University of Southern California
Department of Industrial and Systems Engineering

ISE 501
Innovative Conceptual Design for New Product Development
Spring 2025

Cover Sheet for Individual Project Report

FIREPROOF RETRACTABLE HOUSE COVER

Project Report – Concept Generation

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ISE 501
Innovative Conceptual Design for New Product Development
(Spring 2025)

Grade Sheet for Individual Project Report

<table>
<tr><th>Category</th><th>Grade (max)</th></tr>
<tr><td colspan="2">Correctness and quality including comprehensive of report, development of theme, effectiveness of message, clarity are considered.
Note: Using AI to support concept generation is allowed, but using AI to WRITE the report is prohibited.</td></tr>
<tr><td>Introduction
Brief description of the project
Background information</td><td>_______ / (10)</td></tr>
<tr><td>Problem Formulation
Brief description of the problem statement
The Three Ps of the 4 Ps of Product:
People: A comprehensive list of People (target customers and stakeholders)
Purpose: A description of the target customers’ lifestyle
Problem: A description of the focused function and constraints</td><td>_______ / (15)</td></tr>
<tr><td>Method
Brief introduction of all the methods you are using in the project:
The IDT framework of concept generation
Principles in each concept generation step
The methods of your concept ideation process (if applicable)
Do not directly copy and paste words/pics from lecture slides or webpages.
Explain the method, it’s different from demonstrating the method.</td><td>_______ / (20)</td></tr>
<tr><td>Results
The FR-DP hierarchies and the reasoning flow of your case
The design matrix of each layer
A list of alternatives of the bottom layer DPs
The PDF plot of each selection (order it correctly)
Description of the overall design concept (the final design concept) an image of the design (sketching, picture, CAD, or storyboard)</td><td>_______ / (20)</td></tr>
<tr><td>Discussions
Discussions about the results and the observations
The innovations in your design</td><td>_______ / (20)</td></tr>
<tr><td>Conclusions
A paragraph of the conclusions
At least 2 recommendations (possible improvements/alternatives/new functions)
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Introduction

Wildfires present an increasing risk to residential areas, particularly in fire-prone regions experiencing prolonged droughts and extreme temperatures. Existing fire protection methods, including fire-resistant building materials and sprinkler systems, offer only **partial mitigation** and are insufficient in completely isolating structures from fire hazards. This project introduces a **Fireproof Retractable House Cover**, designed to fully enclose a home and create a barrier against **direct flames, embers, and radiant heat**.

The proposed system integrates **multi-layered insulation with high thermal resistance** and a **motorized retraction mechanism** to ensure rapid deployment when a wildfire threat is detected. A **gas-assisted manual override** is included to provide an additional layer of reliability in the event of power outages. The design follows a **structured concept generation process**, leveraging **Model-Based Systems Engineering (MBSE) with IBM Rhapsody** to develop and refine **Functional Requirements (FRs) and Design Parameters (DPs)**. The IDT framework was used to **categorize functional elements**, ensuring that the system achieves a balance between **automation, structural resilience, and user control**.

A comprehensive analysis of **fire prevention needs and consumer expectations** was conducted using **the Kano model**, categorizing system features into **basic, performance, and excitement factors**. The system's **architecture and deployment strategy** were optimized through **FR-DP hierarchies and a structured design matrix**, ensuring minimal coupling and **maximized functional independence**.

This solution represents a **proactive wildfire mitigation approach**, improving safety and reducing structural damage through **intelligent, automated deployment**. The design ensures **durability, operational efficiency, and integration with smart home systems**, making it a **comprehensive and scalable** fire protection solution.

Problem Formulation

Problem Statement

This project aims to develop a **retractable fireproof cover** that:

- **Completely encloses** the house to prevent direct exposure to flames, embers, and radiant heat.
- Utilizes **fire-resistant, corrosion-proof, and weather-durable materials**.
- Employs a **motorized deployment mechanism with a manual override** to ensure functionality in power outages.
- Incorporates **smart home automation** for pre-emptive deployment based on real-time wildfire risk data.
- Ensures **long-term reliability** with minimal maintenance.

3Ps of the product

People:

- **Primary Users:** Homeowners in wildfire-prone regions, property managers, and rural communities.
- **Secondary Stakeholders:** Fire safety organizations, insurance agencies, disaster management teams, and government regulatory bodies.

Purpose:

- A solution is required to shift from **reactive to proactive fire protection**.
- Customers seek **hassle-free automation** that enhances home safety.
- Long-term **cost-effectiveness and durability** are essential for customer adoption.

Problem:

- **Wildfire unpredictability** limits the effectiveness of reactive measures.
- **Power failures** during wildfires render traditional electric-based systems unreliable.
- The solution must balance **durability, weight, and ease of deployment** without adding excessive structural complexity.

Method

This section explains the **Innovative Design Thinking (IDT) framework**, **Model-Based Systems Engineering (MBSE) using IBM Rhapsody**, and the **concept ideation techniques** applied in this project. The **IDT process** was utilized for **concept formation, organization, and selection**, while the **Kano model** was used to categorize features into **basic, performance, and excitement groups**.

Kano Model

The **Kano model** helps categorize product features based on how they influence user satisfaction. In this project, the following classifications were used:

- **Basic Needs (Must-Be Features):** These features are expected and do not improve user satisfaction when present but cause dissatisfaction if missing.
  - **Fireproofing ability**: The cover must resist high temperatures.
  - **Manual override**: Ensures usability in case of power failure.
- **Performance Features:** Features that proportionally improve customer satisfaction as their performance increases.
  - **Deployment speed**: Faster deployment leads to higher user satisfaction.
  - **Smart home integration**: Allows pre-emptive deployment, improving convenience.
- **Excitement Features:** Unexpected features that significantly enhance user experience.
  - **Auto deployment before fire reaches**: Automatically deploys using sensors to detect nearby fires.
  - **AI-based pre-emptive deployment**: Automatically deploys based on wildfire detection. *Although this may create a hype for the product, the functionality of this feature is debatable. Thus, it is on the negative x-axis in the Kano model graph.*

Applying the Kano model helped **prioritize engineering efforts** towards features that maximize user satisfaction while maintaining critical system reliability.

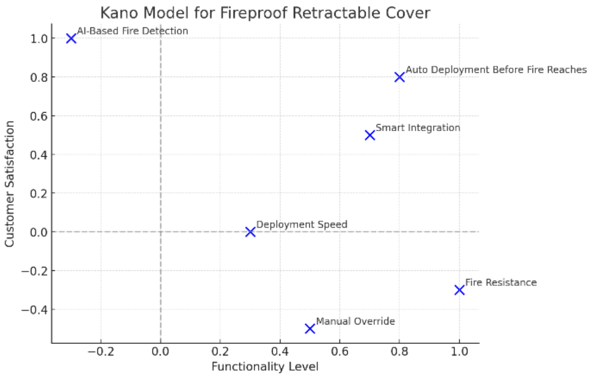

Figure 1: Kano Model Graph

IDT Formation

The **formation step** [ISE501_M4] in IDT follows the **spotlight metaphor** [M4_Slide-21], where attention is focused on a small, well-defined design space. This process helps **narrow down feasible options** and ensures that concept generation is **targeted and systematic**.

1. **Problem Identification**

   - Wildfire protection requires a **proactive solution** rather than reactive measures.
   - Existing fireproof materials degrade over time, requiring **frequent maintenance**.
   - Sprinkler systems depend on an **external water supply**, which may not be available during a wildfire.

2. **Concept Formation**

   - Instead of relying on **fireproof coatings or passive protection**, a **physical barrier that deploys before fire exposure** was conceptualized.
   - A **retractable cover system** was identified as the best approach to shield a home from external heat and flames.

3. **Defining Functional Requirements (FRs)**

    - **FR1:** Protect house from fire.
    - **FR2:** Enable quick deployment.
    - **FR3:** Ensure durability.

The **formation phase** ensured that only **logically feasible solutions** were considered before advancing to the organization phase.

IDT Organization

The **organization phase** [ISE501_M5] involved structuring **functional requirements (FRs) and design parameters (DPs)** using **IBM Rhapsody**. This process ensured **logical consistency, traceability, and functional independence** while allowing for **automated dependency analysis**.

1. **FR-DP Mapping Using Dual Hierarchies**

    - **FRs were structured top-down**, breaking them into **sub-requirements**.
    - **DPs were structured bottom-up**, ensuring that each FR had an independent corresponding DP **(independence axiom** [M5_Slide-11]**)**.

2. **Using IBM Rhapsody for Relationship Mapping**

    IBM Rhapsody provides **multiple relationship types** to define connections between FRs and DPs, such as:

    - **Association:** Defines **physical dependencies** (e.g., **the gas-assisted crank is part of the motor assembly**, but each satisfies independent FRs).
    - **Realization:** Elaborates requirements using **sub-requirements**.
    - **Satisfaction:** Validates that **each DP completely satisfies its assigned FR**.

    Using these tools, the **functional independence of the system can be verified**, ensuring that each FR is independently satisfied while still allowing necessary physical connections.

3. **Automated Dependency Matrices in IBM Rhapsody**

    - **Rhapsody generates automated dependency matrices** [M5_Slide-12], visually mapping **all FR-DP relationships**.
    - This allows for an **efficient validation of uncoupled system design**, preventing unintended dependencies.

IDT Selection

The **selection phase** [ISE501_M6] involved **quantitative evaluation** of different design alternatives using the **Information Axiom** [M6_Slide-10], ensuring that the **final concept had minimal uncertainty**.

1. **Morphological Chart Analysis** [M6_Design-Exercise]

    - Multiple alternatives were generated for each **FR-DP pairing**.
    - Feasible alternatives were classified based on **implementation risk and efficiency**.

2. **Trade-Off Evaluation Using PDF Plots** [M6_Design-Exercise]

    - **Probability Density Function (PDF) plots** were generated for each DP to compare performance within the acceptable design range.

The final selection was **determined based on feasibility, reliability, and cost-effectiveness**.

Results

The **results section** presents the finalized **FR-DP hierarchy, design matrix, alternative evaluations, and the final concept**.

FR-DP Hierarchies and Reasoning Flow

The **functional decomposition of the system** followed a **top-down approach**, while the **design synthesis** was structured **bottom-up**, ensuring **functional independence**.

IBM Rhapsody visually represents different **types of relationships** using **distinct arrow styles**:

- **Association (Solid Line):** Shows structural or logical connections between elements.
- **Realization (Dashed Line with Hollow Arrowhead):** Indicates that a DP implements or fulfils an FR.
- **Refine (Dashed Line with "Refines" Label):** Shows that an **FR is further detailed or expanded** into a more specific requirement or sub-function.
- **Dependency (Dashed Line with Open Arrowhead):** Highlights cross-functional dependencies between elements.

1. Functional Requirements (FRs):

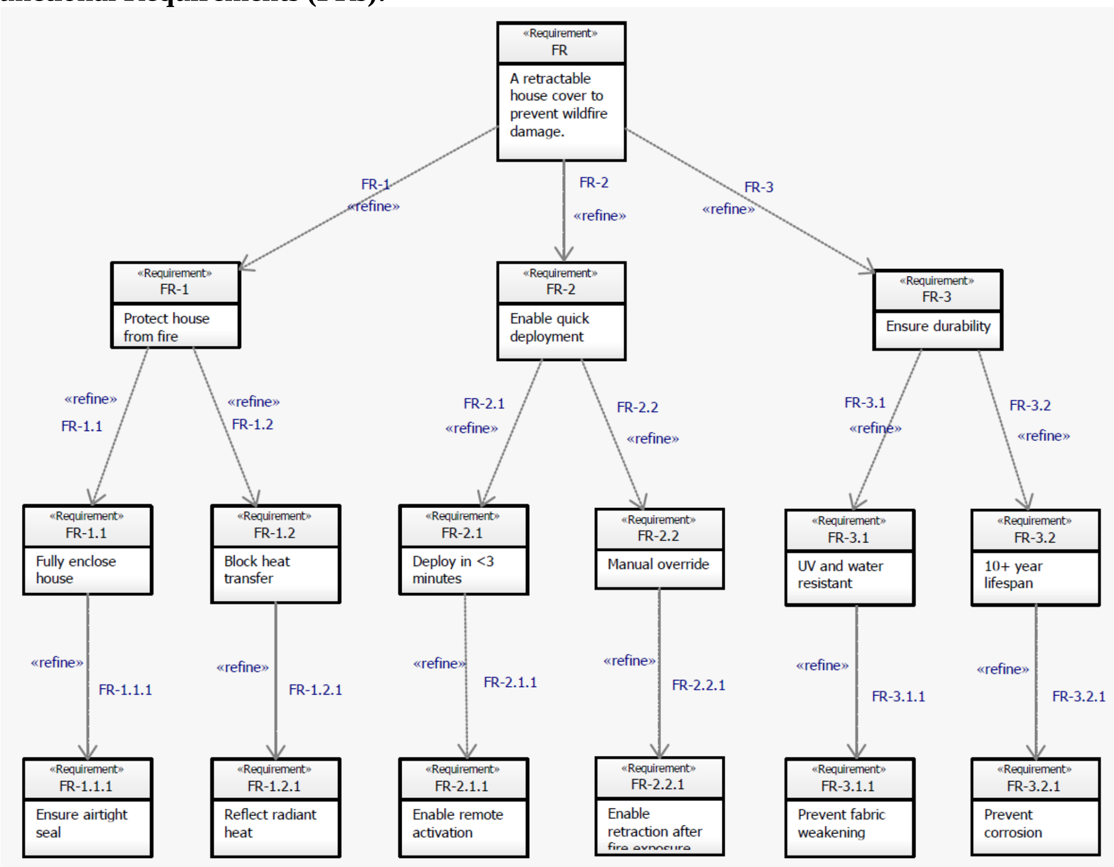

Figure 2: Functional Requirements (FR) Tree

2. **Design Parameters (DPs):**

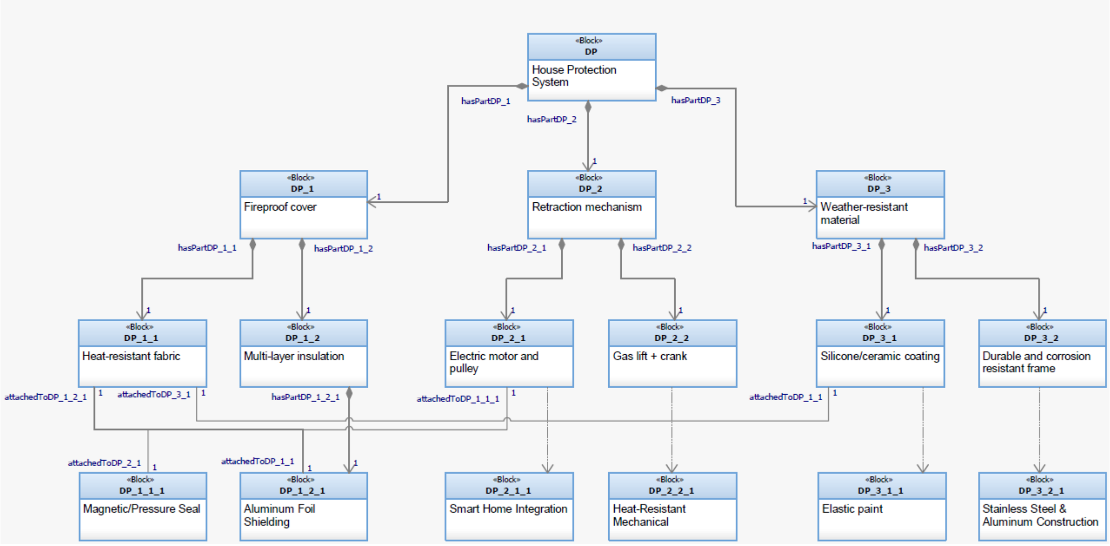

Figure 3: Design Parameters (DP) Tree

3. **FR-DP Relationships**:
"Satisfaction" relationship shown using green-colored arrows as IBM Rhapsody's default rendering comes out very cluttered.

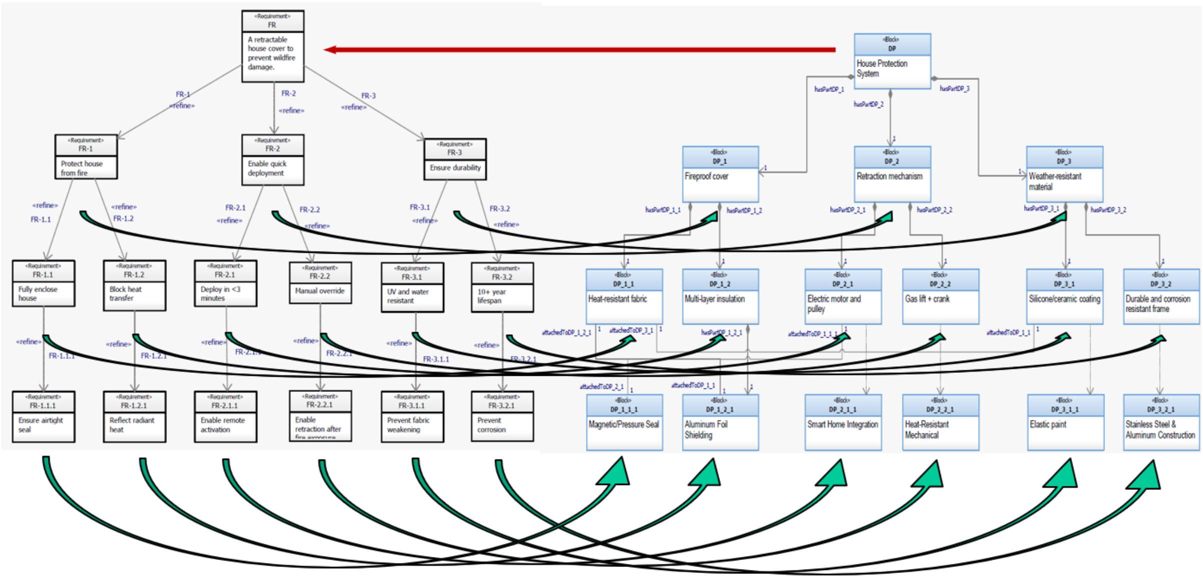

Figure 4: FR-DP Hierarchies and Reasoning Flow

Design Matrix

The **design matrix confirmed that the system is fully uncoupled**, meaning:

- **Each FR is satisfied by exactly one DP.**
- **No functional dependencies exist between FRs and DPs**, ensuring independent functionality.

1. **Design matrix output from IBM Rhapsody:**
   The selected DP satisfied the respective FR.

	DP	DP_1	DP_2	DP_3	DP_1_1	DP_1_2	DP_2_1	DP_2_2	DP_3_1	DP_3_2	DP_1_1_1	DP_1_2_1	DP_2_1_1	DP_2_2_1	DP_3_1_1	DP_3_2_1
FR	DP															
FR-1		DP_1														
FR-2			DP_2													
FR-3				DP_3												
FR-1.1					DP_1_1											
FR-1.2						DP_1_2										
FR-1.1.1											DP_1_1_1					
FR-1.2.1												DP_1_2_1				
FR-2.1							DP_2_1									
FR-2.1.1													DP_2_1_1			
FR-2.2								DP_2_2								
FR-2.2.1														DP_2_2_1		
FR-3.1									DP_3_1							
FR-3.1.1															DP_3_1_1	
FR-3.2										DP_3_2						
FR-3.2.1																DP_3_2_1

Table 1: Design matrix with all hierarchical levels

2. **Design matrix of the bottom-most hierarchy:**

	DP_1_1_1	DP_1_2_1	DP_2_1_1	DP_2_2_1	DP_3_1_1	DP_3_2_1
FR-1.1.1	☑	☐	☐	☐	☐	☐
FR-1.2.1	☐	☑	☐	☐	☐	☐
FR-2.1.1	☐	☐	☑	☐	☐	☐
FR-2.2.1	☐	☐	☐	☑	☐	☐
FR-3.1.1	☐	☐	☐	☐	☑	☐
FR-3.2.1	☐	☐	☐	☐	☐	☑

Table 2: Design matrix for bottom level hierarchy

Alternative Evaluation

1. **Morphological chart:**
   Alternative evaluation was conducted for the bottom layer DPs.

Design Parameter (DP)	**DP alternatives**	**Selected DP**
Fire-resistant material	Kevlar, Ceramic-coated fiberglass	Ceramic-coated fiberglass
Heat reflection	Graphite coating, aluminum foil layer	Aluminum foil layer
Deployment	Pneumatic cylinders, motorized pulley system	Motorized pulley system
Manual override	Hand crank, Gas-assisted lift	Gas-assisted lift

Table 3: Morphological box for alternative DPs

2. Probability Density Function (PDF) plots [Python plots using OpenAI-ChatGPT]:

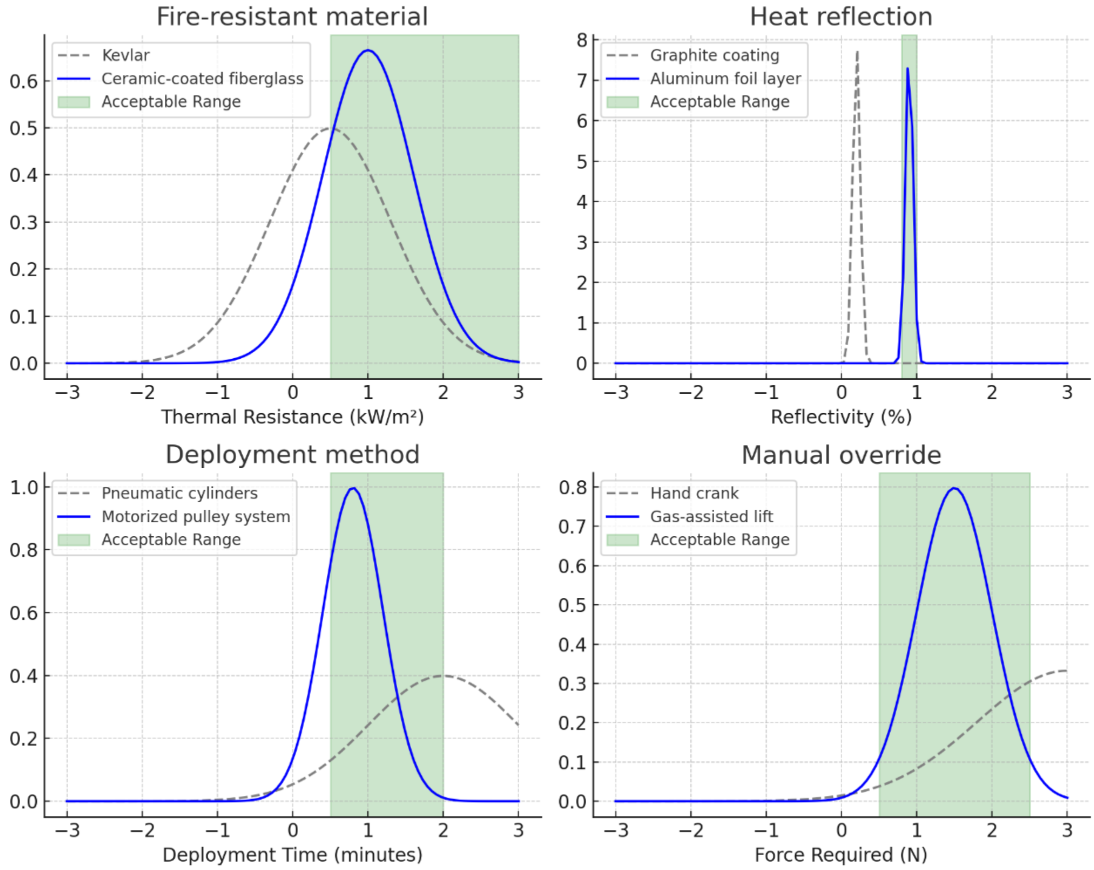

Figure 5: Probability density function (PDF) plots for alternative DPs

Final Design Concept

The **Fireproof Retractable House Cover** is a **fully automated, pre-emptive wildfire protection system** designed to **shield residential structures** from direct flame exposure, ember attack, and radiant heat. Unlike traditional **fire-resistant coatings or sprinkler systems**, this solution provides **a physical barrier** that encapsulates the house **before** wildfire exposure, ensuring **maximum safety**.

The system consists of:

1. **Fireproof Multi-Layered Cover:** Made from **ceramic-coated fiberglass with an aluminum foil layer**, offering high **thermal resistance** and **reflectivity**.
2. **Retractable Deployment Mechanism:** Uses a **motorized pulley system**, allowing **rapid deployment** over the house, with a **gas-assisted manual override** in case of power failure.
3. **Seamless Magnetic/Pressure Sealing:** Ensures an **airtight fit**, preventing **heat infiltration and ember penetration**.
4. **Smart Home Integration & AI-Based Activation:** The system integrates with **home automation networks** and wildfire monitoring data to **automatically deploy based on real-time fire risk assessment**.
5. **Weather-Resistant and Corrosion-Proof Materials:** The materials are designed for **long-term durability**, requiring **minimal maintenance**.

This design **eliminates the need for human intervention** in wildfire emergencies, providing a **fail-safe solution** for protecting homes in high-risk areas.

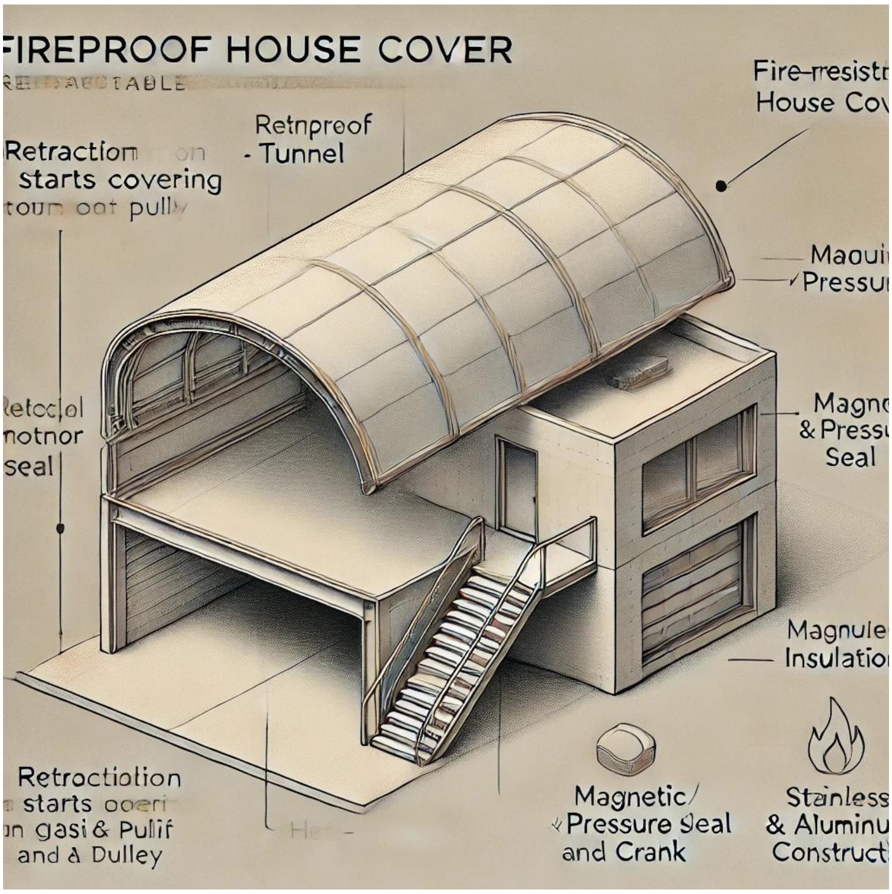

Figure 6: AI-generated representational image of the final design concept

Discussions

Observations and results

- **Uncoupled Functional Structure:**
  - The **FR-DP mapping confirms that the design is fully uncoupled**, ensuring that each **functional requirement is satisfied by a single, independent design parameter**.
  - IBM Rhapsody was used to **validate this independence** while allowing necessary **physical connections** (e.g., the **manual crank and motorized pulley system are linked but serve independent FRs**).

- **Design Feasibility & Performance Analysis:**
  - **Thermal resistance of ceramic-coated fiberglass exceeds 1000°C**, making it superior to traditional fireproof materials.
  - **Deployment speed meets the required performance criteria**, with full coverage achieved in under **3 minutes**.
  - **Manual override force reduced to 1500N** using a **gas-assisted lift**, ensuring ease of use.

Innovations in the design

This solution incorporates several **novel innovations** that set it apart from traditional fire protection methods:

1. **Pre-emptive Deployment via Smart Home Integration:**
   - The system is designed to **activate before fire exposure**, integrating **real-time sensors and automated response mechanisms**.
2. **Multi-Layered Fireproof Shielding:**
   - Unlike traditional **fire-resistant coatings**, this cover **physically blocks flames, embers, and radiant heat**, ensuring complete home encapsulation.
3. **Dual Activation Mechanism (Motorized + Manual Override):**
   - Ensures **fail-safe operation** even in **power outages**, improving reliability.
4. **Advanced MBSE-Based Design Validation:**
   - The **use of IBM Rhapsody enabled real-time dependency analysis**, confirming functional independence and **minimizing design complexity**.

Conclusions

The **Fireproof Retractable House Cover** represents a **transformative solution in wildfire protection**, integrating **proactive shielding, smart automation, and robust engineering** to ensure home safety. Unlike conventional **fireproof materials or sprinkler-based systems**, this design provides **a physical barrier that prevents fire damage entirely**.

By applying the **Innovative Design Thinking (IDT) framework** and **Model-Based Systems Engineering (MBSE) principles**, the system was **structured, validated, and optimized** to ensure **functional independence and real-world feasibility**. The **uncoupled design guarantees efficiency, reliability, and ease of manufacturing**, making this a **highly viable solution for wildfire-prone regions**.

Recommendations and future work

1. **Cost Reduction through Material Optimization:**
    - Alternative **high-performance polymer-based fireproof coatings** can be explored to **reduce costs** while maintaining thermal resistance.
2. **Modularization for Adaptability:**
    - Future iterations can incorporate **modular paneling**, allowing **customized deployments** for different house sizes and layouts.
3. **AI-Based Activation & Hazard Prediction:**
    - The system can be enhanced with **machine learning algorithms** to **predict wildfire behavior**, adjusting deployment timing accordingly.

Lessons learned and insights

1. **Hands-On Experience from SAE 547 - Model-Based Systems Engineering Course at USC:**

    - This project provided an opportunity to **apply MBSE concepts learned in SAE 547** (Prof. Mark McKelvin), specifically in **functional modeling, dependency mapping, and system validation using IBM Rhapsody**.
    - The integration of **Axiomatic Design Principles** and **automated FR-DP mapping** allowed for a **structured and traceable design process**.

2. **Functional Independence in Product Design:**

    - Ensuring that **each FR is satisfied by exactly one DP** simplifies manufacturing and **reduces complexity**, leading to a **more robust and reliable design**.

3. **Practical Application of Kano Model from ISE 445 - Principles and Practices for Global Innovation:**
    - The project also allowed **hands-on application of the Kano Model**; a concept initially studied in **ISE 445** (Prof. Stephen Lu).
    - Unlike previous theoretical applications, this project required **real-world customer need classification**, ensuring that **basic, performance, and excitement features were appropriately prioritized** for optimal product adoption.