Team 67: Lithium-ion Battery Risk Management in Micromobility Devices

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Lithium-ion Battery Fires are Dangerous

Oliver Cai

Figure 1. NBC Lithium-ion battery fire warning video [1]

The design must meet the needs of the Toronto Shelter System

Oliver Cai

Figure 2. Shelter Locations Map [2]

- Temporary housing and support services
- Design must operate outdoors

The client needs a design to mitigate risks of lithium-ion battery fires in the Toronto Shelter System

Oliver Cai

Problem

Micromobility devices are fire hazards

Shelter residents rely on micromobility devices

Need

Safely and securely store lithium-ion batteries belonging to micromobility devices for shelter residents

Our design effectively mitigates the damages of lithium-ion fires

Daniel Dot

Idea Generation → 55+ Solutions → Idea Selection → 3 Alternative Solutions

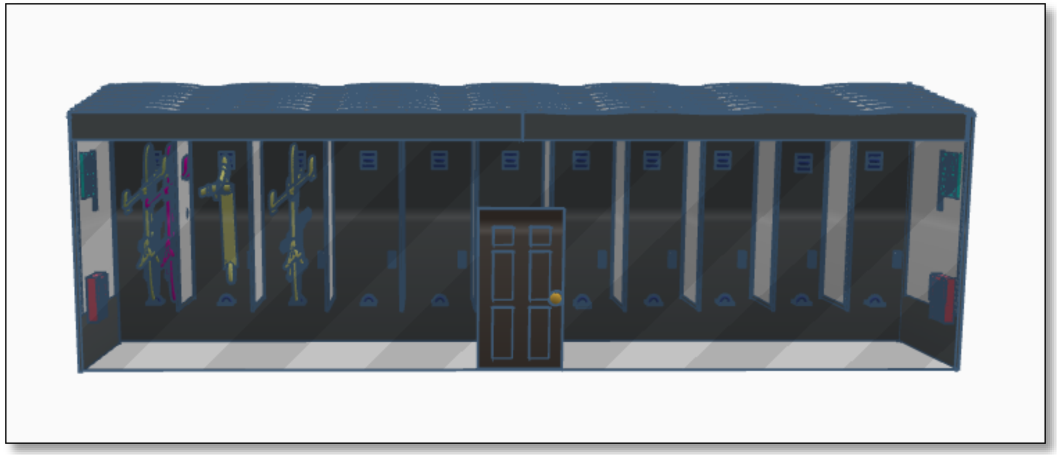

Figure 3: *Bike Shed* Design

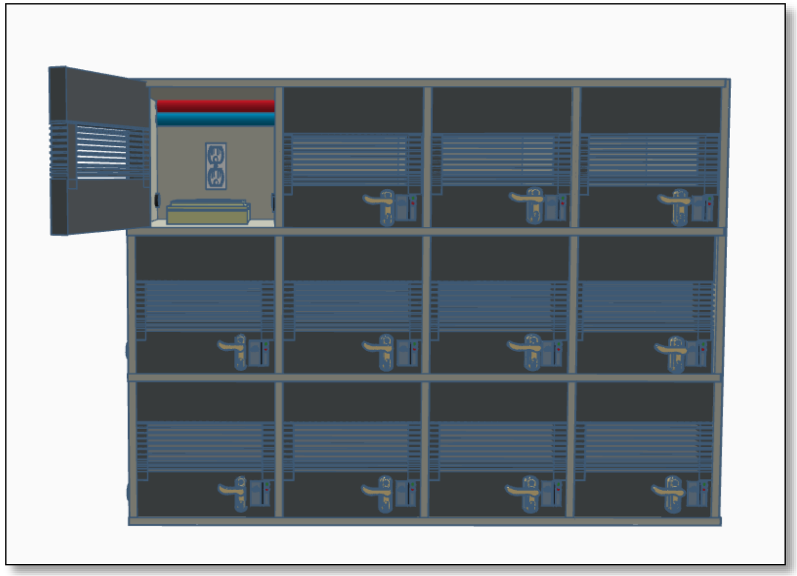

Figure 4: *Battery Locker* Design

The *Double Locker* effectively mitigates the damages of lithium-ion fires

Daniel Dot

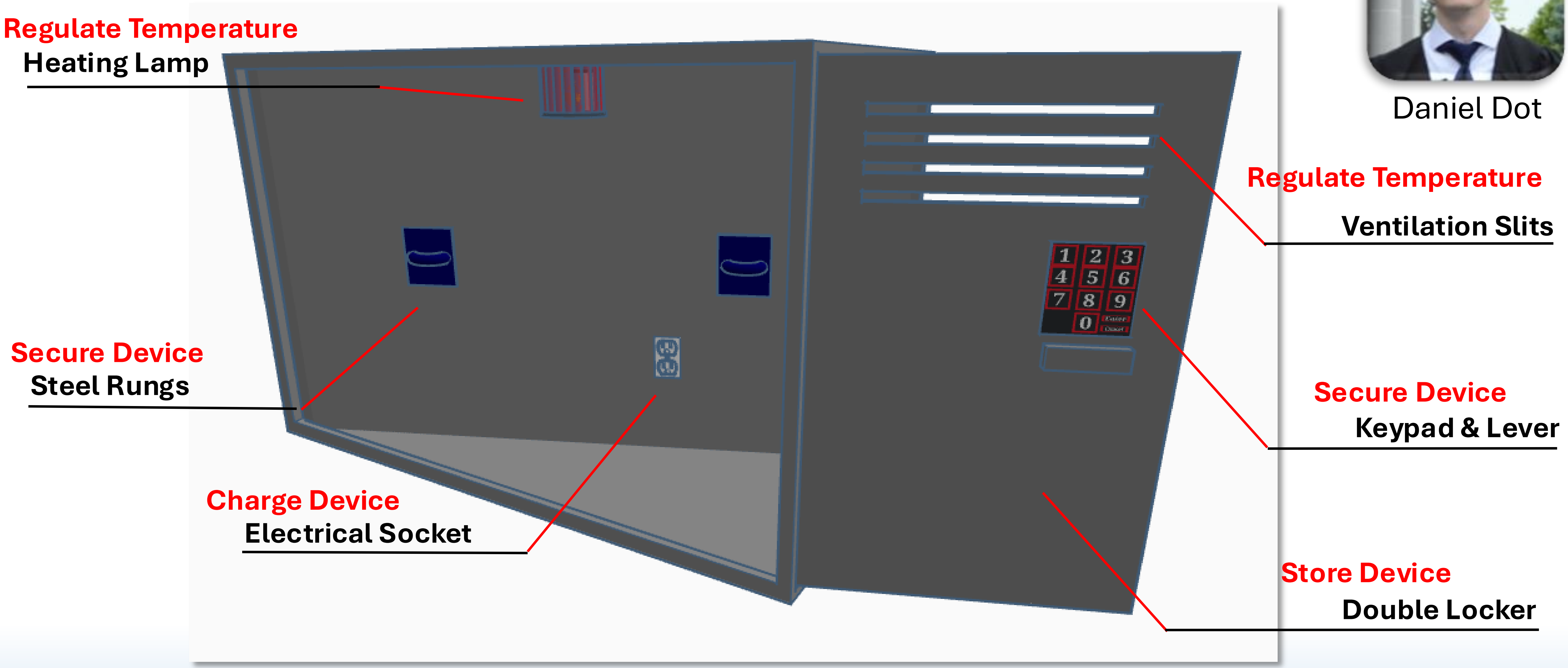

Figure 5: *Double Bike Locker*

The *Double Locker* effectively mitigates the damages of lithium-ion fires

Daniel Dot

Durability

- Material: 316 Stainless Steel [3]
  - Yield Strength: 310 MPa [3]
  - Ignition Temperature: 1400 °C [4]
- Lock Grade: ANSI Security Grade 1 [5]
  - Fail Safe Mechanism

Modularity → Approx. 292 kg [3] → Area: 0.825 m^2 per bike

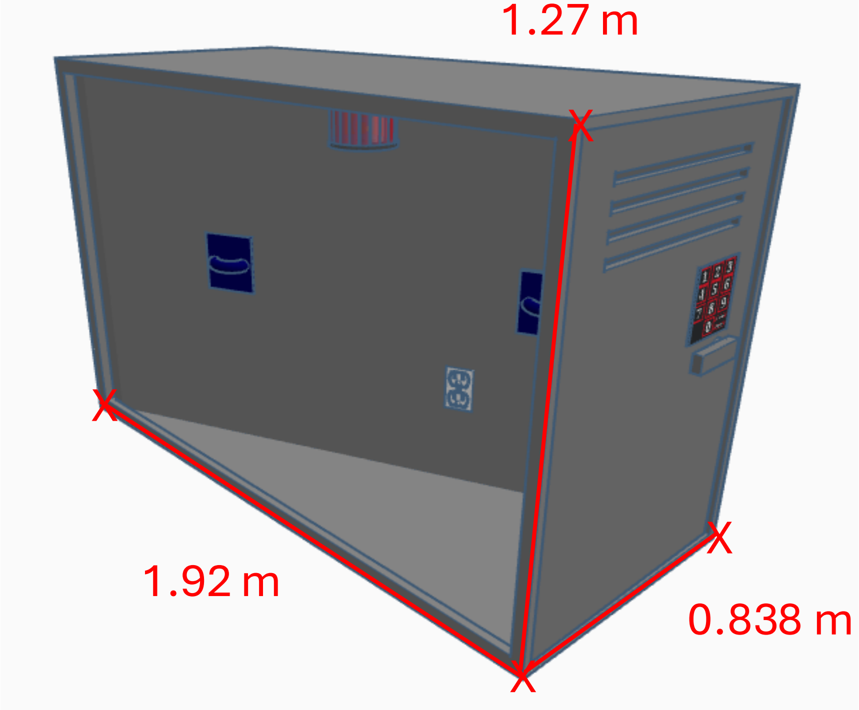

Figure 6: *Double Bike Locker* Dimensions

The *Double Locker* performs better than existing solutions

Taha Syed

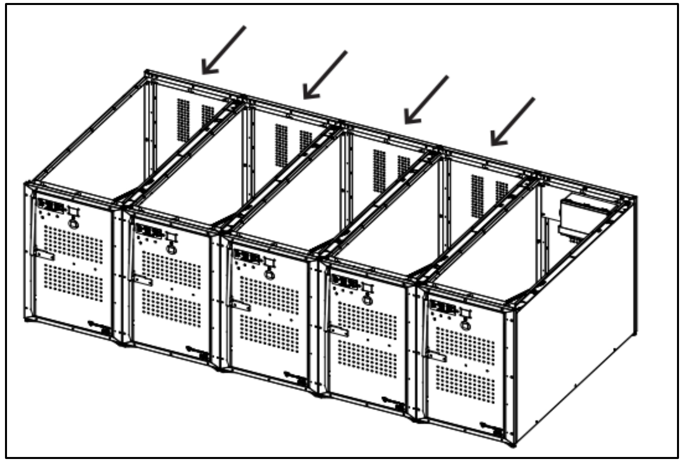

Figure 7. Bikeep Smart Locker [6]

Similarities

- Locker-style storage
- Built-in outlets
- Passive ventilation

Improvements

- Active temperature control
- 50% less space per bike
- Raised ignition temperature [4] [7]

Trade-Offs

- Increased weight
- No Wi-Fi control

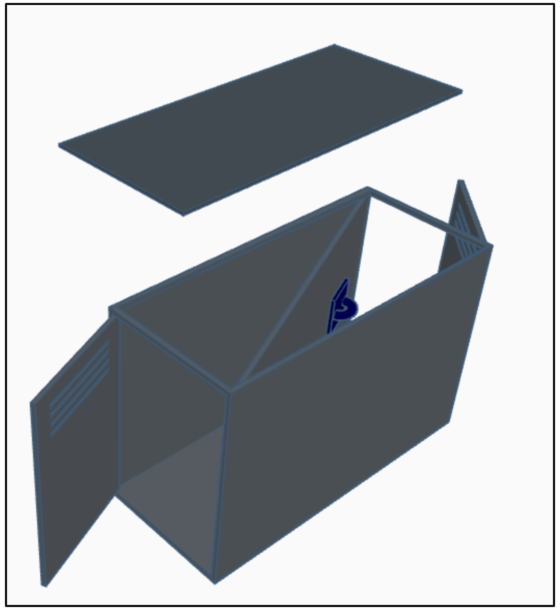

Figure 8. The *Double Locker*

The *Double Locker* performs better than existing solutions

Taha Syed

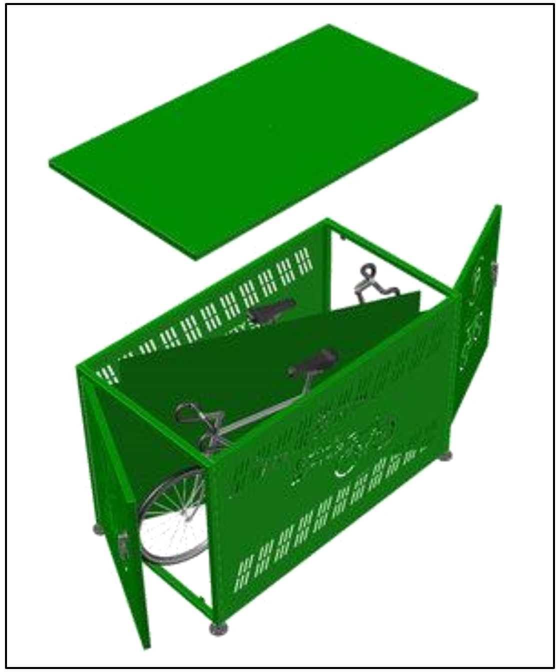

Figure 9. Greenspoke Cycle Sitter [8]

Similarities

- Same storage design
- Passive ventilation

Improvements

- Active temperature control
- Added outlets for charging

Trade-Offs

- Increased weight

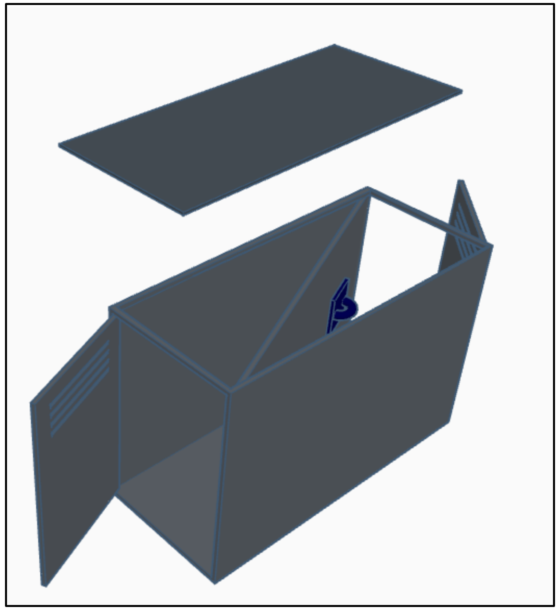

Figure 10. The *Double Locker*

The *Double Locker* is secure and durable in an outdoor setting

Ethan Xiao

To assess the design's durability, we use SolidWorks Simulation [9]

Table 1: The goal loads and estimated maximum loads for three durability tests

Test	Stacking Load	Concentrated Load	Torque Test
Goal	Ontario Building Code requires 1.2 kPa [10]	96.8 kg person on one foot applies 950 N on 23x7.5 cm^2 area [11] [12] [13]	675 N force [14] at end of door creates 560 Nm of torque
Estimated Maximum Withstand-able Load	6.633 kPa	1490 N	4573 Nm

The *Double Locker* is secure and durable in an outdoor setting

Ethan Xiao

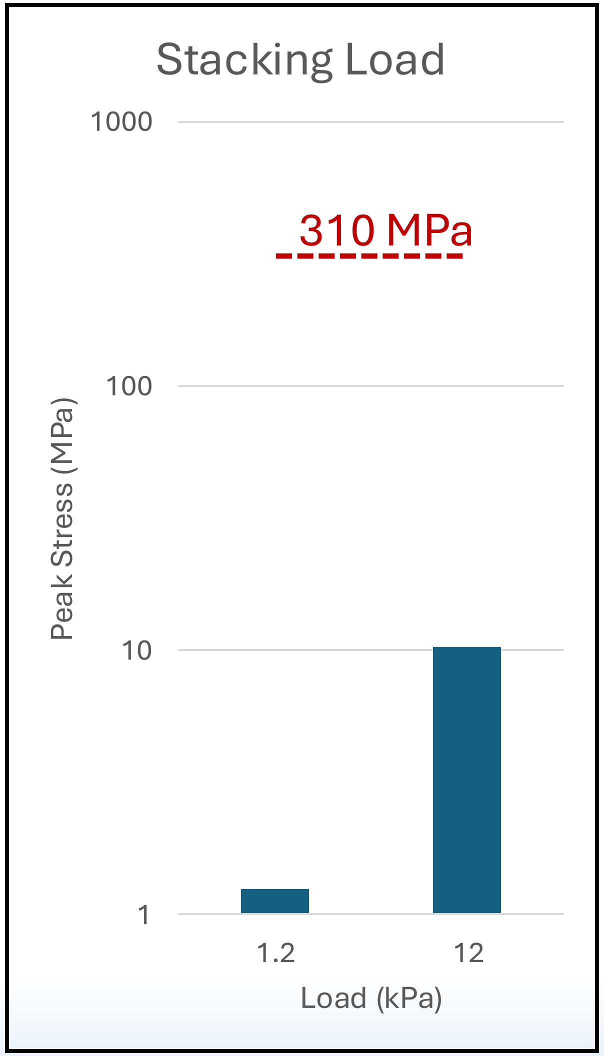

Figure 11. Stacking Load

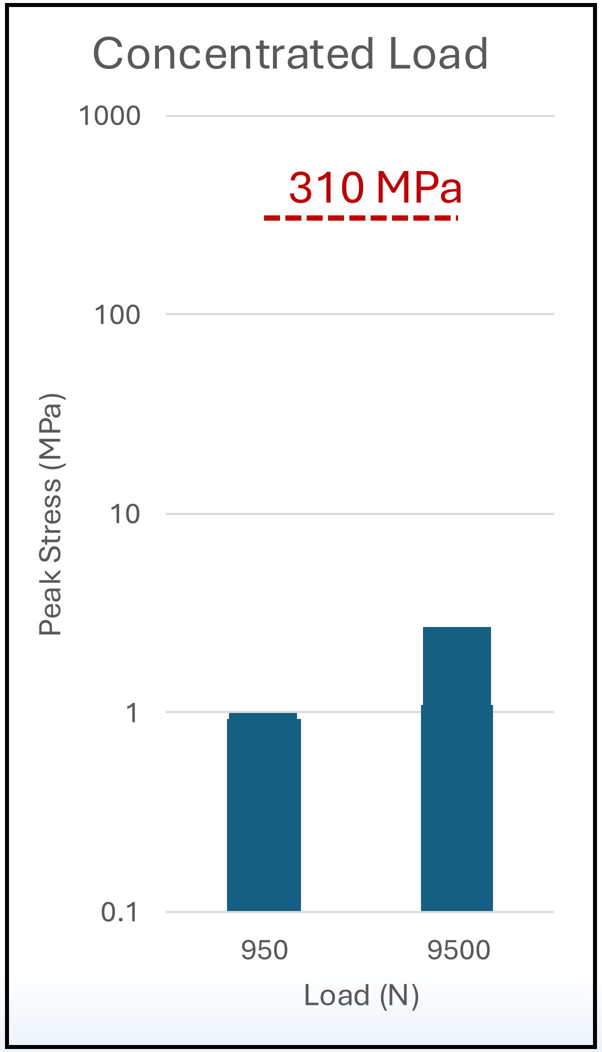

Figure 12. Concentrated Load

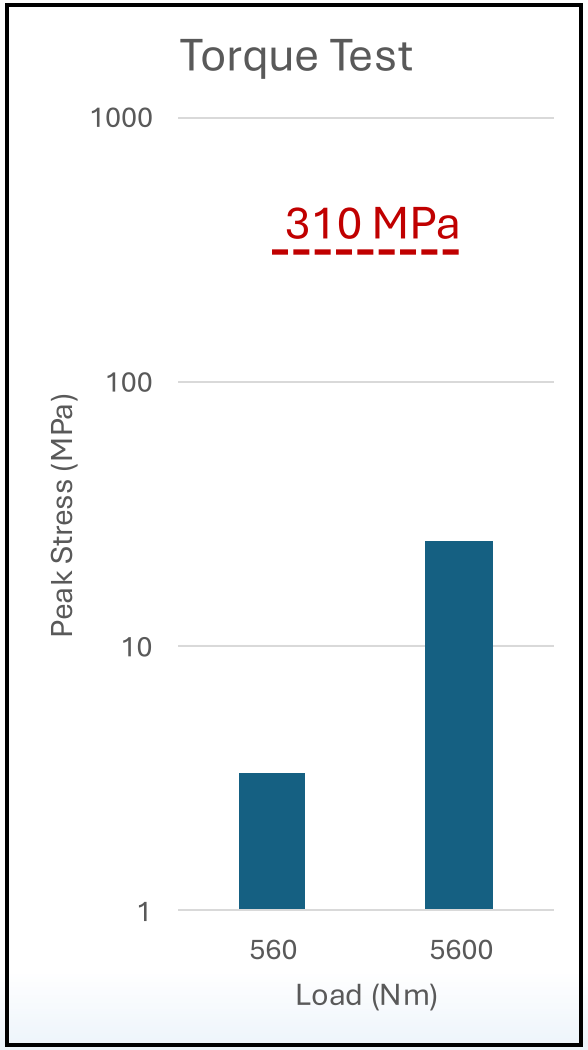

Figure 13. Torque Test

The *Double Locker* must be iterated upon

Mazin Mukhtar

Consolidate Standards Further

Develop System for Accessing Locker

Improve Ventilation, Weight, Heat Detection

Model Fire Resistance

Testing Fire Resistance

Continuity Equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_{\mathrm{j}}}(\rho u_{\mathrm{j}}) = 0$$

Momentum Equation:

$$\frac{\partial}{\partial t}(\rho u_{\mathrm{i}}) + \frac{\partial}{\partial x_{\mathrm{j}}}(\rho u_{\mathrm{j}} u_{\mathrm{i}}) = -\frac{\partial P}{\partial x_{\mathrm{i}}} + \frac{\partial}{\partial x_{\mathrm{j}}}\left[\mu\left(\frac{\partial u_{\mathrm{j}}}{\partial x_{\mathrm{i}}} + \frac{\partial u_{\mathrm{i}}}{\partial x_{\mathrm{j}}}\right)\right] + \rho g_{\mathrm{i}}$$

Concentration Transport Equation:

$$\frac{\partial}{\partial t}(\rho Y_{\mathrm{s}}) + \frac{\partial}{\partial x_{\mathrm{j}}}(\rho u_{\mathrm{j}} Y_{\mathrm{s}}) = \frac{\partial}{\partial x_{\mathrm{j}}}\left(D\rho \frac{\partial Y_{\mathrm{s}}}{\partial x_{\mathrm{j}}}\right) - w_{\mathrm{s}}$$

Enthalpy Transport Equation:

$$\frac{\partial}{\partial t}(\rho c_{\mathrm{p}} T) + \frac{\partial}{\partial x_{\mathrm{j}}}(\rho u_{\mathrm{j}} c_{\mathrm{p}} T) = \frac{\partial}{\partial x_{\mathrm{j}}}\left(\lambda \frac{\partial T}{\partial x_{\mathrm{j}}}\right) + w_{\mathrm{s}} Q_{\mathrm{s}}$$

Figure 14. Combustion Modelling Equations [#]

The *Double Locker* is implementable

Mazin Mukhtar

Develop Prototype [Appendix C]

Physical Strain Tests

Security Testing

Mazin Mukhtar

Engineering can be a means to an equitable society

Appendix A: Maximum Withstandable Loads

Table A1. Estimated and simulated maximum withstandable loads

	Stacking Load	Concentrated Load	Torque Test
Estimated	Equation of peak stress in a sheet due to uniform load [16]: $$\sigma = \frac{\beta_2 q b^2}{t^2}$$ 6.633 kPa	Equation of peak stress in a sheet due to rectangular area load [17]: $$W = \frac{\sigma t^2}{\beta}$$ 1490 N	The maximum shear stress the hinges can withstand is found from the following formulas [18]: $$\tau_{Shear} = 0.577 * \tau_{yield}$$ $$T_{Max} = \tau_{Shear} \times \frac{\pi d^2}{16}$$ 4573 Nm
Simulated from SolidWorks [9]	730.5 ± 0.5 kPa	1735 ± 5 kN	49950 ± 50 Nm

Appendix B: Simulation Visuals

Using SolidWorks Simulation [9]

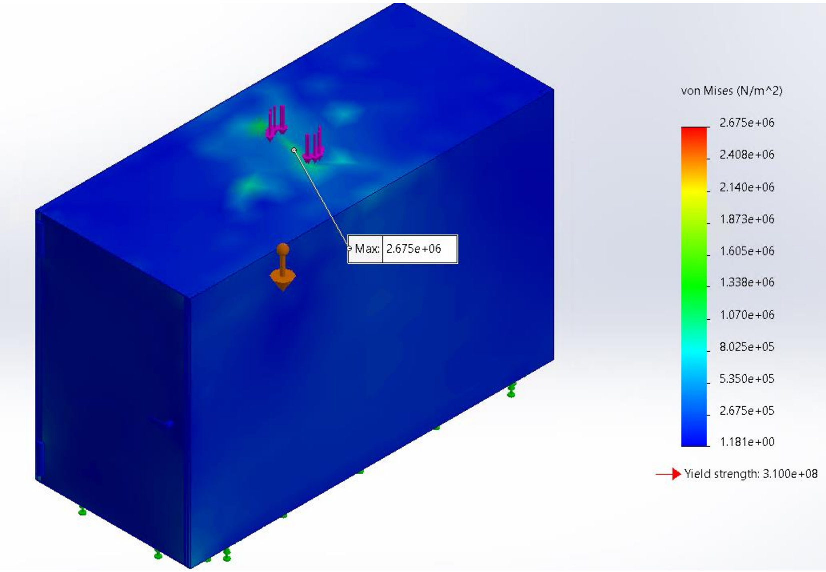

Figure B2. Screenshot of SolidWorks concentrated load simulation

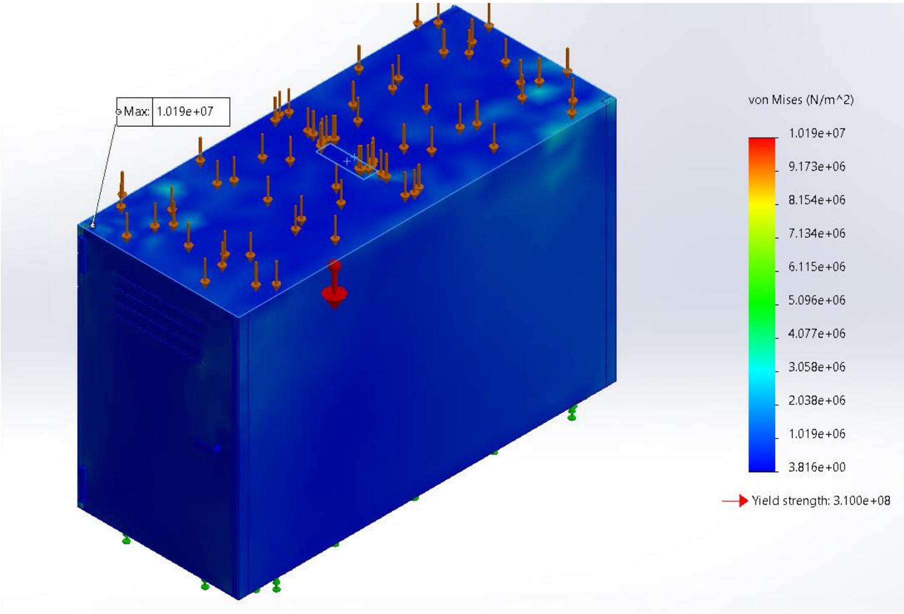

Figure B1. Screenshot of SolidWorks stacking load simulation

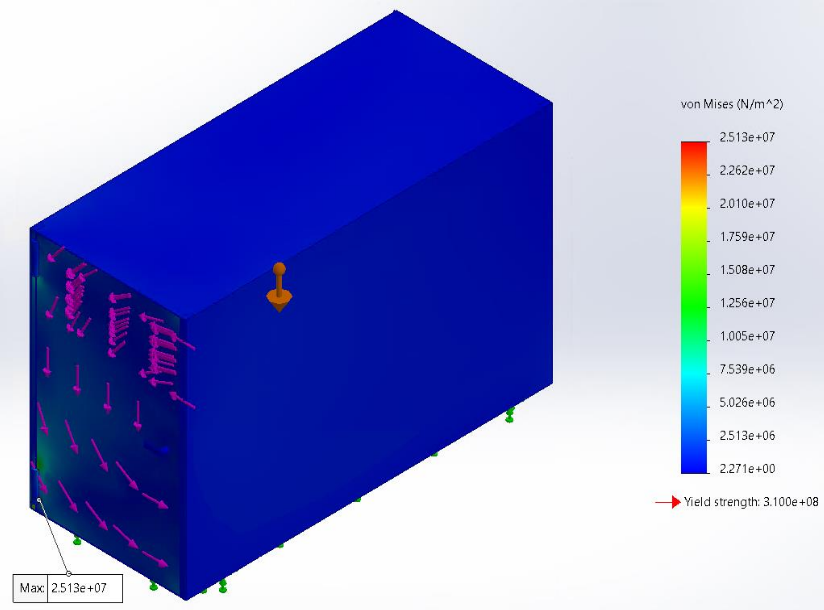

Figure B3. Screenshot of SolidWorks torque test simulation

Appendix C: The *double locker* is an implementable design

Manufacturing

Materials Required:
- 2x 3.175mm Stainless Steel (1.92m x 0.838m) at $1103.52/Plate [19]
- 2x 3.175mm Stainless Steel (1.27m x 0.838m) at $726.00/Plate [19]
- 2x 3.175mm Stainless Steel (1.92m x 1.27m) at $1672.00/Plate [19]
- 1x 3.175mm Stainless Steel (2.10m x 1.27m) at $1826.00/Plate [#19]
- 4 x Hinges (15.24cm x 15.24cm) at $24.59/Hinge [20]
- 2 x Digital Keypad Mortise Locks at $722/Lock[21]
- 4 x Steel Alloy Tubes at $30.71/Tube [22]

Estimated Cost: $9606.34

Further Scoping

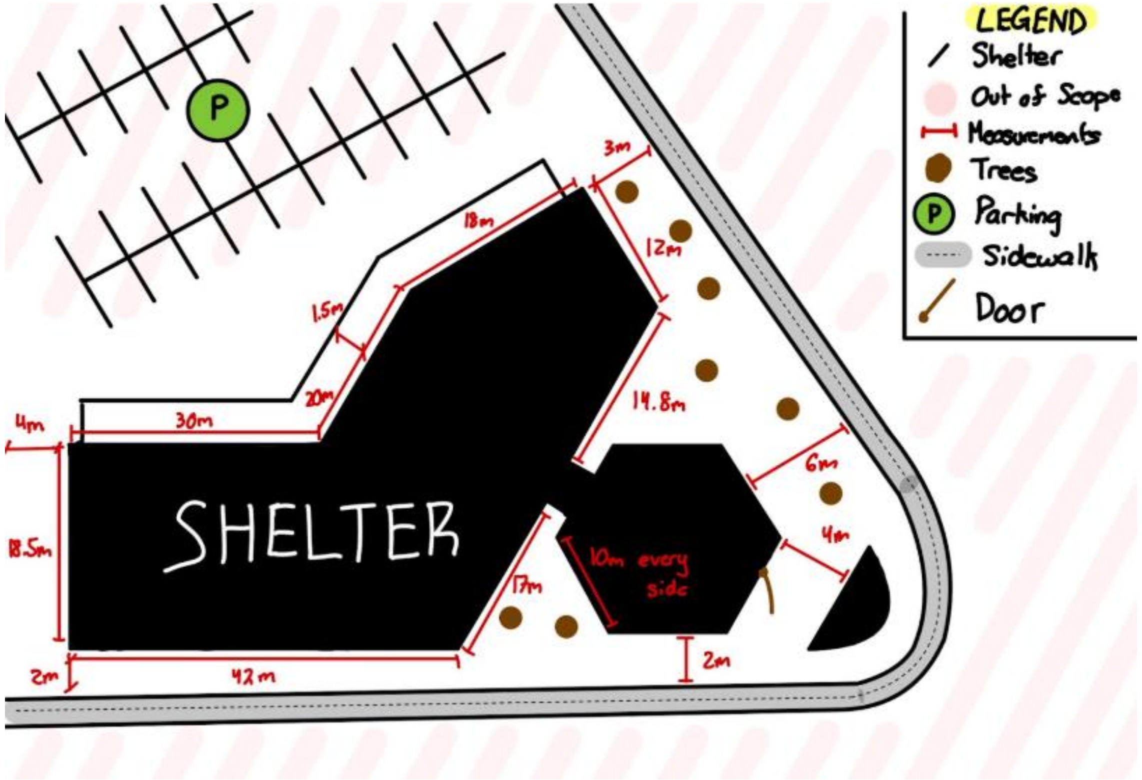

Figure C1. Scope and dimensions of the design (from site visit on Friday, February 14, 2025).

Appendix D: Event of Fire

- Due to limited time and resources, the team was unable to map fire spread. Although, it is considered in our next steps to model it.
- **Preventative measures:**
  - Designed to vent hot air away from neighboring device
  - Each device is physically isolated from other devices.
  - Units should be arranged at an appropriate distance to prevent unit to unit spread.
    - We do not know the exact distance required since we were unable to perform the required tests.
- **During a fire:**
  - An iterated heat detection system will shut down all electricity to the locker to avoid electrical fires
  - The steel will be able to last for a while due to its ignition temperature.
- **After a fire:**
  - Damaged electrical and security components.
  - Weakened steel panels
  - Preferable to recycle the old design and utilize a new one.

Appendix E: Intricacies of the Design

- **Heating Lamp**
  - A heating lamp outputting 250 W will result in the design requiring around 5 seconds to heat the compartment by 1 degree.

$$Volume:\ (l * w * h)/2 = (1.92 * 1.27 * 0.838)/2 = 1.021\,m^3$$

$$Mass\ of\ Air:\ 1.3kg\ per\ 1\ cubic\ metre$$

$$Time\ Required:\ Q = mc\Delta t,\ 250\,W * s = 1300g * 1.005\,J/gC * 1°C,\ s \approx 5.3\,s$$

Figure E1.Calculation to determine time it takes to heat locker

- **Outlet**
  - Many electric bikes need a maximum of 60V to charge, so a standard 120 V plug will be sufficient to charge the bike [23]

- **Lock**
  - A lock we considered for the design would be the XME 2000 [24], which is Grade 1 ANSI rated, and is commonly used for implementation for house doors.

Figure E2. XME 200 Lock

- **Wiring**
  - The wiring of the design is intended to run through the diagonal plate of the design, so it can power both the lock and outlet without wrapping around the design. Each locker will be equipped with a breaker for when the temperature indicates a fire, or power drawn is excessive to prevent improper chargers.

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