MOBILIZING SEARCH & RESCUE TRAINING

FOR LA ACADEMIA NACIONAL DE BOMBEROS IN COSTA RICA

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ABSTRACT

The purpose of this project was to create a conceptual design of a mobile training unit for La Academia Nacional de Bomberos that would aim to decentralize search and rescue firefighter training in Costa Rica. This mobile training unit would provide the opportunity for over 30 search and rescue training exercises to be performed at any of the 78 fire stations across the country. Various simulations were implemented into the mobile unit's design, including a customizable labyrinth and a second floor with removable railings and foldable walls. Material availability and cost were considered throughout the design process. Multiple layouts of the design were provided to the Bomberos which reflected the goal to minimize space and maximize training benefits at a feasible cost.

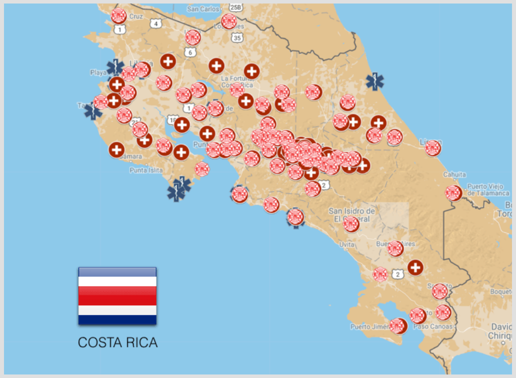
An Interactive Qualifying Project submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Bachelor of Science

WPI

Executive Summary

The Bomberos Fire Academy

Firefighters across the globe must respond to a multitude of emergencies at any given time. Obtaining proper training is critical as a firefighter to effectively perform necessary tasks under pressure. Fire academies today are extensively trying to find improved methods and technology that will help best train their firefighters for real-world situations. One of these fire academies is La Academia Nacional de Bomberos in Costa Rica. This fire academy in San Jose trains all firefighters from across the country in a variety of areas, including in search and rescue training. The Bomberos want to improve their training methods to make them more efficient for firefighters to receive search and rescue training without having to travel from their respective fire station to San Jose. With 78 fire stations in Costa Rica, (see E.S. Figure 1) this would allow firefighters from each of those stations to receive the necessary training without the need for traveling to the capital.



E.S. Figure 1: Map showing the 78 fire stations located across Costa Rica, represented in pink[1].

Designing a Mobile Training Unit

To successfully design a mobile training unit that would meet the needs of the Bomberos, we closely followed the design process focusing on the following objectives:

1. Research and obtain a fundamental understanding of search and rescue training exercises and simulations that take place in the United States and at the Bomberos Fire Academy.
2. Perform a needs assessment to determine the Bomberos' expectations in creating a conceptual design of the mobile unit.
3. Develop a series of design layouts of the mobile unit for the Bomberos to review.
4. Configure the layout of the selected mobile unit model once designs were approved from sponsor review and calculate the cost of the finished mobile unit.

There were 36 search and rescue training exercises expected to be performed on the mobile unit, and training guides for each exercise were provided to us by our sponsor. Each guide explained the training procedure, the necessary equipment required to perform the exercise, and the number of participants who would be involved in each exercise. These guides also relayed information on the types of simulations that trainees would be utilizing. There were several simulations that had to be accounted for in determining what was to be implemented into the mobile unit, such as negotiating obstacles in tight spaces, passing through a wall wearing full firefighting gear, and rescues from a second story window.

As a part of the needs assessment, it was necessary to figure out a means of storing and transporting the necessary simulations to make the mobile unit a reality. The Bomberos proposed using a 48-foot shipping container and flatbed trailer that could transport the container. Aligning our objectives with the design process, we sketched a series of design layouts to satisfy the needs of the Bomberos including designs for the structure, the labyrinth, and contents of the container, a collapsible second story, and the entire mobile unit itself.

From these sketches, we initiated design reviews with our sponsor. Based on the feedback from our sponsor following each design review, new iterations of sketches were made to best suit their needs. Once all the designs were approved, we began modeling the finalized mobile unit via SolidWorks. During the process of modeling the unit, cost estimates were calculated to account for the costs of all material that made up the design according to available vendors and suppliers in Costa Rica. At the end of the modeling process, we were able to create multiple layouts of the mobile unit, giving the Bomberos the most options possible to meet their needs.

Final Design Models of the Mobile Unit

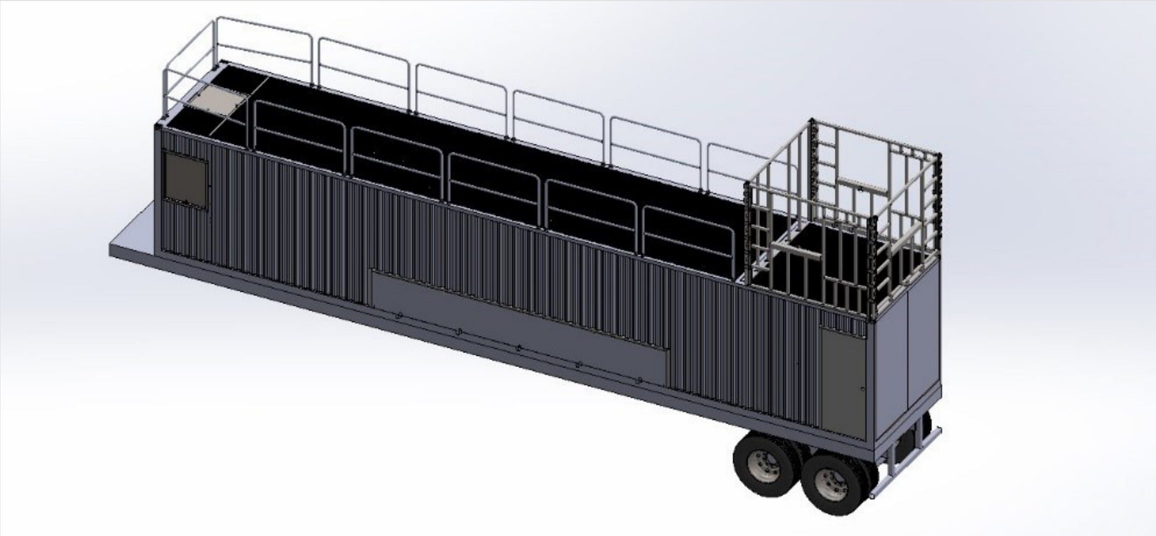
Multiple features of the final design were presented to the Bomberos, including the entire model. Additional specific areas shown include the inner layout displaying the inner labyrinth and optional configurations of the floor and wall panels.

The Complete Mobile Unit

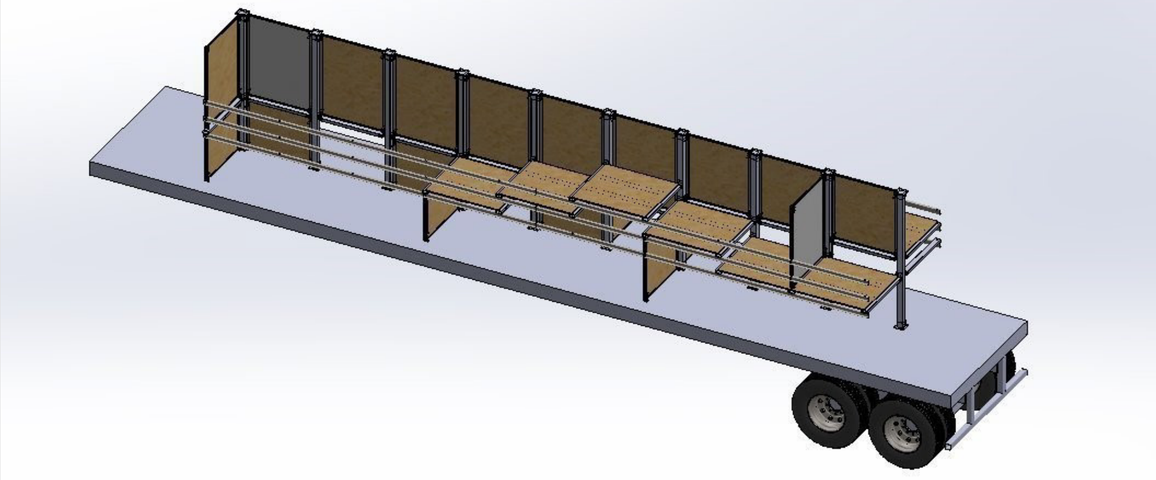
A full model of the mobile unit was created to encompass all the search and rescue simulations and functional space for training exercises, both within and outside of the container. The second-floor features include a 3-ft. square manhole, a removable railing along the outside of the container, and four foldable walls with windows or studs. The four second-floor walls can collapse using hinges for transportation. Due to the corrugations of the roof of the container, inserting an expanded metal sheet allowed for the roof to still mimic a flat second floor for added safety. Entrances along the outside of the container including windows, a door, and emergency exits were also implemented into the mobile unit (see E.S. Figure 2).

Potential Layout Design for Interior

The interior labyrinth is comprised of removable vertical and horizontal steel beams. The central vertical beams, or Z-beams, span 40 feet with four feet of functional space between them. Fixed U-channel runs along the sides of the container at 3 different heights: 3, 4 and 5 feet each. With this framing method, a plethora of different layouts can be assembled ensuring different looks and all desired functions are achieved by utilizing floor and wall panels (see E.S. Figure 3).



E.S. Figure 2: The Entire Mobile Unit



E.S. Figure 3: Potential Interior Layout Design

Total Cost

After designing the model, we calculated the total materials cost of the mobile training unit to be approximately 8,660,300 colones (US$16,960). This cost breakdown does not include the chassis trailer or the container. We broke down the cost into multiple sections and these are materials that were used in the interior of the container, wall panels, floor panels, LED lights, scaffolding, second story walls, manhole, railings, and the grip that will be added to the second floor for safety reasons (see E.S. Table 1).

E.S. Table 1: Cost breakdown of the mobile unit.

Item	Cost (Colones)	Cost (US Dollars)
Material used Inside Container	C3,650,000	$7,100
Wall panels	C1,110,000	$2,200
Floor Panels	C514,000	$1,000
LED lights	C20,500	$40
Scaffolding	C980,000	$2,000
Foldable walls	C410,400	$800
Manhole	C165,400	$320
Railings	C1,450,000	$2,800
Floor Grip	C360,000	$700
Final Total	₡8,660,300	US$16,960

Conclusions & Reccomendations

The project aimed to design a mobile unit to facilitate search and rescue training for Costa Rican firefighters. Multiple designs were presented, and feedback from the Bomberos was incorporated into the final model. The design considered the need for maximum functionality and versatility in selection of training exercises, evaluated constraints of on-site training exercises, and assessed material availability and distributor accessibility in Costa Rica. Cost estimates were compiled for the entire mobile unit.

Materials selected for the design were based on those used in existing simulations at the academy; however, this remains a conceptual design. It is highly recommended that the Bomberos contract a professional engineer to complete structural computations to ensure the mobile units' safety. Recommendations were also suggested for auxiliary equipment, such as emergency lights, cameras, and speakers.

The team believes that introducing a mobile training unit will enhance Bomberos training through decentralization. This design will improve the efficiency and effectiveness of the Bomberos training programs, allowing firefighters in remote areas to access essential training without the need to travel to San Jose. The aim was to provide Bomberos with a mobile training solution that better prepares them for real-world scenarios, enhancing their ability to protect the people of Costa Rica.

MEET THE TEAM

Luke Grady (left)

"Hello, I'm Luke, and I am a student at WPI studying computer science. I was interested in this project because I would be able to make an impact on Costa Rica by helping improve the Bomberos training."

Pedro Salomao (right)

"Hey, I'm Pedro and I am a Mechanical Engineer. I gravitated towards getting involved in this project the most because I wanted to gain more experience in designing and modeling."

Beck Carrier (left-center)

"Hi, I'm Beck, and I am studying Aerospace Engineering. I was drawn to this project with the Bomberos due to its systematic approach towards more efficient training for the nation's firefighters. The prospect of designing a means to better prepare the nation's bravest people to save lives was more than enough to rope me in."

Liz Goncalves (right-center)

"Hi, I'm Liz, and I am studying Chemical Engineering. I was really interested in getting involved in this project because I thought it would be an impactful way to integrate my knowledge of engineering into creating a more effective form of training to ensure a greater level of safety in emergencies."

Effective Fire Training Ensures Safety

Across the world, fire safety has been an everlasting issue that has severely impacted multiple communities. With situations ranging from fires in confined spaces to wildfires, firefighters must respond to a multitude of emergencies. Obtaining proper training to respond to any emergencies that may happen is key to ensure the safety of humanity as situations arise. The Institute for Simulation and Training (IST), and the University of Central Florida, along with the US Army and the Orange County (Florida) Fire Rescue Department executed a study which confirmed that utilizing simulations in fire rescue training resulted in making firefighters much more prepared in time sensitive situations as compared to using traditional training methods[2]. The goal of all fire academies is to provide proper training, greater access to reliable equipment, and more research and development to minimize the loss of life due to fire.

Over the past thirty years, the Costa Rican Academia Nacional de Bomberos has put a great emphasis on training courses via simulations specifically for search and rescue. The purpose of these mock-ups is to incorporate elements of search and rescue procedures in a safe interactive form to prepare the fire force for specific scenarios during a fire. The academy has developed multiple simulations driving their protocols related to search and rescue but lacks a method of efficiently spreading the curriculum nationwide to other stations. Currently, all training happens at the headquarters in San Jose (see Figure 1), which makes it difficult for firefighters located in different parts of Costa Rica to get access to these necessary trainings. Transporting all the firefighters to San Jose leads to a variety of issues in terms of cost. The academy must pay for housing for all the firefighters as they train and their lack of presence at their home station hinders the station's function.

This project's goal is to mobilize their curriculum to the rest of the organization by designing a mobile unit that includes various simulations. The curriculum, composed of multiple individual trainings, was implemented into a trailer to effectively train firefighters in search and rescue protocols across the country. We assessed their needs and created a conceptual design to initiate the process of developing this mobile unit for the Bomberos.

Figure 1: Academia Nacional de Bomberos in San Jose, Costa Rica

Understanding Current Training Methods & Constraints

To create a proper mock-up of a mobile search and rescue training unit for the fire academy, many topics must be understood. In the first parts of this chapter, we discuss relevant regulations and protocols for the training methods. The status of Bomberos training academy and available training equipment are discussed, including individual search and rescue simulations that could be incorporated into the mobile unit design.

NFPA Regulations

The goal of the U.S. National Fire Protection Association (NFPA) is to minimize the risk of fires and other emergencies through the publication of over three-hundred consensus codes[3]. Developing countries, such as Costa Rica, with fewer financial and administrative resources to advance their own codes, use pre-established codes to fit their needs, such as those from the NFPA[4]. Costa Rica is currently in the process of tailoring the NFPA codes to their specific architectural building designs.

Mockups that are created in Costa Rica to train firefighters must be able to replicate the local architecture with the goal of providing effective training opportunities. There are three main NFPA regulations that must be considered for this project, including the reference for search and rescue[5], the standard on facilities for fire training and associated props[6], and the standard for fire service rapid intervention crews[7].

Code 1001 of the NFPA explains the importance of firefighters receiving the training they require to respond to any search and rescue mission. The code consists of a variety of interrelated performance standards which firefighters must follow[5]. The training must give firefighters the ability to operate in scenes of emergency with the proper equipment to navigate these situations. The types of training necessary for search and rescue covered by the code include forced entry and exiting a hazardous area as a team, which are necessary training to include in the mobile unit.

Code 1402 discusses the functionality of mobile and transportable props in training. The code also relays information regarding implementing augmented and virtual reality simulations[6]. Code 1407 of the NFPA provides more detail about the safety requirements needed in specific search and rescue trainings, including the requirements of the instructors, prerequisites any trainees must have, and other informative policies regarding safety precautions[7]. The code briefly mentions the training in which a downed firefighter would be rescued from a hole in the floor, which will become useful for a deeper understanding of search and rescue exercises for the mobile unit.

Fire Academy Technology & Training Methods

Fire academy training methods are designed to comprehensively prepare new firefighters for the demanding and diverse challenges they will face in their careers. These programs typically combine classroom instruction with hands-on training. Recruits learn fire science, hazardous materials management, emergency medical procedures, and incident command systems through classroom lectures and coursework. However, the heart of the training lies in practical exercises using various cutting-edge technologies and simulators to provide comprehensive training for firefighters. These tools help prepare recruits for the diverse and challenging situations they may encounter in the field.

Simulators, such as fire behavior training systems, allow trainees to experience and understand the dynamics of fire, smoke, and heat in a controlled environment. Additionally, vehicle extrication simulators replicate scenarios involving vehicle accidents, enabling recruits to develop the necessary skills for rescuing individuals trapped in automobiles. Advanced medical training equipment, like high-fidelity mannequins, helps firefighters hone their emergency medical skills because they can

NFPA Code 1001	Standard for Firefighter Professional Qualifications
NFPA Code 1402	Standard on Facilities for Fire Training
NFPA Code 1407	Standard for Training Fire Service Rapid Intervention

Figure 2: Three relevant codes provided by the National Fire Protection Association (NFPA)[3].

exhibit real-life emergencies[8].

Virtual reality (VR) and augmented reality (AR) applications enable firefighters to practice navigating through smoke-filled buildings, identifying hazards, and performing various firefighting techniques without risk of injury or even death[7]. More firefighters are turning away from live-fire training situations and opting for AR and VR alternatives because "although these scenarios provide live-fire situations, they can be expensive in terms of personnel time and equipment and can also create the risk of unintended property damage or harm to the trainee"[9]. All these technologies ensure that firefighters receive realistic, hands-on training that enhances their readiness and capabilities when responding to emergencies.

Recruits also practice using firefighting equipment and tools, honing their skills in controlling and extinguishing fires. In addition, training includes physical fitness regimens to ensure firefighters are in optimal shape for the strenuous demands of the job. Safety and teamwork are emphasized throughout, as trainees develop the essential skills and mindset required to respond effectively to fires, medical emergencies, and hazardous incidents. By blending theoretical knowledge with hands-on experience, fire academy training methods equip new firefighters with the expertise and confidence they need to protect lives and property in their communities.

In search and rescue missions, firefighters follow systematic methods and protocols to enhance efficiency and prioritize safety. The incident command system, a standardized management structure, is commonly utilized for clear communication and coordination during emergencies. Firefighters assess the situation, identify hazards, and employ systematic search patterns like primary, secondary, and tertiary methods for a thorough examination. The primary search focuses on quick identification and evacuation of occupants, with adherence to strict protocols. The secondary search involves a detailed examination to locate overlooked individuals, emphasizing continuous communication for safety and information relay[10]. These practiced methods, combined with ongoing training and adaptability, empower firefighters to navigate complex scenarios for successful search and rescue outcomes.

Previous Mock-Up Created for the Bomberos

The mockup shown in Figure 3 was designed to teach firefighters about residential fires and air movement on a small scale[11]. The mockup features multiple removable panels to allow air flow and test different methods of ventilation and their effectiveness. The doll house is comprised of various rooms and floors to mimic a residential building. The Bomberos wanted to test and observe the difference between horizontal and vertical flow of air and observe the pressure of the air as well. To make this mockup reusable, there is an inlet to the house where a smoke pump can be attached to so that the mockup isn't burned and destroyed after one use.

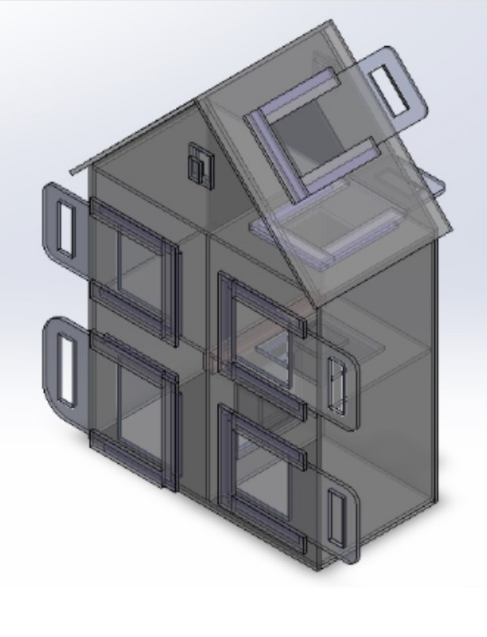


Figure 3: Palmer's Doll House[11].

Potential Mock-Ups: Search & Rescue

Before proceeding with the design and layout of the mobile unit, it is imperative to understand the current functions of the mock-ups that are being used for search and rescue training at the academy. These include forced entry, passing through a wall, passing through cables, and extracting a firefighter through an opening. The capabilities of each mock-up are described on Page 8.

Existing Mobile Fire Training Units

Dräger is a global safety and technology company involved in a wide array of industries including firefighting safety. The company's live-fire training system was brought to North America from Sweden in 1990 to train firefighters for extreme fire behaviors through simulations of real-world scenarios. One of their products, the Dräger Mobile Live Fire Training Unit (MLFTU), is a 53-foot trailer equipped with live-fire props for simulation. The mobile unit is highly customizable and can produce repeatable and controllable live fires that address many real-world scenarios[12].

These props consist of simulations such as a kitchen mock-up comprised of side-by-side kitchen stovetops. The MLFTU has a second story that can be raised and lowered hydraulically for even more flexibility for training, the advantage of this being the additional height and the windows in the top compartment. This grants access to the simulations shown in Figures 6 and 7 where multiple levels are required for evacuation. The MLFTUs frame and general purpose make this a high-end example of the solution and subsequently the main source of inspiration for this project (see Figure 8).

Figure 4: Forced Entry. This metal door is used to practice breaking a lock to enter a building with a Halligan bar.

Figure 5: Passing Through a Wall. Methods include standing, crouching and crawling.

Figure 6: Extraction of a Firefighter from a second-floor window. Rescues may occur by pulling them up or letting them down.

Figure 7: Extraction of a Firefighter through an opening in the floor. Rescues through manholes involve using a rope or a hose.

Figure 8: The Dräger Mobile Live Fire Training Unit (MLFTU)[12].

Design of the Mobile Training Unit

The purpose of this project was to improve the way in which firefighters receive search and rescue training across Costa Rica. The final goal is to create a conceptual design of a mobile training unit capable of training firefighters across the nation using search and rescue simulators. To meet our sponsors' expectations and to aid in improving the current training capabilities in Costa Rica, we:

1. Researched Search and Rescue Training Methods/Courses

2. Performed a Needs Assessment and Established Specifications of the Unit

3. Developed Layouts for Sponsor Review

4. Configured Layouts of Selected Mobile Unit Model

This chapter outlines the acquisition process of the relevant knowledge required to mobilize the Bomberos fire training. We followed the design process in a series of steps, as shown in Figure 9.

Researched Search and Rescue Training Methods & Courses

To initially define our problem and begin a needs assessment, we investigated search and rescue training methods and courses. To gain

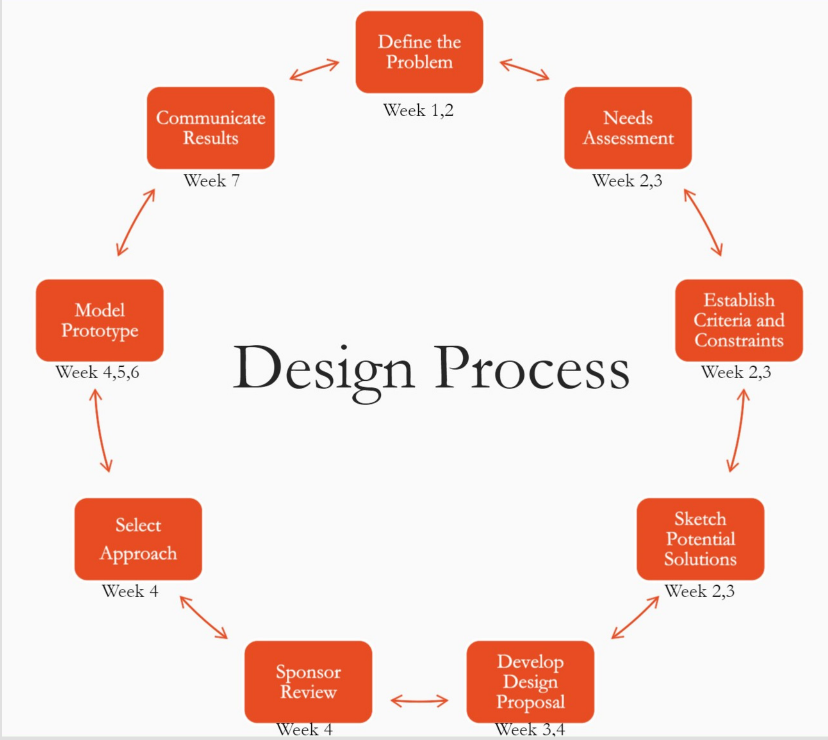


Figure 9: Our Design Process

To initially define our problem and begin a needs assessment, we investigated search and rescue training methods and courses. To gain insights into the practical aspects of search and rescue training, we interviewed a part-time firefighter from the Danbury, Connecticut, Fire Department. Key Bomberos instructors, Minor Villalobos and Andres Baca, were interviewed to gather first-hand information about the structure of training programs, the incorporation of certain training elements, and the emphasis on practical simulations. The information gathered through these interviews and experiences served as a foundational basis for understanding the current landscape of search and rescue training methods, thus contributing to the overall depth and richness of the research project.

Observed Danbury Firefighting Facility

To investigate search and rescue training methods and courses we interviewed Provisional Lieutenant, Paul Perroti, who is an active firefighter in Danbury, CT with over 20 years of experience. Interviewing Mr. Perroti aided in further understanding how firefighters think and react in real-life situations and helped identify the equipment they use to complete their necessary tasks. Mr. Perotti provided a full tour of their firefighting facility and we had the opportunity to ask questions about their current training methods. Our tour included a variety of training practices, including training outside of search and rescue. Mr. Perotti mentioned that multiple simulations pertaining to search and rescue were prevalent in Danbury's training facility, including forced entry, maneuvering through confined spaces, and passing through mobile wires. Though they did not have the physical training to show us, as we were at the engine house, Mr. Perotti thoroughly explained their experiences with us and what is needed for search and rescue training.

Interviewed the Bomberos Instructors

Through interviewing instructors and administrators at the Bomberos, we got a sense of the search and rescue training that takes place at the National Fire Academy. Our series of interviews with the Bomberos began on a weekly basis with their Administrative Program Manager, Alejandro Rosales-Castillo, during the preparatory term and continued with Alejandro, and two of the Bomberos course instructors, Minor Villalobos and Andres Baca, during our time in San Jose. To prepare for our project, the Bomberos outlined the goals and expectations for the mobile unit design, which included the overall budget, the training exercise guides explaining the desired trainings to take place in the mobile unit (see Figure X), and the training simulations they expected to be included in the design. Our weekly meetings with Alejandro gave us more insight into determining what the Bomberos needed through the project and additional information about the need for mobilizing their search and rescue training curriculum.

In San Jose, our team began interviews with Bomberos instructors, Minor and Andres. We developed a better understanding of how the exercises were conducted and which simulations corresponded to the respective exercises. We were also able to watch videos demonstrating their current exercises. Unfortunately, we were unable to witness search and rescue training in person, but the videos were helpful for understanding how firefighters perform search and rescue exercises. These videos gave us a sense of the amount of working space they needed for utilizing simulations and provided an opportunity for us to inquire about which exercises would be of utmost importance to be performed in the mobile unit.

PRACTICAL GUIDE #12 A

Practice Name: **Rescue: Through the Floor with Rope**		Revision 11/2017	
Place: Tower		Agenda Location:	
Estimated duration: 15 min.	Attendees: 1	Security Attendees: 0	Group size: 6-8
AUDIOVISUALS AND LITERATURE			
Video: No **Power Point Presentation:** **Literature:** **Instructional Guide EIR Manual**			
MATERIAL AND EQUIPMENT			
Participant's Team: EPP ARAC **Instructor Team:** EPP ARAC		**Equipment needed to carry out the practice**: 1 Simulator (hole in the floor) 2 Rope Sacks 12mm	
SAFETY			
The transit of people in the area where the exercise takes place is prohibited.			
OBJECTIVE OF THE INTERNSHIP			
Perform a rescue of a conscious firefighter who has fallen through a hole to a lower floor and only has a rope to carry out the rescue.			
PREPARATION			
1. All staff will have to review the movement to unify criteria and finalize details.			
STEPS			
1. Quickly assess where the firefighter fell. 2. Make eye and verbal contact and ask about your physical condition. 3. Take the measurement of the rope (three-meter breasts) 4. Descend the first breast of the rope, explain the procedure: pass it under the strap of the right shoulder and pass it crossed to the left leg, where the leg is inserted through the breast. 5. Descend the second sinus of the rope, explain the procedure of step #5 only that it is done in reverse (left shoulder, right leg). 6. Verify that the procedure was performed correctly. 7. Ask the firefighter to stretch out his arms and grab the rope, adopting a parachute position. 8. Each shape of the ropes that formed the breasts will be distributed to the rescuers. In this way, the weight will be supported by four points. 9. Explain that the correct way to carry out the haul is done parallel to the hole. 10. The personnel who are at the top at the voice of the LEADER initiate the ascent of the firefighter, always using the commands READY, GO, for this the model of the order will be used. Emphasize that the READY command will only be used when the movement is initiated and then the VAMOS command will be used in a row until the firefighter exits through the gap. 11. Once the firefighter exits through the hole, one of the rescuers hands the rope to the firefighter next to him, and he moves. to be attached to the harness of the ARAC and carried to a safe area.			
NOTES			
Remind participants at all times that they are emergency movements. 1. Explain that the movements are simultaneous. 2. Only the voice of the LEADER should be heard while the movement is being executed. 3. The technique can be used to ascend as well as to descend.			

Figure 10: Training Exercise Guide Example for a Rescue through a Manhole using a rope. Each guide includes equipment required, safety guidance, objectives, preparation requirements, the steps of the exercise, and any additional notes for the instructors. This document was translated, originally in Spanish.

Needs and Specifications of the Unit

Before designing the unit, we performed a needs assessment with the purpose of determining exactly what the Bomberos expect as a final product. We developed an understanding of each specific simulator that was implemented into the unit, any auxiliary equipment that had to be

accounted for, and the system level requirements for the unit itself. Together, these elements formed the foundation for designing an effective training system that met the needs for the challenges that the Bomberos face in real world scenarios.

Characteristics of Potential Simulators

The team first identified the individual purposes and functionality of the training simulators. Physically comprehending the capabilities and requirements of each training exercise had to be understood before configuring the unit's layout. The Bomberos provided multiple photographs, videos, training guides, and other resources to further develop our knowledge of the simulations currently in use. Upon further communication with our Bomberos liaison, we received confirmation that multiple individual elements had to be implemented into the unit to support specific training exercises. These exercises include following the hose, forced entry, passing through cables, passing through a wall, and extracting a firefighter from an opening.

It was essential to determine and organize all the necessary characteristics of each simulation, including the dimensions. Tracking the sizing information and dimensions for all the simulators was necessary for designing the layout and for mobility purposes. It was critical to determine which structural elements would remain stationary and which could be reconfigured or moved within the trailer for designing purposes. It was of utmost importance to analyze not just the physical characteristics of each simulation, but its individual functionality and deployment.

With the overarching goal being that we wanted to minimize space and maximize training benefits, we analyzed space requirements and developed a configuration design. Our team determined if there were any possibilities that we could multipurpose training materials. In terms of thinking about transporting each simulation, we had to consider, in addition to functional dimensions, the dimensions for storage and transport. The overall cost of each simulation was also determined based on calculating the amount of material needed and researching the type of fabrication required for each simulation.

Analyzed Characteristics of Auxiliary Equipment

An auxiliary system had to be implemented into the trailer to allow the course instructors visibility and communication in an emergency. The equipment needed to employ this system included cameras, speakers, emergency lights, emergency exits, and a control panel. This project entailed the integration of both speakers and cameras for the instructors to observe and coach the trainees on the drills at task. The unit must also facilitate emergency protocols such as accessible evacuation routes in case of panic or disaster. The design inspiration came from the existing Bomberos container training simulators where full obstacle courses and evacuation routes are implemented into said stationary containers. The academy's training grounds include multiple different layouts of obstacles to guarantee instinctual training in different residential areas.

Our plan was to systematically organize the equipment via table tracking individual characteristics of each piece of equipment. Some of the different elements recorded include the dimensions, the wiring, and the cost. This is the shortlist, with the intent that it would grow more while developing the design.

Researched System Level Requirements

To determine the amount of usable space both within the mobile unit and externally, we had to investigate the system level requirements of transporting shipping containers in Costa Rica. Aside from looking into the dimensions of the unit itself, we had to inquire with the Bomberos about the method they would be using to transport the mobile unit, whether this be the use of a flatbed or an alternative method. From there, once we knew how they would transport the mobile unit, we used the Costa Rica system level requirements for shipping containers to determine how much width, height, and length we could work with in the design.

Developed Layouts for Sponsor Review

Multiple different layouts equipped with different simulators and arrangements were developed to give our sponsor different options for potential final designs. With three or more different layouts, our sponsors had the opportunity to critique each to ensure the best layout moved forward. The Bomberos had previously shown us more simulators than possible to fit within the unit, so we consulted with the Bomberos instructors to determine the relative importance of each element when determining which of them would be included in the proposed layouts.

Configured Layout of Selected Unit Model

To effectively design a mobile training unit for the Bomberos, we utilized the knowledge gained through initially sketching our proposed layouts. From these sketches of individual elements along with their constraints, we were able to determine which elements to put on the unit and how they could best be incorporated with one another. A few of these methods included simultaneously finding the best configuration designs as well as the best packaging designs for transportation purposes. The selection of which elements to be included in the container was a team effort with the training coordinator of the Bomberos to see what could most realistically be put on the trailer. With that understanding, each simulator on the trailer was designed for function, with the intention that multiple elements could be easily moved to efficiently train the firefighters with different layouts and scenarios on search and rescue procedures.

The Execution of Our Design Process

Search and Rescue Training Methods

In San Jose, we were able to confirm that 36 training exercises would take place within the mobile unit (see Table 1). Using the training guides as a resource, we could correspond each exercise with the respective simulations used (see Table 2). For example, three training exercises take place with the wall studs, so they were placed into the passing through the wall category. Examining the number of exercise variations that correspond to each simulation emphasized the importance of each simulation we were implementing into the mobile unit.

We also confirmed with the Bomberos that the trainees will be performing the training exercises in 4 groups of 4 to 6 people in each group on a rotating basis in stations. 2 of the groups will be performing different training exercises simultaneously within the mobile unit, and the remaining 2 groups will be performing other exercises outside of the mobile unit. This means that 24 firefighters, plus training instructors, will be utilizing the mobile unit from inside or outside the unit during training practices.

Table 1: Table listing all the training exercises provided by the Bomberos which will be performed in the mobile unit. Colors represent the type of simulations each exercise uses.

All Training Exercises

PASSING THROUGH A WALL: HALF SIDED	RESCUE THROUGH THE FLOOR WITH A ROPE	PUTTING THE ARAC ON AND OFF	DRAG: SIMPLE
PASSING THROUGH A WALL: PRAYING	RESCUE CONSCIOUS FIREFIGHTER THROUGH A HOLE	VICTIM ASSESSMENT & AIR SUPPLY	DRAG: HALLIGAN TOOL
PASSING THROUGH A WALL: SWIMMING	RESCUE THROUGH A GAP IN THE FLOOR WITH A HOSE (CONCIOUS)	TRANSPORTATION FIREFIGHTER RESCUE	DRAG: SIMPLE WITH TAPE
EMERGENCY ESCAPE WITH A ROPE	RESCUE THROUGH A GAP IN THE FLOOR WITH A HOSE (UNCONCIOUS)	TRANSPORT (CRUTCH)	DRAGGING WITH 2 FIREFIGHTERS
PULL & PUSH (LIFT THE FIREFIGHTER TO THE WINDOW)	HEAD-ANCHORED HARNESS	FORCED ENTRY	PREPARING A FIREFIGHTER FOR CPR
HARNESS WITH TAPE FOR PERSONAL USE	CABLE ENTRAPMENT	EMERGENCY EXIT WITH STAIRS	2 ON 1 CARRY SYSTEM
FIREFIGHTER DECENDING THE LADDER FACING THE RESCUER	CONFINED SPACE RESCUE (TUBING)	RESCUE UP STAIRS (2 FIREFIGHTERS)	FOLLOWING A ROPE TO GET OUT
EXITING A WINDOW WITH A ROPE	NARROW SPACE SEARCH	RESCUE DOWN STEPS	FOLLOWING A HOSE TO GET OUT
2 ON 1 RESCUE WITH A ROPE AND LADDER	DENVER MENUEVER WITH LADDER	DENVER MENUEVER HEADFIRST	RESCUE EXTRACTION WITH TAPE

Passing Through a Wall | Manhole | Forced Entry | Denver Rescue

Window/Railing | Confined Space | Stairs/Steps | Other

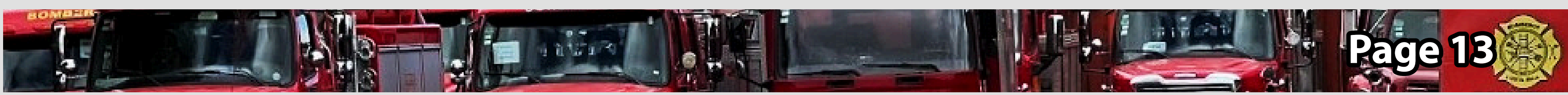


Table 2: Table showing the required simulations compared to the number of training exercise variations corresponding to each. For example, there are five variations of training exercises that use the second-floor window or balcony. Open space was required for exercises that do not utilize a specific simulation, such as "Victim Assessment and Air Supply."

Required Simulations	Variations of Exercises
Window/Railing	5
Manhole	5
Passing Through a Wall	3
Confined Space	3
Stairs/Steps	3
Denver Rescue	2
Forced Entry	1
Open Space	13

As seen in Table 2, the greatest number of exercise variations comes from the trainings that take place in the second-floor window and the second-floor manhole. This greater number of training exercises for the second-floor specific simulations emphasizes the importance of implementing a second floor for the mobile unit.

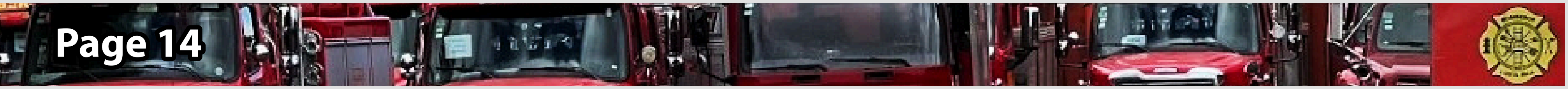
While there were 36 exercises in total, it is important to note that exercise variations vary from station to station, so the variations of training exercises exceed the 36 we were provided.

The Needs Assessment and Specifications of the Unit

The first training simulation our team looked at was the labyrinth, a simulation used to teach firefighters how to maneuver in tight spaces. The fixed framework of this labyrinth is welded to the structure, as shown in Figure 11. The labyrinth at the Bomberos facility was split into even quadrants, two on top and two on the bottom. Both the top and bottom sections are equipped with adjustable wall panels that allow the Bomberos to change the labyrinth's layout as they wish. The labyrinth also contains stairs connecting the first and second levels that allow firefighters to practice changing levels. Our team also looked at the wall studs training simulation that is utilized to teach firefighters how to pass-through walls when they are fully equipped with gear as shown in Figure 4.

The next training simulation was the Denver Rescue. At the Bomberos training facility this training simulation is performed outside of the search and rescue building. For the mobile training unit, the Bomberos only require a window on the first floor and open

Figure 11: Photo of the labyrinth framework that is in the onsite search and rescue training building.



space in the container to be able to recreate the Denver Rescue (see Figure 12). This is an important training simulation because it resembles a real situation where a firefighter was trapped in a very tight space that sadly took his life in Denver, Colorado.

Figure 12: Picture of the Denver Rescue training simulation onsite at the Bomberos Academy.

All the other training simulations require a second story floor for the mobile unit. The second floor requires an airtight manhole that has open space below within the container, so that the Bomberos can train rescuing people through the floor. There must also at least one wall with a window, so the Bomberos can practice using ladders and ropes. With an understanding of the Bomberos' needs regarding each individual training simulation, we assessed the characteristics of each element.

The Bomberos also instructed our team to think about implementing places for auxiliary equipment to go into our design of the mobile training unit. The Bomberos IT team will take care of the cameras, speakers and the design of a control panel, but they prefer we include emergency lights and emergency exits. Since the emergency lights will be on the walls of the labyrinth, they need to be small and controlled remotely. With the safety of the firefighters training inside of the mobile unit in mind, the Bomberos need emergency exits spanning the container. The emergency exits open the full height from the base to the top of the container to facilitate access to both levels inside the unit. After understanding the needs of the Bomberos regarding these auxiliary systems, our team was able to research specific components to include in our designs.

For the design, we selected a shipping container because the Bomberos currently utilize containers for a variety of their training exercises onsite and it is also a cost-effective solution. After thoroughly investigating the system level requirements for the transportation of shipping containers in Costa Rica, a comprehensive understanding of the available space both within the mobile unit and in its external transportation became evident.

After talking with the Bomberos, our team has decided to move forward with a chassis trailer to transport the mobile unit. The chassis trailer was the obvious choice not only because it is cheaper than a normal flatbed but is also lower to the ground. This is a key aspect because the height of the container is 8" 6' and the height of the trailer that the Bomberos plan to use is 4 feet. The height restriction for transportation in Costa Rica is 4.15m (13.6 feet)[13] and any extra space for above the container is crucial for our designs, as the mobile unit relies heavily on incorporating a second story (see Figure 13).

Figure 13: Picture showing the trailer that the Bomberos plan to use to transport the container. By utilizing this trailer, that is only 4 feet high, restrictions for weight, length and height in Costa Rica would not be violated[14].

Characteristics of Training Simulators

After completing the needs assessment for each individual simulation, we performed research on the characteristics of each simulation for the design. Measurements were taken of the training simulations the Bomberos had at their training facility and all the measurements were recorded in a series of tables. The wall studs used to practice passing through walls were 16" on center and were made of 2"x2" steel studs. The steel studs can be 2"x2", which differs from the standard 2"x4" dimension, as the depth of the studs is irrelevant to the passing through the wall exercise objective.

Next, we measured the window design that the Bomberos wanted us to use for our mobile unit. The bottom of the window was 42" from the ground, the width of the window was 50" and the windowsill had a depth of 4". After talking to the Bomberos about the window measurements, they stressed to us that it is necessary for the window to be exactly 42" from the ground, as enforced by NFPA regulations (see Table 3). We were informed that using wood instead of concrete would be a stronger option and would require less depth by 2".

Table 3: Table showing the dimensions of the second-floor window onsite at the Academy.

2nd Floor Window	
Width	40-50in (1-1.27m)
Height from ground	42in (1.07m)
Depth (if using wood)	4in (10.2cm)
Depth (if using concrete)	6in (15.2cm)

The final simulation that we took measurements of at the academy was the Denver Rescue (see Figure 11 and Table 4).

Table 4: Table showing the dimensions of the Denver Rescue onsite at the Academy.

Denver Rescue	
Window	
Height from Ground	42in (1.07m)
Height	39in (0.99m)
Width	27in (0.69m)
Notes	2x2 Square Aluminum Tubing

The Bomberos stated that the manhole can be in the range of two to three feet in width and length and that this gives them plenty of space for the required training. They also mentioned that it did not matter if the manhole was round or square.

These characteristics were used as a starting point and from there we designed each training simulation to best suit the Bomberos needs in the confined space of the container.

Layouts Developed for Sponsor Design Review

Our team developed multiple layouts to conduct a comprehensive sponsor design review with the Bomberos. The session served as a crucial milestone in the collaborative design process, allowing for valuable feedback and insights from our sponsors. During the review, we discussed concepts for various simulations including the labyrinth, the second story elements and their deployment, and emergency exits.

During the design review, there were three different fundamental designs of the labyrinth along with various designs for the second-story enclosure. The first labyrinth design utilized 80/20 (see Figure 14), a company that produces aluminum tubing made to have parts mate and fasten to each other in many ways through its unique T-slotted design. The main disadvantage was its inflated price due to import fees into the country, exceeding the target budget.

Figure 14: 80/20 Aluminum Tubing

The next design implements the current internal layout within the training academy's labyrinth (see Figure 15 and Figure 16). This option was the cheapest and simplest to make but would not be a practical solution for the mobile unit. The fixed internal beams and welding methods would not allow for the desired customizability, making the training exercises repetitive within the constraints of our shipping container. Over time, the trainees would naturally learn the labyrinth patterns, reducing the search and rescue exercises' effectiveness.

Figure 15: Picture showing a spring-loaded pin that the Bomberos currently utilize in their labyrinth design at the academy.

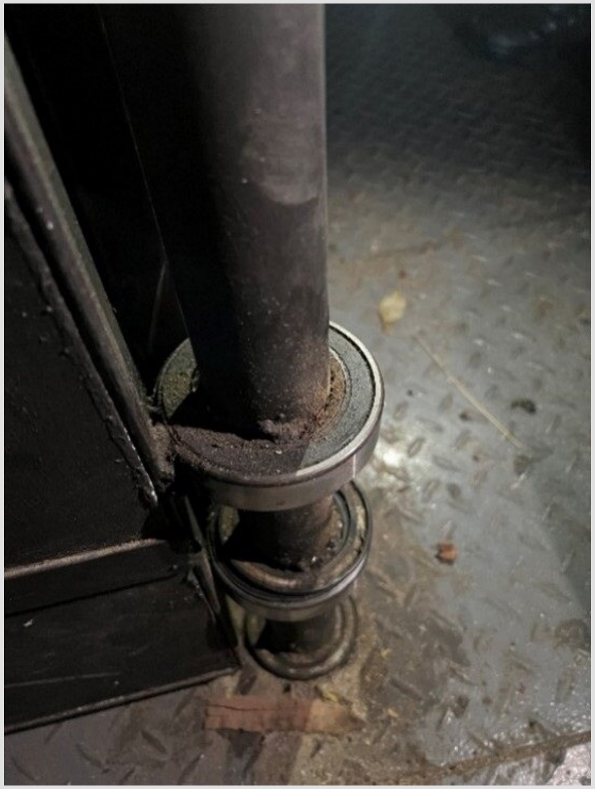


Figure 16: This is a photo of the current wall panel system used in the Bomberos facility. The wall is welded to bearings on the center beams so that the wall can rotate 360 degrees for customizability.

The chosen design is represented in Figure 17 and Figure 18. This design delivers a satisfactory middle ground in both modularity and cost between the previous two approaches because it primarily consists of rectangular metal tubing and U-channel, but is completely modular.

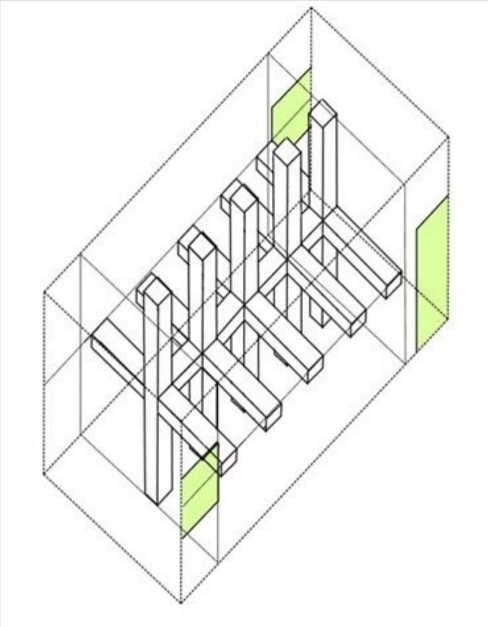
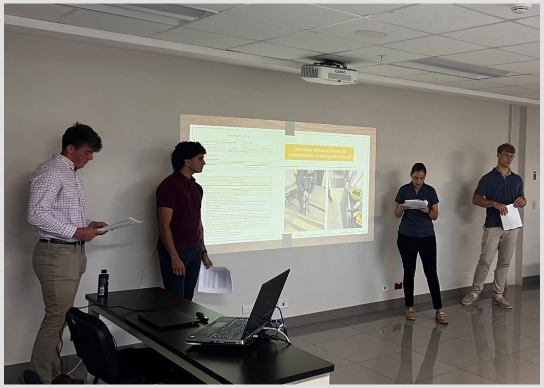


Figure 17: Initial sketch of the design of the general layout of the container (not to scale). This sketch highlights the design for frame of the labyrinth using steel beams in a crisscross pattern.



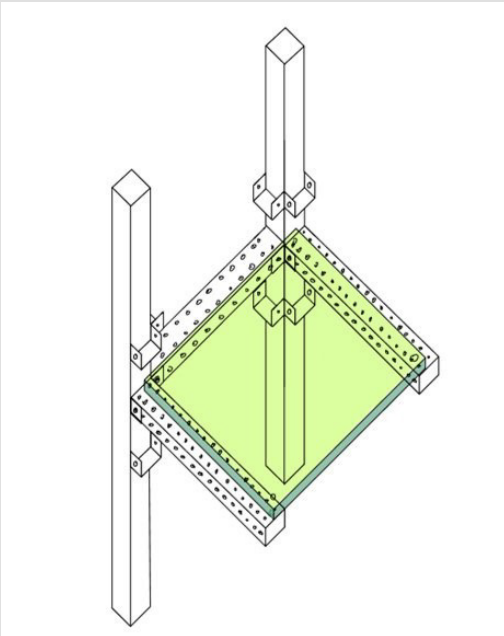


Figure 18: Early sketch showcasing fastening of the floor panels with the vertical and horizontal beams within the labyrinth.

The second story configuration was meticulously designed through discussion with our sponsor to balance optimal function and structural integrity with budget constraints. To remain under the 4.15m (13.6ft) height constraint of motor vehicles, our design incorporates 3 stackable folding walls following a designated folding order based on their corresponding hinge heights. The initial designs differed in their structural safety methods. The first implemented a C-channel metal housing to stack on the tops of the built-up walls.

To strive for a 4:1 factor of safety, another design was raised implementing complete corner support via heavy gauge steel tubing. These walls were connected via U-brackets and detent pins to distribute the loads more evenly.

The final design combined its predecessors by implementing a fourth multi-purpose wall to create a strong square structure for the most effective force distribution while simultaneously serving as a simulator for passing through the walls (see Figure 19 and Figure 20).

In conclusion, the sponsor review session played a pivotal role in shaping the final layout for the Bomberos, fostering a collaborative exchange of ideas and resulting in a more refined and tailored design that aligns closely with the unique needs and preferences of the Bomberos.

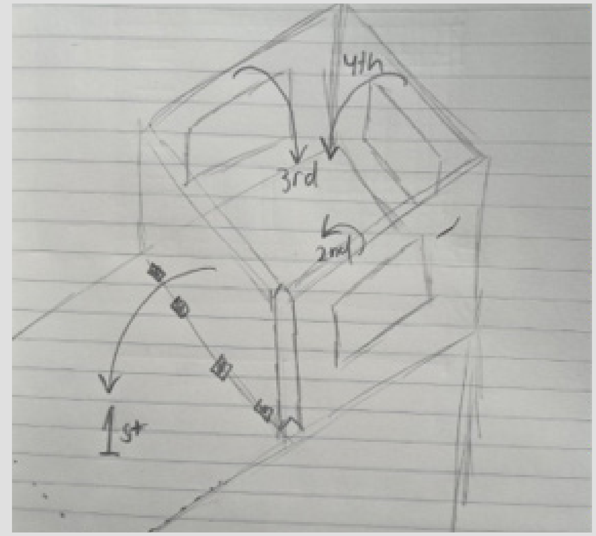


Figure 20: Sketch representing how the second-floor walls would fold on top of one another using hinges, with the passing through the wall stud folding away from the other three walls with windows.

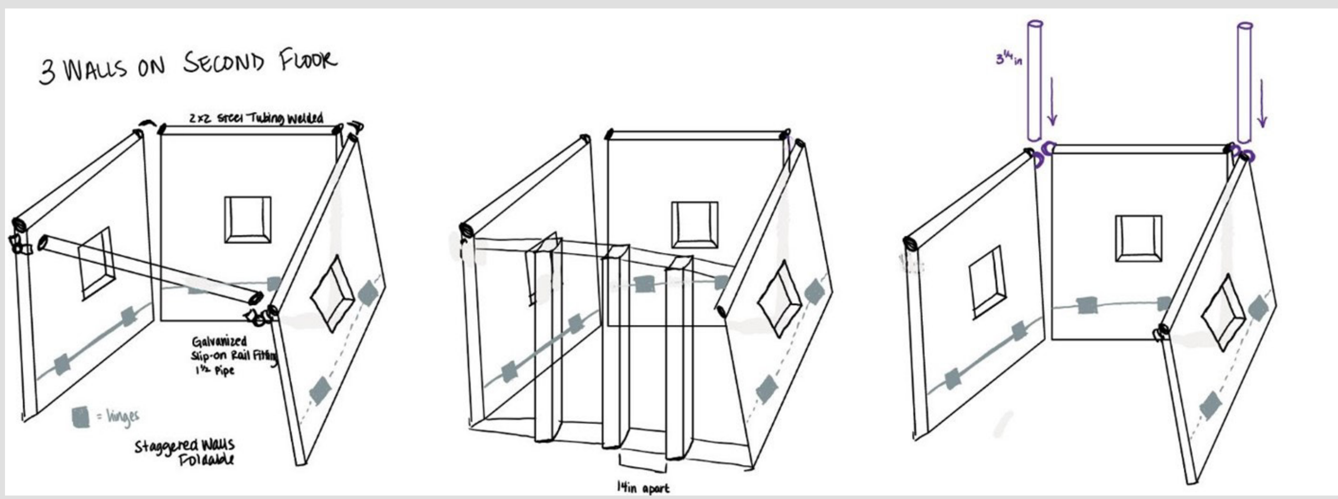


Figure 19: Initial sketches of the design of the three second-floor window walls, each with a window. Hinges at three different heights (indicated in gray) allow the three walls to fold on top of one another.

The Configuration of the Selected Mobile Unit Model

The mobile unit model showcases the 48-foot shipping container fully equipped on a chassis trailer. Atop the trailer rests the built-up window walls requested by the Bomberos necessary for high elevation escape techniques and rescue. The windows have D-rings attached to them (see Figure 21) so that the Bomberos can attach ropes during training exercises. Three out of the four walls have windows while the fourth is the stud wall (see Figure 21). The stud wall is necessary for passing through the wall exercises such as passing through sideways, praying, and swimming motions. On the left side of Figure 21 the manhole can be seen imbedded into the roof of the container; this manhole is used to train lifting a civilian or firefighter up with the use of a rope or firehose. The safety components added onto the roof are the railings and expanded metal sheets.

The railings line the entire edge of the container roof so that a firefighter will not fall off. The railing is installed in a manner that is easily removable for transport (see Figure 22). The other safety feature is the expanded metal sheet which allows for a nonslip surface in all weather conditions. The expanded metal sheet is shown by the black area in Figure 22.

The second-floor walls are collapsable to allow the overall container height to be lower than 13.6ft for transport. The chassis trailer is 4ft tall and the container is 8' 6" leaving about 13in of room above the container. The three

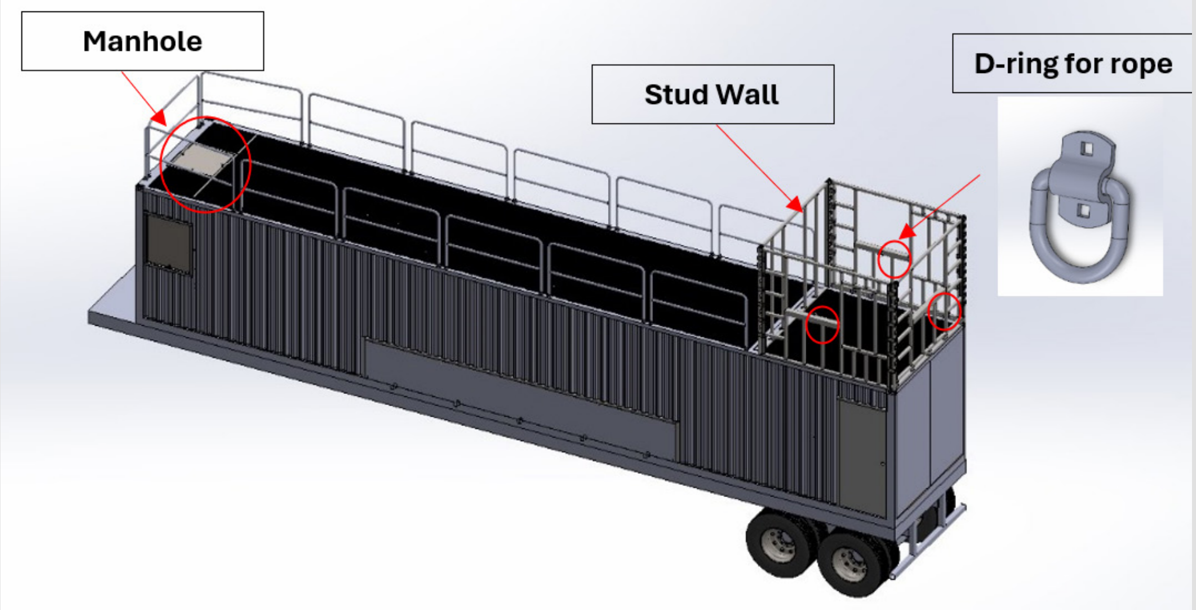


Figure 21: Picture shows fully built trailer.

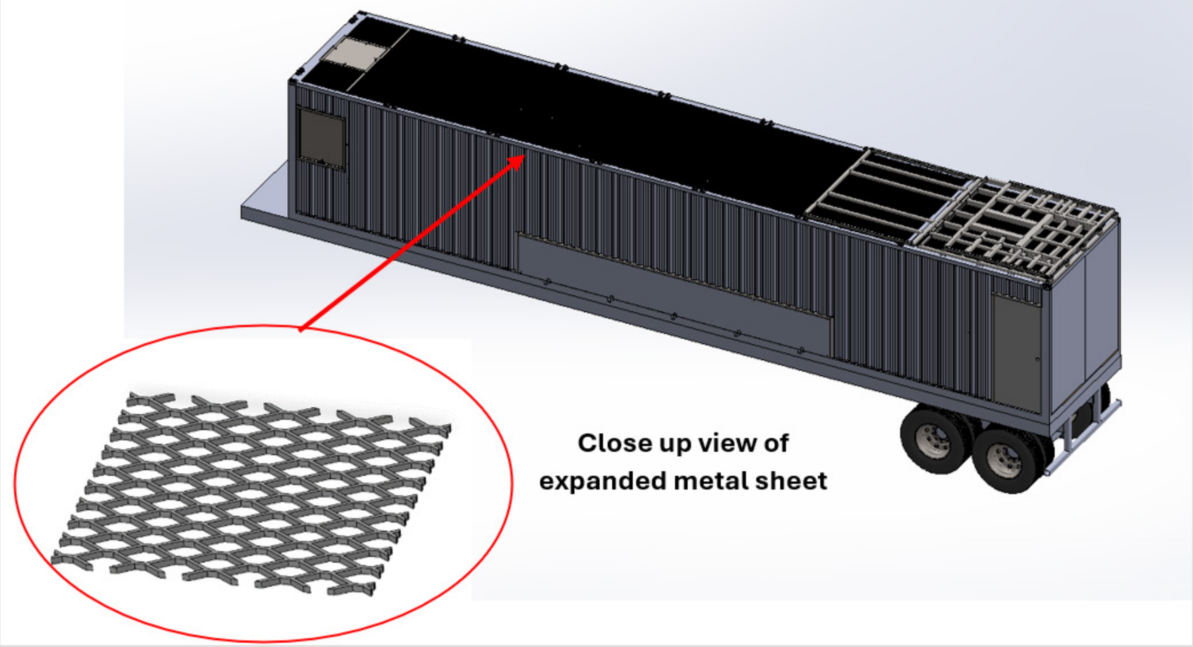


Figure 22: Picture shows fully collapsed trailer for transport alongside a 12x14in expanded metal sheet for reference.

window walls fold onto each other using hinges on each of the walls which adds up to a total height of 7in, providing adequate clearance. We decided to fold the stud wall backwards to minimize overall collapsed height and facilitate use of the stud wall as a simulator

The walls can fold and stand upright by using corner beams and detent pins to hold them into place (see Figure 23). The corner beams have welded sheet metal plates that fit flush around the side beams of two walls. Once the corner beams are slid into place, detent pins are pushed through the holes of the sheet metal and side beams of the wall to hold them in place (see Figure 23).

On the other end of the container opposite to the wall is the manhole. The design for the manhole had to fulfil a few criteria which included an airtight seal, easy removal/replacement, and be resilient to weather. To address the tight seal, we used an Ethylene propylene diene monomer, or EPDM for a gasket which is glued to the manhole metal lid (see Figure 24). The reason for this specific rubber is because it is resilient to harsh weather conditions. This specific rubber has a compressibility of 33% which we accounted for in our design by placing the edge where the cam latch locks strategically at a point where the rubber is at maximum compression to prevent any leakage. Under the manhole, there are steel beams welded across the container for added support and strength (see Figure 24).

Behind the container's walls lies a complete labyrinth layout with its rectangular steel tubing frame, U-channel lined walls, and various wall and floor panels (see Figure 25). Of the 48-foot container, the labyrinth occupies forty feet; the remaining eight feet were split up for the front and back of the container, five feet and three feet, respectively. These are multifunctional spaces necessary for an entrance and exit into the labyrinth while simultaneously providing a clear area below the manhole opening. The container windows were purposefully placed on opposing sides of the container to maximize functional training space for the Bomberos. With the double-sided runway design, one group of trainees can focus on the Denver Escape simulation in one window while another group practices the pull and push rescue method in the other window on the opposite side of the container.

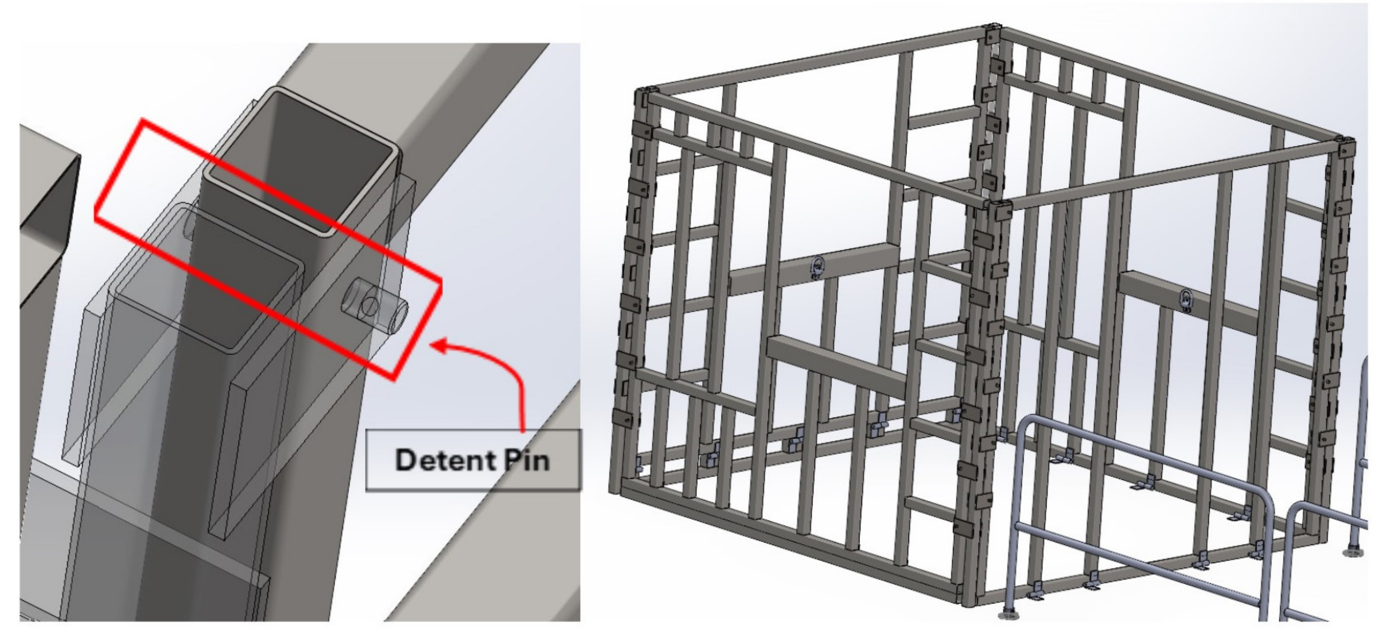


Figure 23: Image shows a closeup of the detent pins and corner beams.

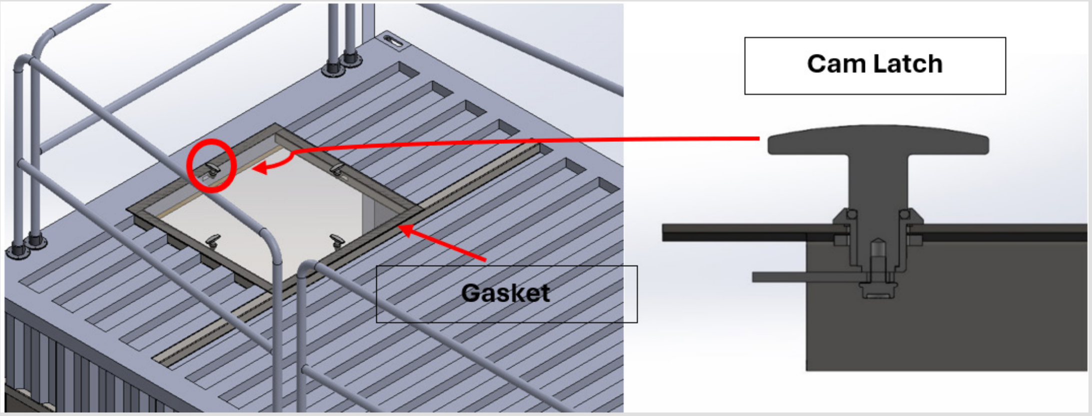


Figure 24: Photo of manhole isolated from the rest of the model. The lid is currently set to transparent for a better view of the gasket and fortifying tubing. The photo to the right shows a close-up section view of the cam latch.

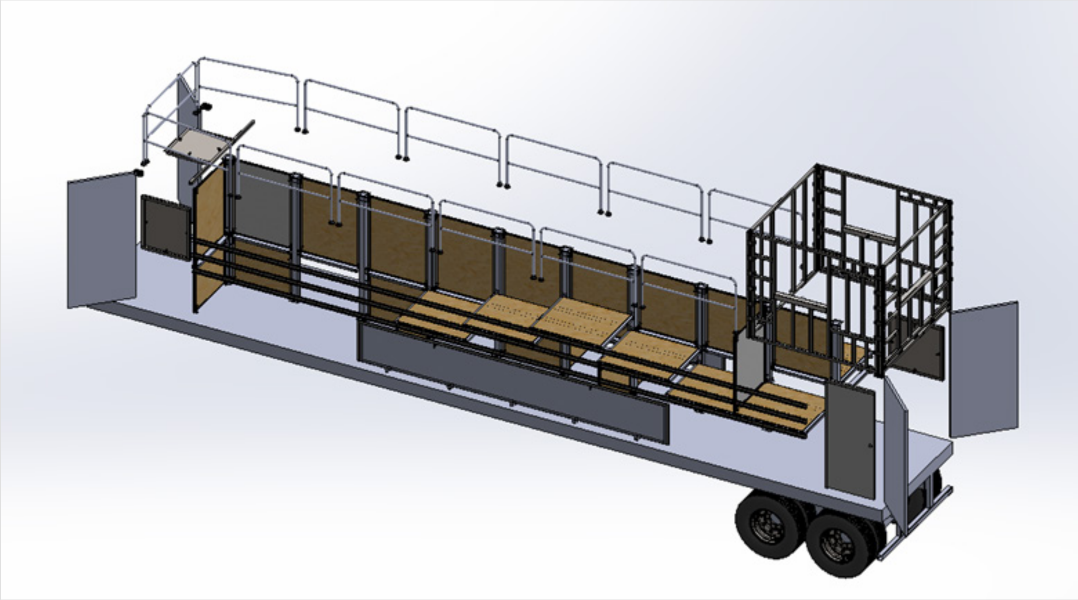


Figure 25: Picture shows fully built trailer including a possible labyrinth layout (walls blanked for visibility).

On the container itself there are many access panels/doors for a variety of reasons. There are two windows so that two groups can practice multiple exercises at the same time (see Figure 26). There are also emergency exit doors (see Figure 26) which are used in case a firefighter gets injured and needs immediate rescue or for maintenance such as cleaning or repairs so that there is more access to the container. The final door is a regular door so that equipment can be stored easily as not all 48ft containers have container doors on either side in case there is not there will be a regular door for access.

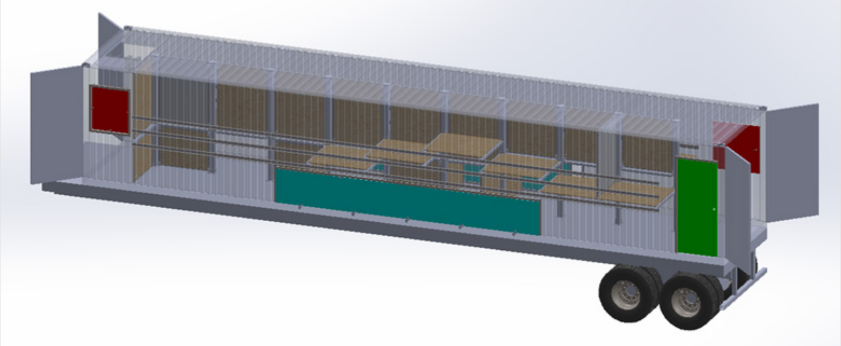


Figure 26: The highlighted components show all windows (red), doors (green), and emergency exits (blue).

The labyrinth assembly starts with the ceiling and floor post bases shown in Figure 27 and Figure 28. First the post bases need to be put into place using bolts then the vertical beams can be bolted onto them. Once the desired number of vertical beams are in place then the sheet metal hook plates can be bolted onto them (see Figure 29). These hook plates can be bolted at three heights: 3ft; 4ft; and 5ft. This allows for the horizontal beams to be placed at different heights for a modular design. In Figure 30, it can be seen how the horizontal beams fix onto the center hooks and bolt to the u channel on the side wall. The center horizontal beams are both fixed by welded U bolts that slot into the hooks (see Figure 30).

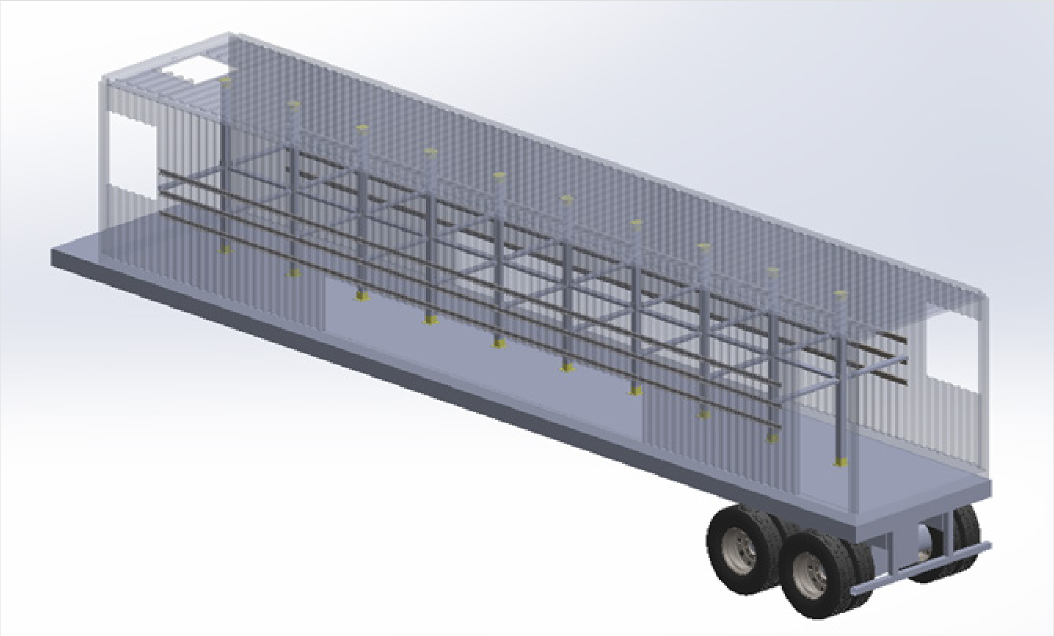


Figure 27: The highlighted yellow parts in the image are the post bases which fix the vertical beams to the ceiling and floor of the container.

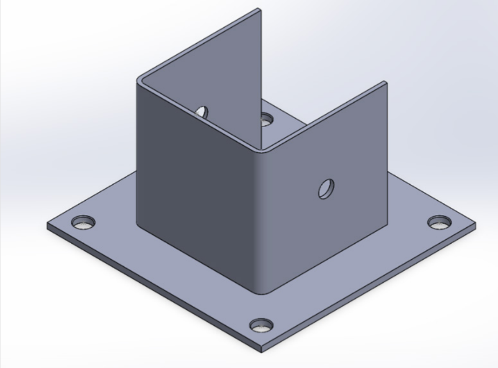


Figure 28: Close up view of post base, the connection between the central vertical beams with the floor and ceiling.

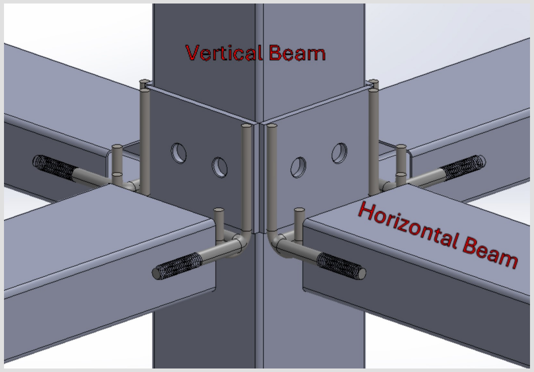


Figure 29: Center beam with sheet metal and hook connection. The horizontal beam has a slot in connection with its welded U-bolt dropping onto the J-hooks.

The wooden floor panels boast a simple design of a roughly 4x4 foot sheet of plywood with 2x4 inch wooden planks attached below for stability and support. Floor panels can be installed between any two horizontal beams bridging the gap between the vertical beams and container walls. With proper assembly, the wall panel sits covering the inside halves of the frame; This allows for smooth transitions between floor panels with tight butt joints together.

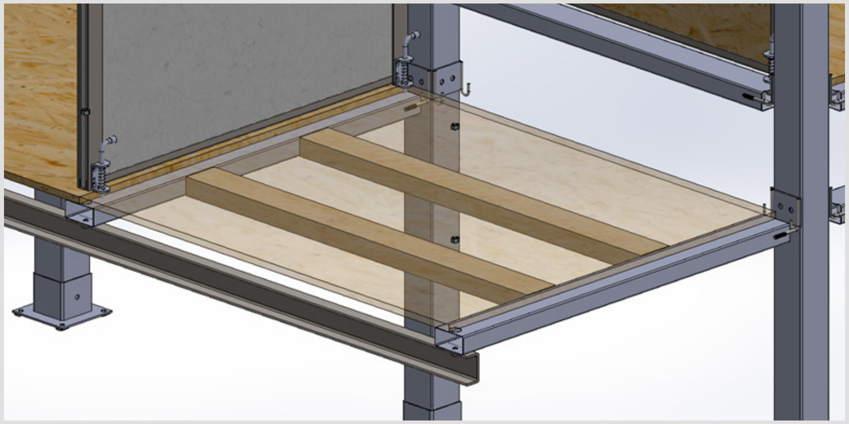


Figure 30: Zoomed in photo of the possible labyrinth layout with floor panel plywood set to transparent. All connection components of the labyrinth are visible such as the horizontal beams and the walls spring latch pins.

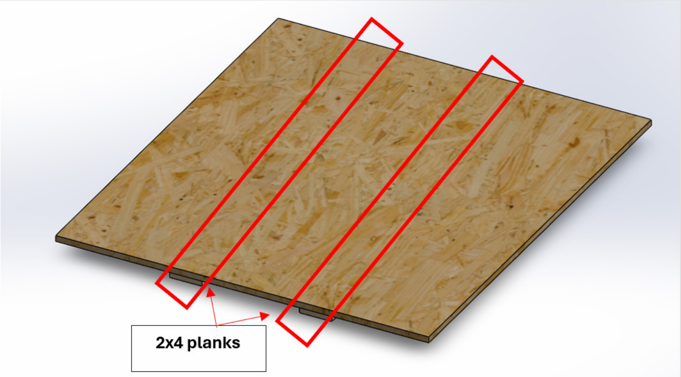


Figure 31: Plywood floor panel with 2x4 wood planks spanning underneath.

The wall panels are key in this design's modularity and a crucial aspect emphasized by the Bomberos. These panels consist of a metal frame constructed from sheet metal, U-channel, and spring-loaded latches (see Figure 32). The red sides are the closed U-channel frame that house the main wall material. The green sides are the sheet metal strips strengthening the frame but leaving open slots for access. These slots allow for the Bomberos to switch from a solid wooden barrier in the labyrinth to a reusable destructible wall simulation training spatial awareness and technique. The wall panel is installed via pin insertion from its spring-loaded latch into concentric holes drilled in the horizontal beam, floor, and ceiling (see Figure 30).

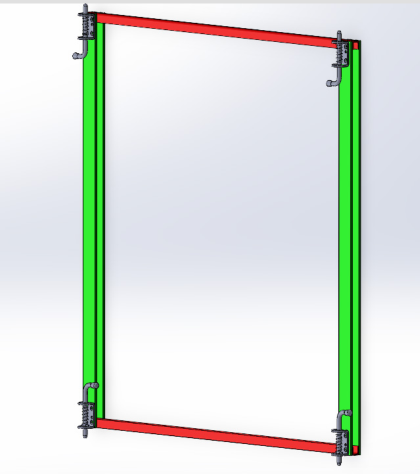


Figure 32: Image showcasing wall panel design; The U-channel can be seen in red, responsible for holding the panel material. The sheet metal strips are green, providing structure while creating a slot for ease of assembly. The spring latch pin can be seen on top locking the panel in place.

Other auxiliary components are needed for the trailer's function, such as a scaffolding platform and stairs. The platform (see Figure 33) is necessary for when the Bomberos are using the first story windows and can exit at a safe height and not fall 7ft to the ground. This platform is especially necessary for Denver Rescue as the training incorporates a firefighter who is incapacitated, which will ensure safety when they are lifted out of the window. It can also be used to access the second-floor windows so that the standard-length ladders will reach above the window at a safe 75-degree angle. The scaffolding platform is an optimal solution not only because it provides a strong elevated surface but because it can be taken apart and stored inside the container during transit.

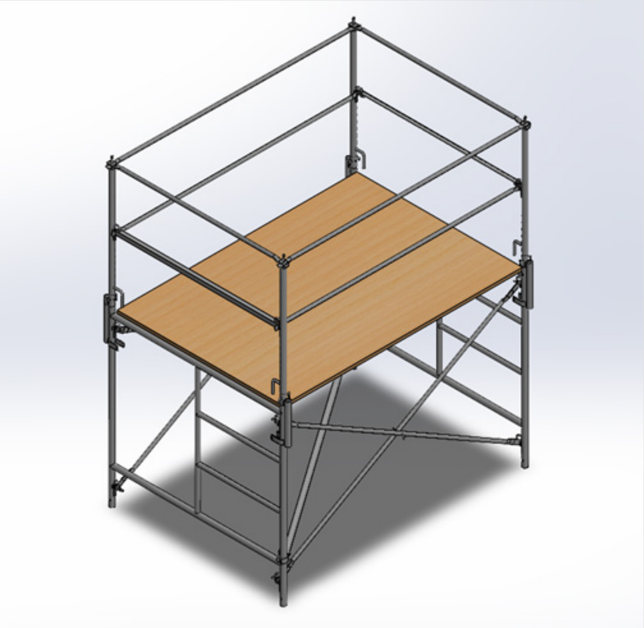


Figure 33: Photo of scaffolding system that will be used.

The unit also requires stairs to climb up to the second floor. The stairs we chose have handles and wheels, where the handles allow for a safe ascent and the wheels provide easy maneuverability when needed. These stairs can also be folded and compressed as they are ladder stairs. Their compressibility of the stairs allows for the option to store them inside the container (see Figure 34).

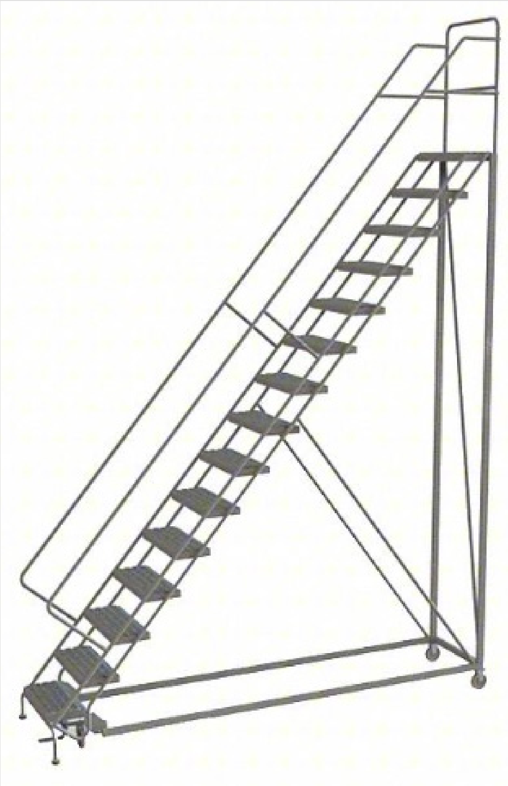


Figure 34: Stairs that will be used on the exterior of the mobile unit.

Conclusions and Recommendations

The goal of this project was to create a conceptual design of a mobile unit that would make it easier for firefighters in Costa Rica to access search and rescue training. Multiple designs and layouts of the mobile unit were provided to the Bomberos and the most desired solutions from the sponsor reviews were modeled. With a fundamental understanding of the search and rescue training exercises the academy executes onsite, the restrictions and limitations that each exercise required were factored into the unit's final design. Executing the needs assessment helped confirm the constraints of the simulations implemented into the design along with determining the material availability and distributor accessibility in Costa Rica.

Cost estimates show that our design is within the $40,000 budget. The total cost is estimated to be 8,660,300 colones, which comes out to $16,960 (see Table 5). It is important to note that this cost breakdown does not include the chassis trailer or the container. Our team also broke down the costs into different sections of the mobile unit. All the materials used in designing the mobile unit can be sourced from distributors in Costa Rica.

Table 5: Cost breakdown of our proposed mobile training unit.

Item	Cost (Colones)	Cost (US Dollars)
Material used Inside Container	C3,650,000	$7,100
Wall panels	C1,110,000	$2,200
Floor Panels	C514,000	$1,000
LED lights	C20,500	$40
Scaffolding	C980,000	$2,000
Foldable walls	C410,400	$800
Manhole	C165,400	$320
Railings	C1,450,000	$2,800
Floor Grip	C360,000	$700
Final Total	₡8,660,300	US$16,960

Design Recommendations

Materials were selected based on those used in the existing simulations at the academy; however, this remains a conceptual design. It is highly recommended that the Bomberos contract a licensed engineer to complete structural computations to ensure the mobile units' safety.

Auxiliary Recommendations

After researching auxiliary components to be placed into the mobile unit, our team has recommendations for the Bomberos. When considering potential solutions for the cameras inside the mobile unit, we suggest that cameras be implemented so that they may be operated wirelessly. Wireless cameras can be placed anywhere in the labyrinth by utilizing Velcro holders attached to any surface and not just in fixed locations. We also recommend the use of infrared cameras, otherwise it may be very difficult to see the firefighters within the container if it is filled with smoke.

We recommend the use of wireless Bluetooth speakers because they can be placed anywhere in the highly customizable labyrinth along with being able to pair the speakers together, so that the desired audio plays across all the speakers.

Final Remarks

Our team envisions that the implementation of our mobile training unit will significantly enhance Bomberos training. By decentralizing training through this innovative unit, we anticipate an improvement in both the efficiency and effectiveness of their training programs. Bomberos stationed in remote locations across Costa Rica will no longer need to disrupt their operations by traveling to San Jose for essential trainings. Ultimately, our goal is to equip the Bomberos with a mobile training solution that enables them to better prepare for real-world scenarios, enhancing their ability to protect the people of Costa Rica.

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