamination for iron workers.

Research Plan

The elements that are being looked into towards this research are the respiratory protection regulations of the Occupational Safety and Health Administration (OSHA) within Canada, the current types of respiratory protective equipment within the field, and what key features are required to ensure reduced air contamination. Additionally, the level of clarity that these respiratory PPE provide towards iron workers' communication, as construction sites produce loud noise due to machinery.

This research will be compiled through multiple datum streams, such as online academic resources, interviews and observations that are related to this topic. With the use of Humber Libraries and supplementary online academic resources, insights on ironworker respiratory health maintenance, respiratory PPE product reviews and communication efforts can be reviewed. Additionally, online academic video resources and statistical evidence of respiratory PPE usage by the OSHA will be documented for further analysis.

Interviews and user observations will also be notarized for primary in-depth knowledge on how air toxins directly and respiratory PPE are used in a construction setting. Interviews will be conducted in-person to expand current knowledge on the topic of mitigating sub-particle contamination for iron workers. With emphasis on the respiratory equipment, construction site, respiratory regulations and personal respiratory effects. User observations will be supplied both online and in-person for effective insights on respiratory PPE detail, maintenance, function and/or possible obstructions that may be experienced. The initial contact with advisors will be done both through email and in-person.

The preliminary research evaluation is scheduled to be completed by the end of week 7 in an effort to support the ideations and concept development within the following weeks. Initial interviews and user observation, both in-person and online, will also be completed at the end of week 7. A secondary interview will also be completed by this time, in order to ensure various insights from different perspectives of users. Product research and benchmarking are completed, but will be revised based on a tightened design direction.

Potential Research Interview Questions:

Preliminary Questions:

1. What is your gender?
2. Currently, what is your age?
3. What type of construction worker are you?
4. Could you describe your typical construction work environment? (I.e. whether you work indoors or outdoors, surroundings of trees or asphalt or dust)
    a. How long have you worked in this construction environment?
    b. Additionally, how long is your typical work shift?
    c. What are the assigned tasks that you do in your field of work?

Primary Questions:

1. When working in a construction environment, what type of respiratory PPE do you wear, if any?
    a. How would you rate the PPE effectiveness?
    b. Why have you chosen or not chosen to wear respiratory PPE?
2. In your opinion, how would you rate respiratory PPE towards its help with communication in a construction environment?
    a. If not, how might you think this can be improved?
4. In your line of work, how often have you experienced respiratory irritation? (I.e. Sneezing, sniffling, coughing, etc.)
5. How would you like to see the future of respiratory PPE while working on a construction site? (I.e. Level of comfort, durability or communication)
6. In your opinion, how would you rate the air quality level while on the job?

7. Are there any designated spaces for lunchtime or when workers want to remove dust?
8. Are there any final thoughts on respiratory PPE for construction workers? (I.e. Obstacles when wearing respiratory PPE, Adaptability when wearing PPE)

Advisor Initiative

Presently, there are two advisors that are planned for participation in the research area of this thesis project. Both advisors are known by myself on a personal level and can be contacted when required. The first advisor is a former construction worker in Toronto, Ontario, whereas the second advisor owns his own construction company for residential and industrial development in Toronto, Ontario.

Advisor 1: Elsworth Walker - Former Construction worker **(CONFIRMED)**

1(416) 417-8693 / Elsworthwalker@gmail.com / Available on Sunday Mornings

Verbal consent given, along with signed information and consent forms as of October 5th, 2022, will be obtained by October 18th, 2022.

Advisor 2: Collin Campbell - Construction Site Supervisor **(CONFIRMED)**

1(416) 294-9566 / Colinrc81@gmail.com / Available on evenings

Verbal consent given, along with signed information and consent forms as of October 9th, 2022, will be obtained by October 20th, 2022.

Conclusion

Through this research and advisor initiative plan, a tangible goal to investigate, interpret and gain insights on the sub-particle contamination effects within the construction field can be utilised towards a greater design solution for iron workers on-site respiratory preservation and maintenance. In addition, product research methods of benchmarking and user observations will be heavily relied on to interpret the efficacy of current respiratory personal protective equipment (PPE) both through a health-wise and communicative perspective. The knowledge from the advisors will provide a greater evaluation on research aspects or identify outstanding areas that should be addressed within the design. Overall, these supports and resources will benefit the design process and development by means of constructing an informed and carefully considered product that answers the thesis topic being addressed.

Appendix L – Other Supportive Raw Data


An official website of the United States government Here's how you know

NIH National Library of Medicine
National Center for Biotechnology Information

Log in

Bookshelf Books Search

Browse Titles Advanced Help

StatPearls [Internet].

Show details

Search this book

Positive Pressure Ventilation

Iordan Potchileev; Maksym Doroshenko; Asif N. Mohammed

Author Information and Affiliations

Last Update: January 30, 2023.

Continuing Education Activity

Go to:

Positive pressure ventilation describes the process of either using a mask or, more commonly, a ventilator to deliver breaths and to decrease the work of breathing in a critically ill patient. Positive pressure ventilation is delivered in one of two forms: non-invasive positive pressure ventilation (either through a mask) or invasive positive pressure ventilation, which requires delivering breaths either through an endotracheal tube or a tracheostomy tube. This activity will highlight the physiology, indications, contraindications, and other key factors for members of the interprofessional team managing the care of critically ill patients who require positive pressure ventilation.

Objectives:

- Outline the physiology behind positive pressure ventilation.
- Identify the indications for positive pressure ventilation.

Views

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In this Page

Continuing Education Activity

Introduction

Anatomy and Physiology

Indications

Contraindications

Equipment

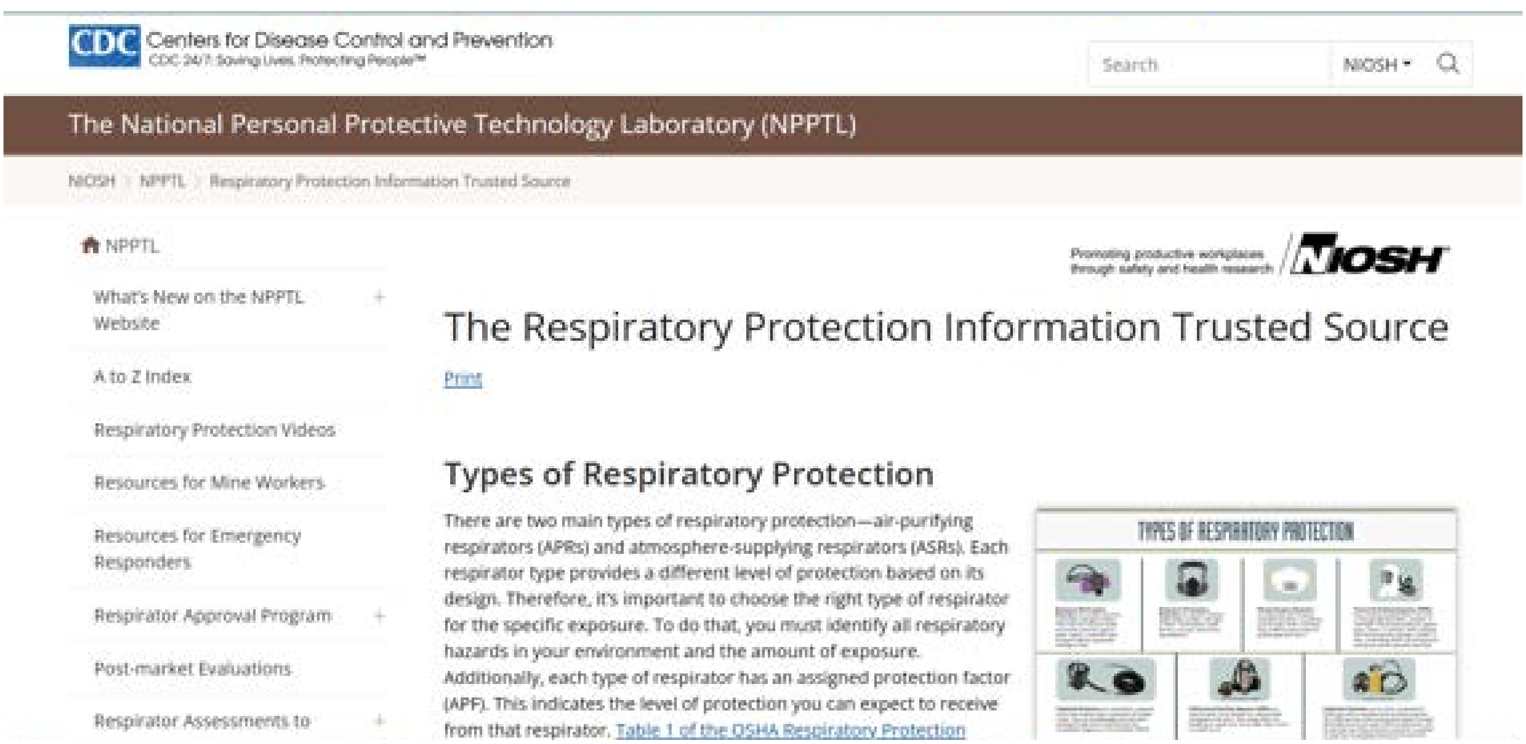
Personnel

Preparation

Technique

Complications

Clinical Significance


CDC Centers for Disease Control and Prevention
CDC 24/7: Saving Lives, Protecting People™

Search NIOSH

The National Personal Protective Technology Laboratory (NPPTL)

NIOSH > NPPTL > Respiratory Protection Information Trusted Source

NPPTL

What's New on the NPPTL Website

A to Z Index

Respiratory Protection Videos

Resources for Mine Workers

Resources for Emergency Responders

Respirator Approval Program

Post-market Evaluations

Respirator Assessments to

Promoting productive workplaces through safety and health research NIOSH

The Respiratory Protection Information Trusted Source

Print

Types of Respiratory Protection

There are two main types of respiratory protection—air-purifying respirators (APRs) and atmosphere-supplying respirators (ASRs). Each respirator type provides a different level of protection based on its design. Therefore, it's important to choose the right type of respirator for the specific exposure. To do that, you must identify all respiratory hazards in your environment and the amount of exposure. Additionally, each type of respirator has an assigned protection factor (APF). This indicates the level of protection you can expect to receive from that respirator. Table 1 of the OSHA Respiratory Protection

TYPES OF RESPIRATORY PROTECTION

Appendix M – Topic Specific Data