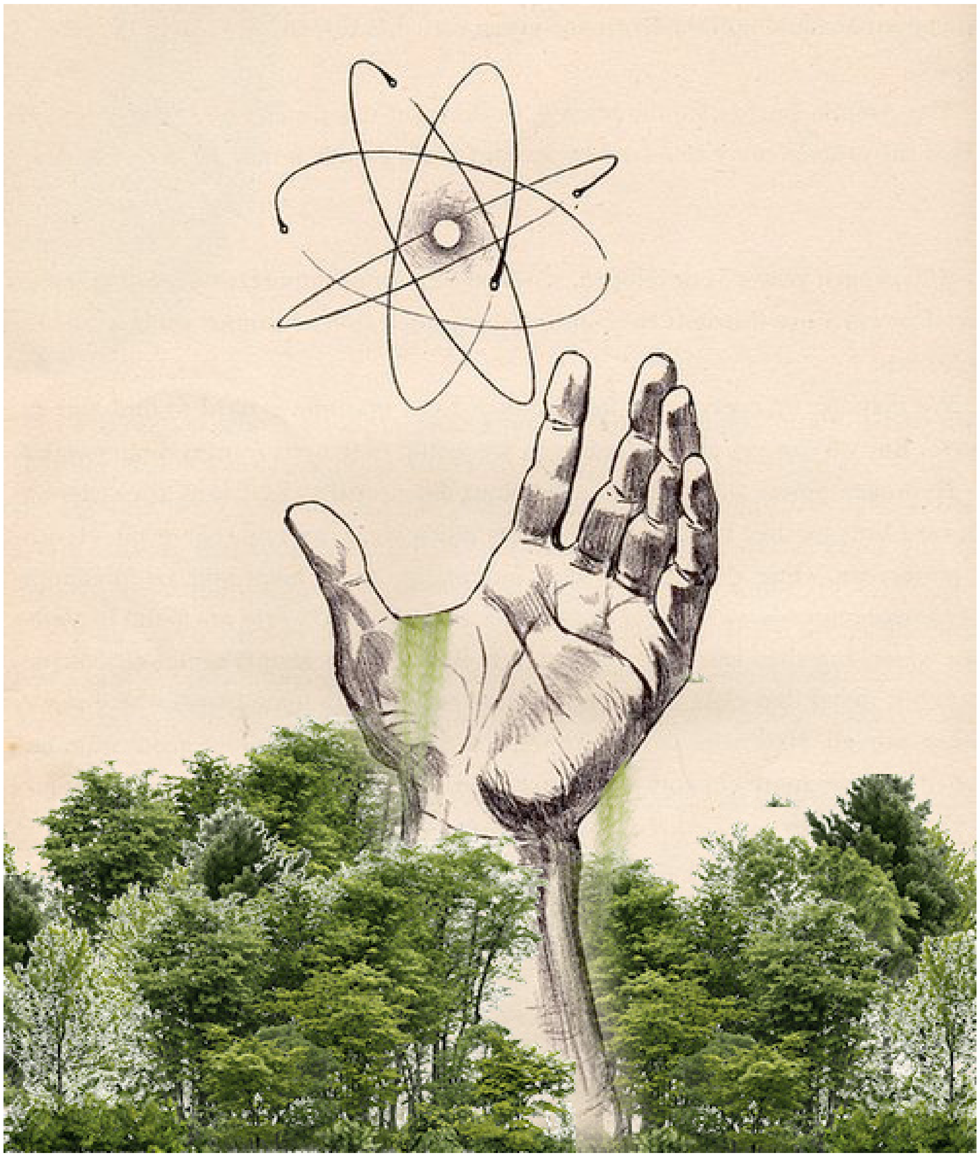

Figure 1 | Our Friend the Atom

RE-IMAGINING THE NUCLEAR POWER INDUSTRY THROUGH INNOVATION, ARCHITECTURE, AND EDUCATION FOR A MORE SUSTAINABLE DYNAMIC BETWEEN THE BUILT AND NATURAL ENVIRONMENT

RE-IMAGINING THE NUCLEAR POWER INDUSTRY THROUGH INNOVATION, ARCHITECTURE, AND ED-UCATION FOR A MORE SUSTAINABLE DYNAMIC BETWEEN THE BUILT AND NATURAL ENVIRONMENT

A Design Thesis Submitted to the
Department of Architecture and Landscape Architecture
of North Dakota State University

By

Luke Hoberg

In Partial Fulfillment of the Requirements
for the Degree of
Master of Architecture

Ronald Ramsey
Primary Thesis Advisor

Stephen Wischer
Thesis Committee Chair

Spring 2023
Fargo, North Dakota

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Abstract

The natural world is being destroyed and needs to be protected. To do that we need low polluting and efficient forms of energy production. The fossil fuel industry is one of the main sources of harmful pollutants that are damaging our environment and contributing to multiple health, social, and environmental crises. The need to transition to clean reliable energy has never been greater. Nuclear power is the only method that has comparable, if not less, carbon emissions rates than green energy and is able to be sited in a variety of geographies and climates. After decades of innovation the latest Gen IV nuclear reactors are safer and more efficient. One reactor that is in development by General Electric is a sodium-cooled fast reactor called PRISM. These fast reactors convert unusable isotopes into more fuel during the fission process. Fast reactors can reuse spent fuel from older Gen II and III reactors that are currently in operation. This reduces the radioactivity lifespan of the fuel from thousands of years to hundreds. This thesis proposes a contemporary plant design with fast reactor technology to recycle spent fuel while generating electricity and lowering the fuel's radioactivity lifespan. Recycled fuel will then be stored in an underground repository until its radioactive lifespan has ended. This facility will clean up current high level spent fuel waste sites, reduce utilization of polluting fossil fuels, and educate the public through the incorporation of a visitor center where people can learn about the process and safety features in hopes that through education and architecture the public can accept and support the widespread adoption

Figure 02 |
Commercial Nuclear Reactor
Muehleberg, Switzerland

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NARRATIVE OF THE THEORETICAL ASPECT OF THE THESIS

Nuclear power being one of the most efficient and low polluting forms of energy production has been underutilized due to significant disasters in the past. Most of which were due to human error and could have easily been prevented. Now with significant advancements in nuclear technology and safety, people are still weary to implement this form of power production.

Instead people and countries choose to put their faith in green energy. There are still some limiting factors when trying to implement these energy production methods. They are often limited to certain climates and geographies. There have also been issues with recycling materials. However, green energy's issues are shadowed when compared to a coal power plant that produces 7 million tonnes of carbon dioxide along with 200,000 in other particulate matter.

A 1,000 megawatt producing nuclear plant only produces approximately 3 cubic meters of high level waste (high level waste refers to spent fuel which can be stored until it is able to be recycled, used as fuel in certain types of reactors, or disposed of).

There are many variables that are compared between the different ways of energy production like initial carbon footprint, yearly waste, or land area needed. However, on almost every one of these variables nuclear power proves to be the most efficient choice when viewed holistically. It is only due to a populace that is unaware of the new advances of safety and waste management that inhibit the use of this technology. It is also one of the few energy production methods that can be sited almost anywhere.

Nuclear power is the only solution to fight high global carbon emissions and overall pollution while still allowing current energy usage.

In order to enact this solution it must first gain public favor. Historically this only happens when people become knowledgeable in said subject or its image which brings an array of stigmas to mind is changed. To do both will result in a much higher chance of acceptance by current, past, and future generations.

Figure 03 |
Oil Rig Fire

This will be the goal. Re-imagining the appearance of a nuclear power plant and the programs held within. If successful, this will ultimately result in the slow acceptance of an old solution that will guarantee future success.

TYPOLOGY

Design project will be focused on two typologies. The first being a nuclear power plant and the other a exhibition center. Historically power plants are known to be very utilitarian in design. As of now they have served one purpose. Generate energy and distribute it to our homes and businesses. They are also our homes and businesses. They are also extremely complicated when analyzing through the lens of the various engineering disciplines. Due to the energy sources being extremely volatile they require many redundancies in place in the event of a system failure. They also tend to be located on the outskirts of cities or remote areas. Overall, they are a background structure not designed to be aesthetically pleasing but fulfill its purpose of generating power.

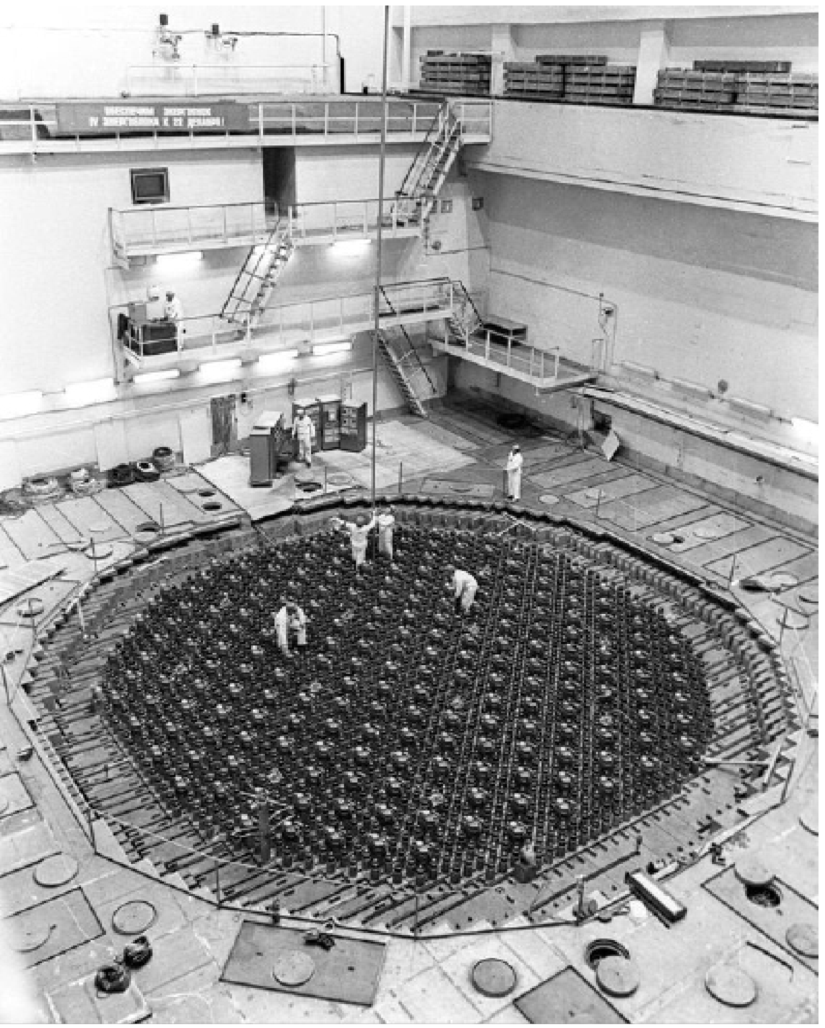
Exhibition centers' purpose is to provide a teaching experience that will inform and captivate their audience. It should be a comfortable experience that allows user experience. Historically, this was not common practice. These centers tended to be very informal with an emphasis on the amount of data that could be housed within an area. Modern exhibition and learning centers focus on interaction between the exhibit and the audience. Research has shown that if more senses are engaged rather than sight alone the more interested your user will be. This tends to lead to a higher level of retention for the user.

There are multiple case studies listed below that will be excellent for researching and learning about each individual typology and the industrial learning center combination.

- Tillamook Creamery
- Sherco Power plant
- Iowa State University Power plant
- Hoover Dam Plant Visitor Center
- Smithsonian
- The National Art Center, Tokyo
- 9/11 Memorial and Museum

Project Justification

Figure 04 |
Chernobyl Core



The natural environment is a beautiful thing that has taken a backseat for global and personal financial growth. The natural world has been grossly taken advantage of and now with tremendous damage done there are few options to correct the mistakes made. The most prevalent mistake being made throughout the world is the use of fossil fuels that pollute the air, water, and land. Whether it be the constant stream of waste that is produced from energy production or the many man made disasters while trying to allocate and distribute these fuels. It has resulted in severe pollution of our environment. This has not only affected the health of the wildlife but humanities as well. The need for a low polluting, high efficiency form of energy is needed. Nuclear is that form, but it is shrouded in stigmas and fear.

By designing a nuclear power plant that incorporates newly discovered safety advancements and re-imagines the appearance and programs of a power plant facility it could help foster the acceptance of nuclear power. In turn creating a more sustainable dynamic between the built and natural environment.

This project will hold many challenges. Nuclear power plants and power plants overall are a difficult category of structures to make aesthetically pleasing while ensuring they are functionally practical. Additionally, there are many other problems that face nuclear energy. Being a target for foreign and domestic attacks is unfortunately a very real possibility. Creating a visitor/learning center within a nuclear plant that will allow members of the public to visit will need a high level of thought on separation and security of the two entities. There are many safety factors that will need to be addressed. The drastic difference of thought processes needed to design each typology will also be a challenge. Trying to combine these two and having a successful solution will be even more demanding of the designer. As a final project it will need the culmination of skills learned during my years here at North Dakota State University.

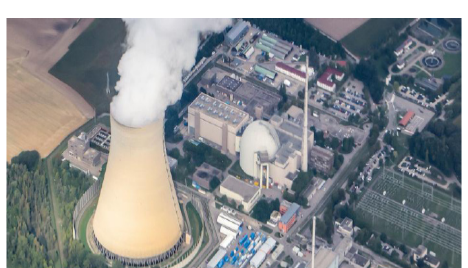


Figure 05 |
German Nuclear Reactor

Project Emphasis

- 1. Incorporating nuclear energy production safety advancements.

As earlier discussed, there have been many new advancements in the nuclear field regarding safety. Utilizing these to create a state-of-the-art facility will be crucial in ensuring the safety of the surrounding population.

- 2. Redefining what a nuclear power plant can be to change public opinion.

Power plants have always served one purpose. To produce energy. Integrating multiple types of programs including a visitor's center and designing an aesthetically pleasing design will be key for popular approval.

- 3. Use of sustainable building methods and materials.

The overall goal is to make a sustainable coexistence with the natural world through the medium of energy production. To use methods and materials for the design that would contradict that goal would be counterproductive and hypocritical.

Figure 06 |
Wind Farm and Nuclear Power

Major Project Elements

Overview

Many of these elements will be intertwined so the people visiting the learning/visitor's center will be able to view most of the energy producing processes. The visitor center will also house more than just an exhibit on nuclear power. I aim for this structure to become a part of the local community that people can hold events and be comfortable being at.

Power Plant

Large
- Containment Building
- Turbine Building
- Cooling Equipment

Medium
- Office
- Parking

Small
- Employee Break room

Visitor Center

Large
- Exhibit area
- Outdoor Garden/Park
- Event Area

Medium
- Parking
- Food court

Small
- Gift Shop

Figure 07 |
Reactor
United States

Project Goals

- Investigate nuclear reactor types and choose the safest and most efficient latest generation reactor for my facility.
- Implement a waste management system for my nuclear power plant along with the surrounding plants.
- Improve my knowledge in architectural design processes that implement programs that historically haven't been included in power production typologies.
- Create a contemporary nuclear plant design that differs from the usual utilitarian designs seen throughout history that will attract visitors.
- Re-brand the nuclear power industry through architecture and education.
- Create spaces for the local community to gather and hold events to have a harmonious relationship with nearby communities.
- Educate people on the benefits and safety of nuclear power.
- Improve my own understanding of nuclear power and the processes it takes in creating it.
- I hope to enforce my growing skills as a designer along with my abilities in various production programs.

User/Client Description

Power Plant Workers | Peak Times: 24/7 (constant number) | 110 daily workers

- These will be the plant operators and will ensure the safe production of nuclear energy. Some will commute to and from work and others will live at the plant as some nuclear plants have monthly periodic shifts.

Public Visitors | Peak times: 11:00am-:700pm | 160-210 daily users

- Visitors to the plant will come from all over the country. Just as some people drive to see natural wonders or historical events. Here they will learn about the nuclear process or hold events in various areas.

Thesis Question

"How can we implement more environmentally sustainable energy production methods to replace fossil fuel dependency that have lower emission rates and overall pollution?"

PLANS FOR PROCEEDING

Research Direction

Research will start with the study of nuclear reactors and their various components. How they relate to one another and what systems need to be within proximity to one another to create a practical and functional design. Compiling a document on various energy production methods with their advantages and disadvantages will also be a subject of research. Lastly, design on creating a successful exhibition will be another large subject in which I research.

Design Methodology Plan

Conducting a site visit and researching site variables using historical data will provide a good understanding of the limitations the site will have. Then using mass models and 3D modeling programs I will be able to coarsely place major elements of the project and compare to site variables like wind, sun, circulation, etc. I will then refine my placements through analyzing relationships between site factors and research done prior.

Documentation of Design Process

Documentation will ultimately be performed digitally. Hand sketches and physical models will be properly documented using photography or videography. Any progress reports or Advisor design advice that affects the project will be noted in a journal that will keep a record of the project at time moves on. Any digital design process will be saved to a hard drive as well as the cloud.

Schedule

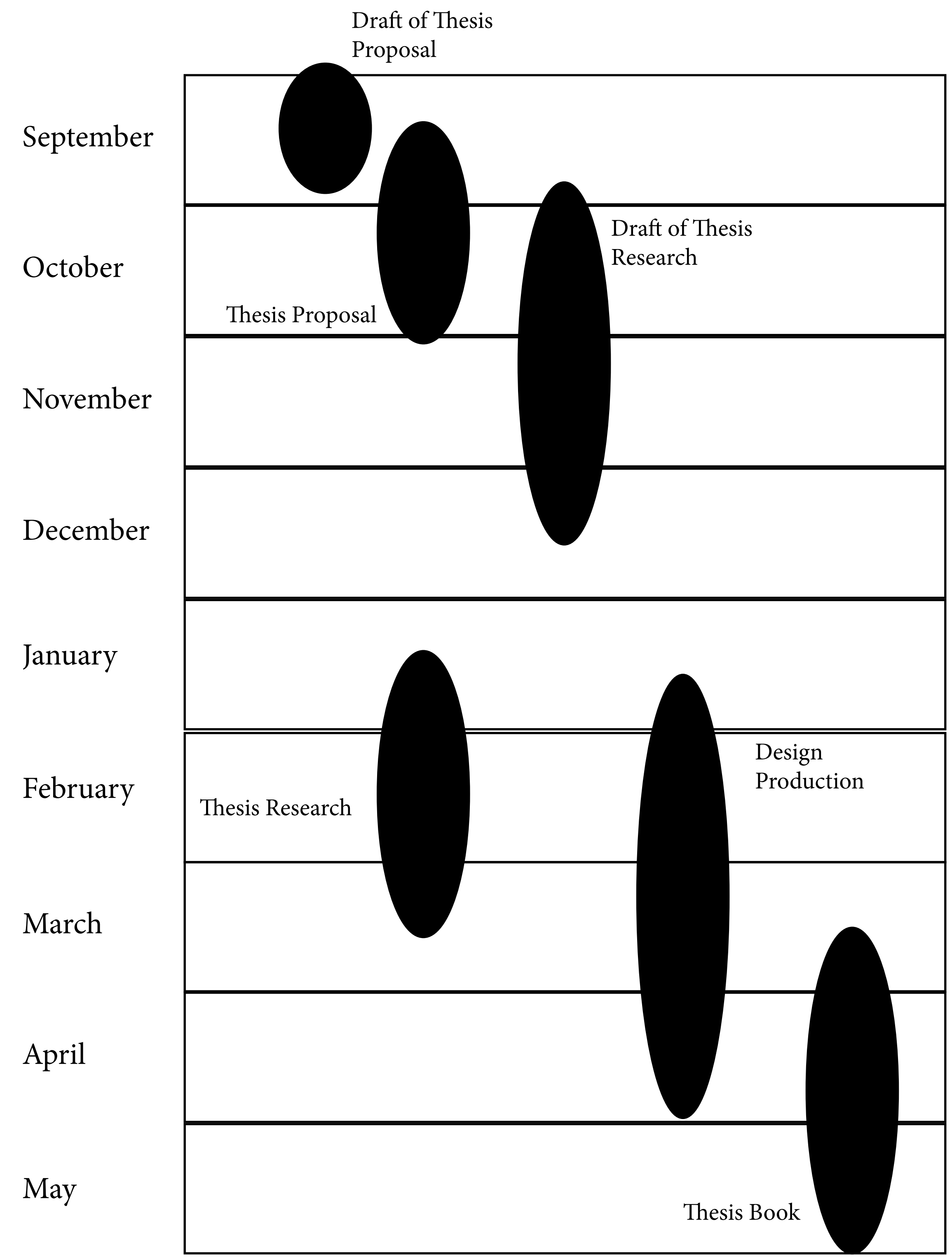


Figure 08 | Thesis Schedule

CASE STUDIES

Tillamook Creamery

Figure 09 |
Tillamook Creamery Exterior

Typology: Factory & Visitor Center
Location: Tillamook, Oregon
Designer: Olson Kundig Architects
Year: 2018

Summary

The Tillamook Creamery produces many dairy products that are shipped all over the world. With wide known brand recognition there were many people that visited their previous visitor center. As the brand grew so did the number of visitors.

Built in 2018, the new visitor center provides an interactive experience from the moment you step on site. The visitor learns through many interactive displays the process of making their dairy products and the history of their company. Once you've completed the self-guided tour that allows the visitor to look and watch the factory floor, they are met with a sampling station. To taste some of the same products that they just witnessed being made. Once the visitor gets their fill at the taste testing area there is a gift shop, food court, and outdoor lawn to relax and enjoy the rest of the visit.

Figure 10 |
Tillamook Creamery Interior

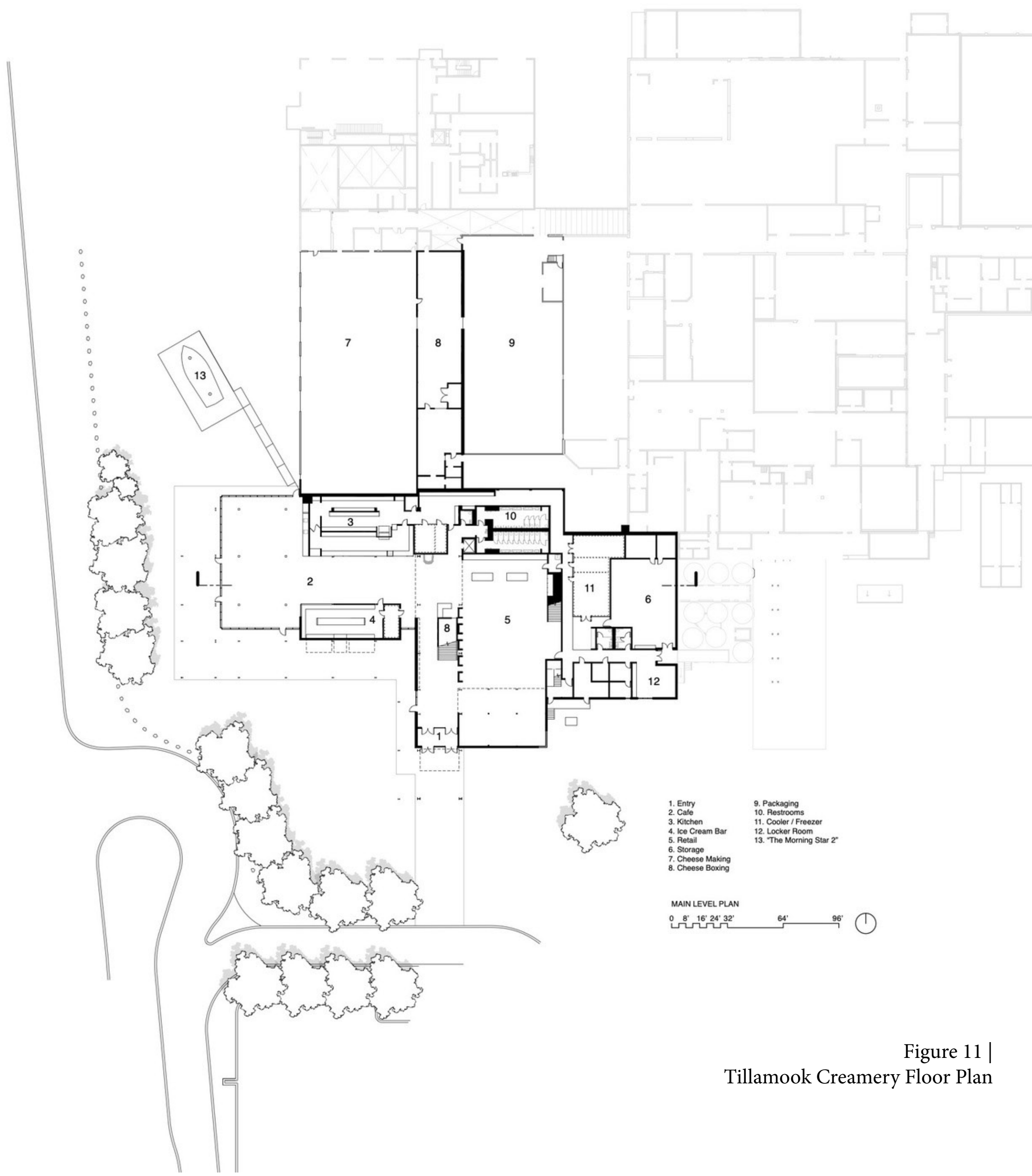


Figure 11 |
Tillamook Creamery Floor Plan

Case Study Takeaway

Figure 12 |
Tillamook Creamery Food Court

The best part of this design was how they were able to seamlessly integrate the visitor center with the factory. Allowing the visitor to go on a self-guided tour at their own pace. Another large aspect that made this design successful was allowing views of the factory floor. Being able to see the cleanliness, professionalism, and technology that are making these products leaves the visitor with a lasting impression that the products being made are produced with care. This develops trust in Tillamook's products. This way of integrating two different typologies will be used in my final design. With nuclear energy having stigmas of being dangerous and volatile I hope to use these design principles to develop trust. Lastly, having fun things like gift shops, food courts, and spaces to relax will be helpful in developing good experiences and memories with the people visiting the nuclear power plant. By doing this people will soon relate safety, fun, and enjoyment with my nuclear power plant.

Figure 13 |
Hoover Dam

Hoover Dam
Visitor Center

Typology: Dam & Visitor Center
Location: Clark County, Nevada
Designer: Henry J. Kaiser, Gordon Kaufmann
Year: 1936

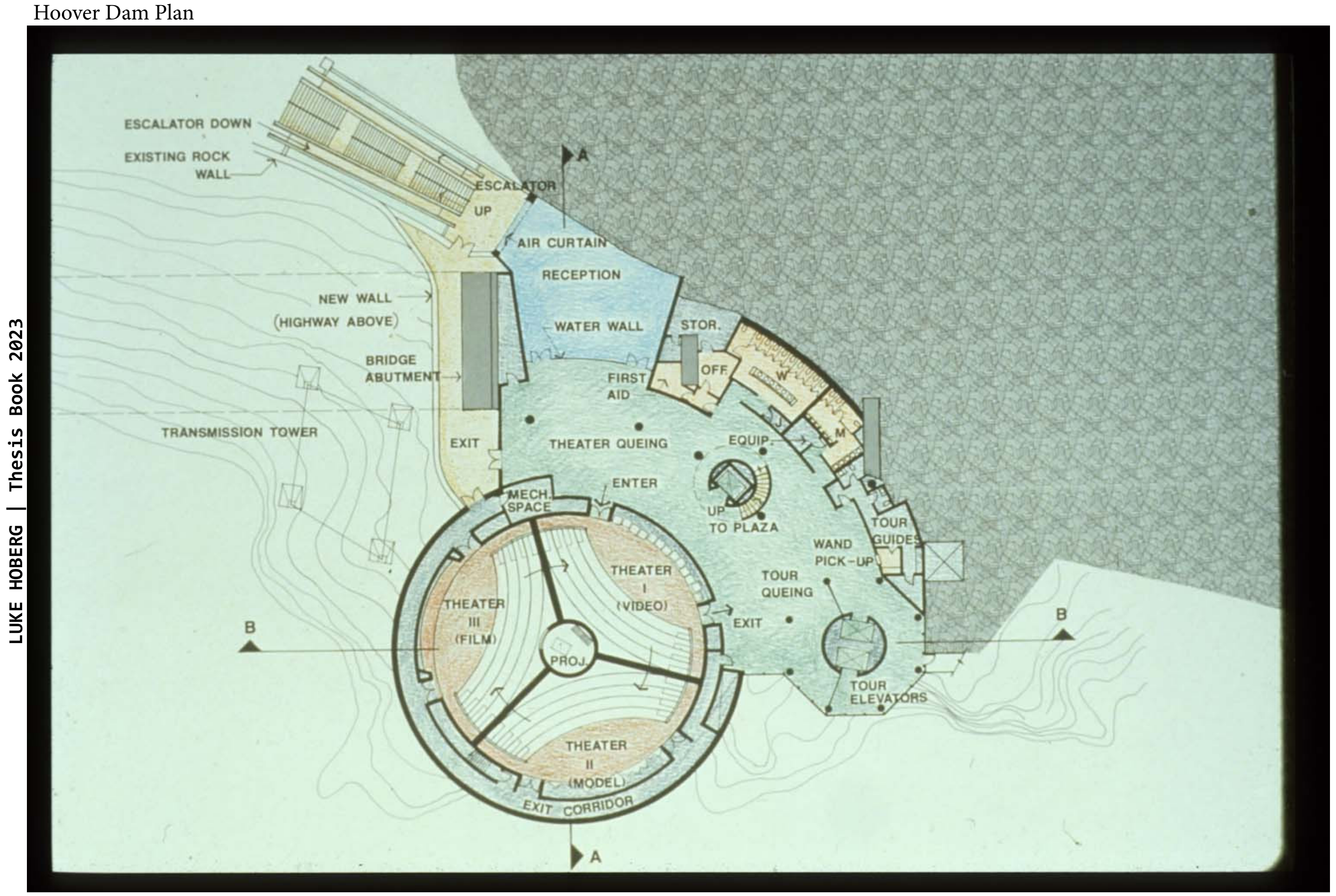
Summary

The Hoover Dam Visitor Center has many exhibits that tell the story of how Hoover Dam was built and the challenges it endured. Showcasing the history and how the dam operates it is an educational experience. In the visitor center they also have theaters where educational videos are show. They allow tours, but only by offical tour guides through the facility.

Figure 14 |
Hoover Dam Turbines

Figure 15 |
Hoover Dam Exhibits

Figure 16 |
Hoover Dam Plan



Case Study Takeaway

This visitor center has a heavy emphasis on education. With three theaters, exhibits, and official tours they strive to give a very formal and educational experience. With this being a complex typology and a very large facility there is a lot of material to cover for the short time the visitor will be there. The use of easy to understand film, exhibits and other forms of educational material will be a must if you wish to have your visitor leave feeling like they have a decent understanding of the facility and how it works. With my power plant also having complex technology using many mediums to accommodate every type of learner will be important.

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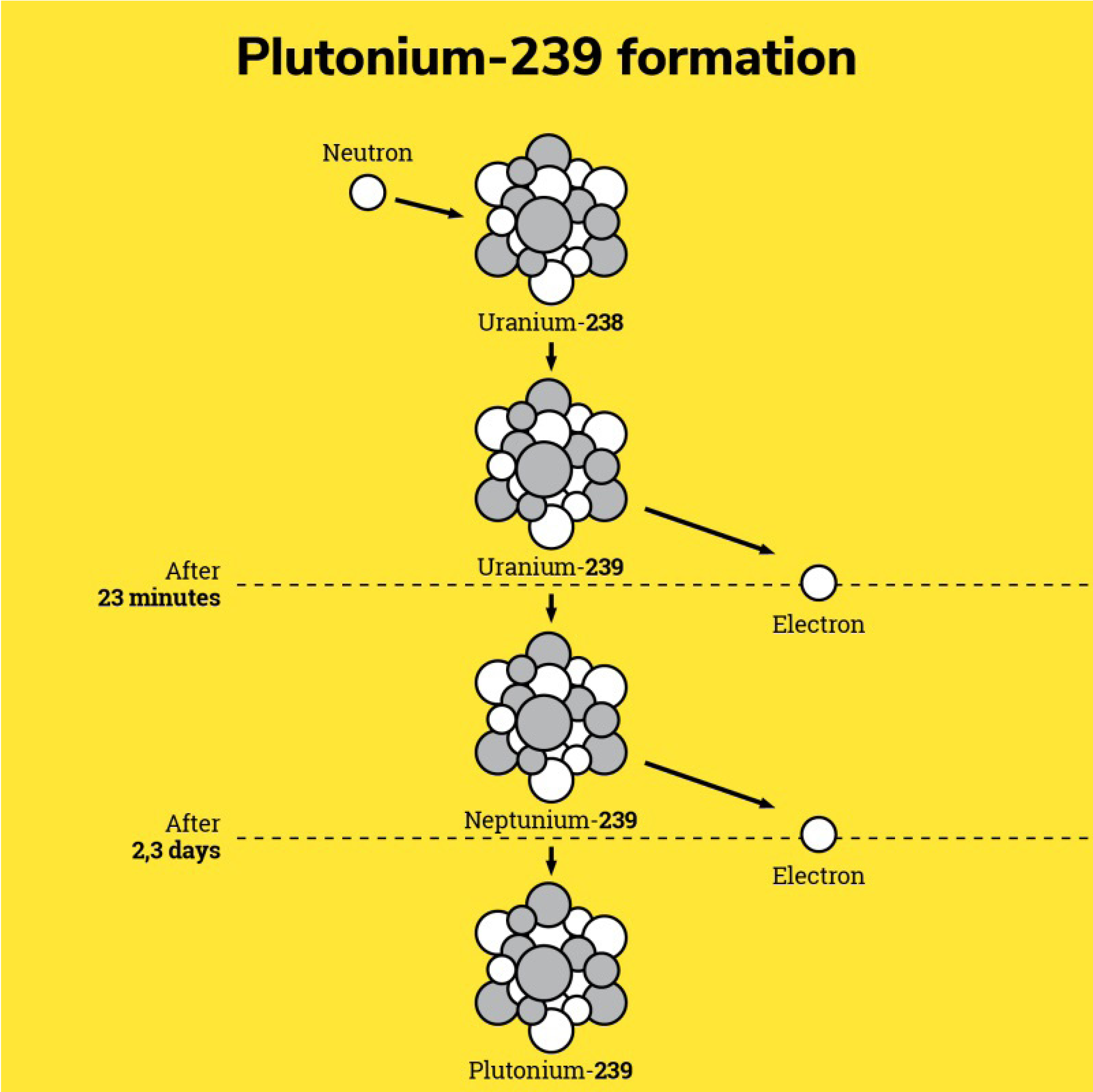
Research

Figure 17 |
Plutonium-239 Formation



Fast-neutron Reactors

These reactors able to "unlock" more energy from the uranium fuel. These reactors differ than the current reactors in operation today which are only able to use approximately 10% of the stored energy in uranium fuel.

How it Works

Uranium fuel consists of approximately of 99.3% 238u and 0.7% 235U. U238 is only able to undergo fission by absorbing neutrons with high kinetic energy(fast neutron). 235U can undergo fission by fast and slow neutrons. A fast reactor utilizes fast neutrons by having U238 capture a fast neutron and through a decaying process convert into plutonium 239. This reaction becomes self-sustaining allowing the reactor to use the plutonium-239 as fuel and create more neutrons to sustain the chain reaction. Through this process fast reactors can use the uranium fuel much more effectively and use spent fuel from other reactors. Which also lowers the fuel radioactivity from thousands of years to hundreds.

Proven Technology: Experimental Breeder Reactor(EBR) 1&2

EBR 1 and 2 were research reactors that were made to test the theory of fast reactor technology. EBR 1 confirmed the hypothesis and EBR 2 was built to demonstrate reprocessing spent fuel from conventional reactors and utilizing it as fuel for itself. It ran from 1965 to 1994 until it was decommissioned.

Figure 18 |
EBR II

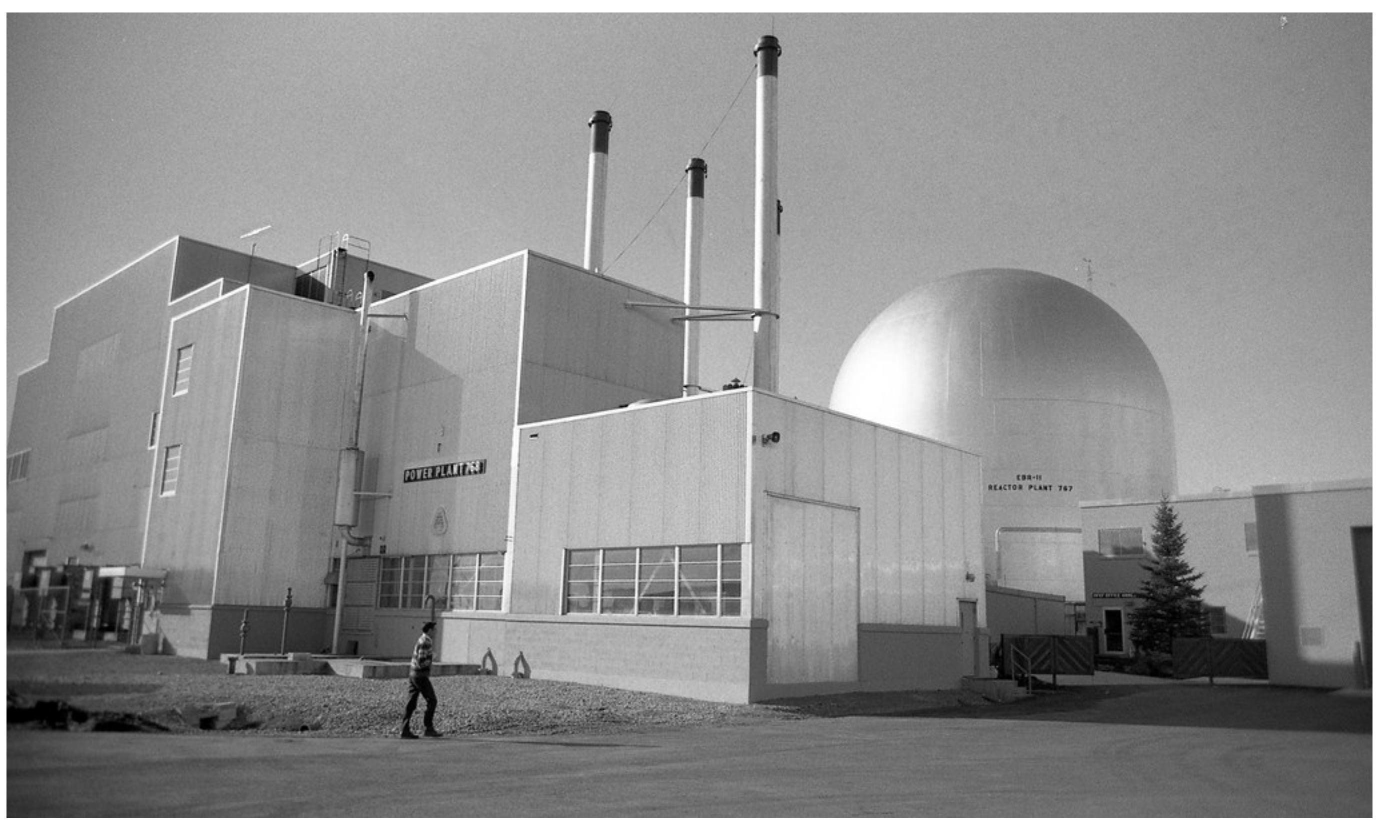


Figure 19 |
EBR I Reactor

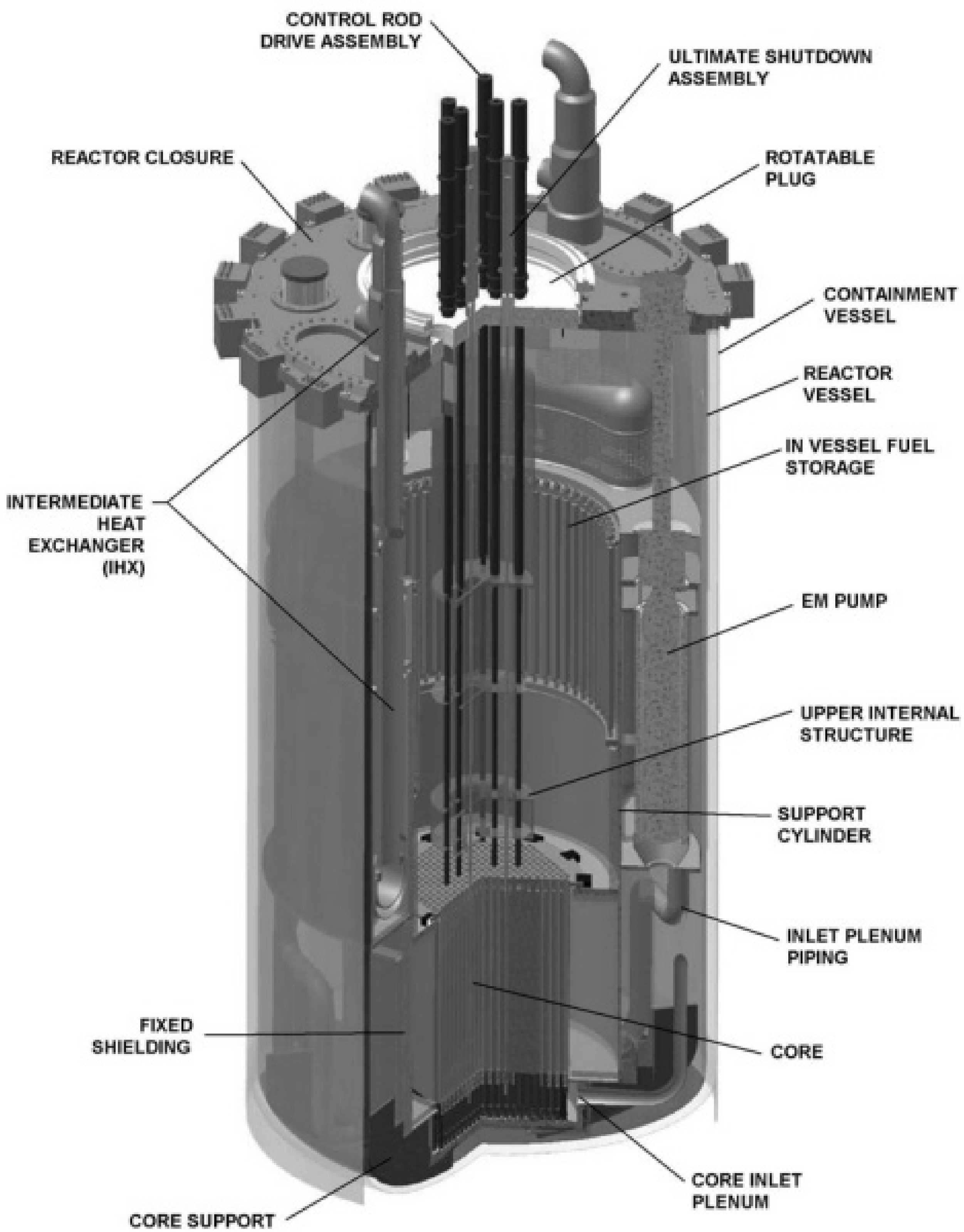


Fig. 3. PRISM reactor module.

Figure 20 |
PRISM Reactor

Gen IV Fast Reactor in Development

GE's PRISM reactor is currently in development and has received funding from the DOE. It is one of the multiple Gen. IV prototype reactors that are receiving funding to be commercialized with the next decade. This is the reactor that I have implemented in my design. This reactor will allow to eat up current stockpiles of high level waste also known as spent fuel

The PRISM reactor uses molten sodium as a coolant. This allows for the reactor to operate at higher temperatures and at lower pressures. Negating the possibility of an explosion scenario like Fukushima. If temperatures rise too high the core will expand which decreases its density slowing the fission reaction. The molten sodium dissipates this heat very efficiently and stops the core from a meltdown. There have also been many technological advancements in digital automation that reduces the chance of human mishaps. With external threats in mind the reactor is designed to site below ground as well.

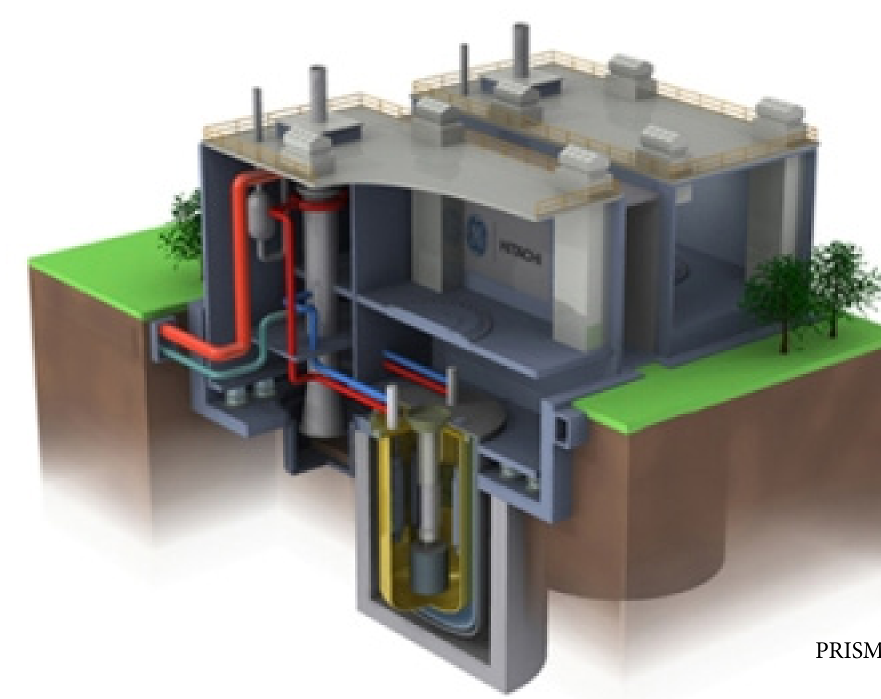


Figure 21 |
PRISM Reactor Render

Figure 22 |
Nuclear Waste Canister

Geological Repository

A nuclear repository is an underground storage area to stockpile spent fuel also known as high-level radioactive waste. Once spent fuel from current stockpiles has been reused in the fast reactor the waste will be stored in an underground repository to live out its remaining radioactive lifespan.

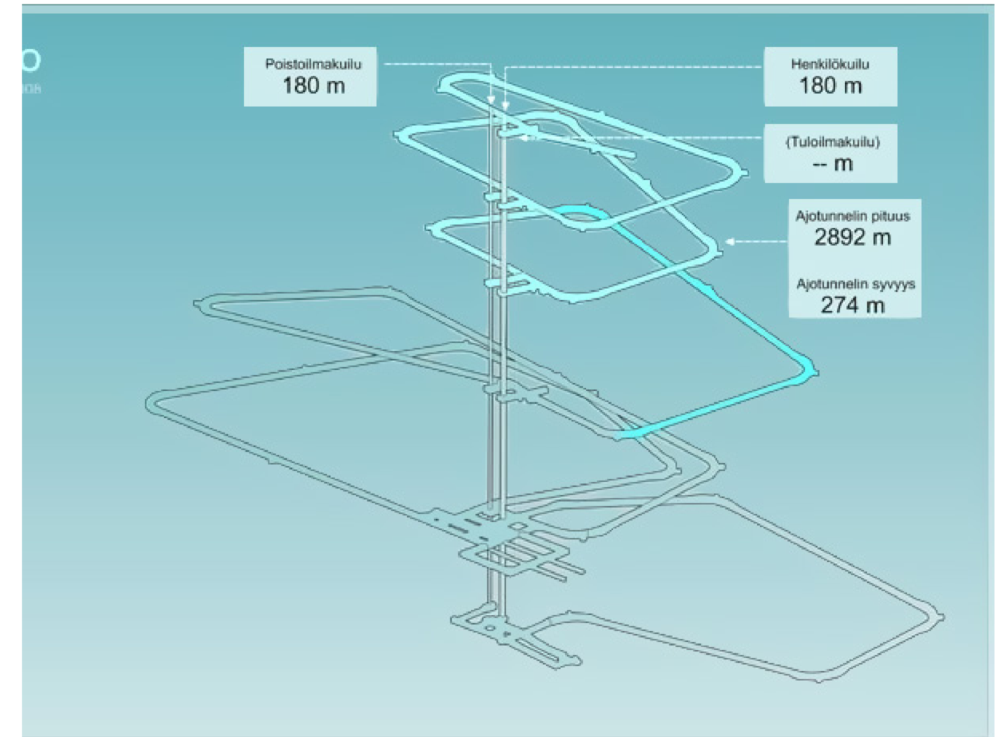


Figure 23 |
Onkalo Repository

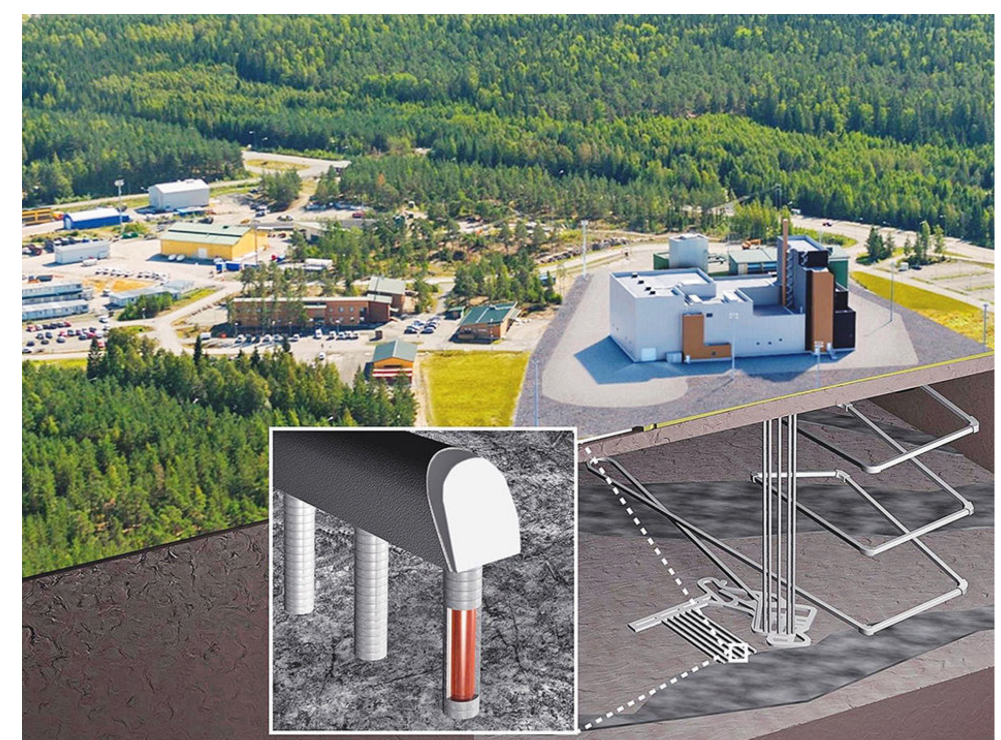


Figure 24 |
Onkalo Repository Section

Site

Site Selection

There were many factor that went into choosing my site for a nuclear power plant. Firstly, since my facility will be using fast reactors which can use spent fuel from other reactors, I want to be in close proximity to current reactors in operation and spent fuel stockpiles. Next I want to avoid any high seismic zones. Lastly, for my underground repository I wanted granite outcrops for their strength and sealing capabilities that would be able to securely hold the reused fuel. This lead me to the North-Eastern part of the United states.

Figure 25 |
Granite Outcrops Map

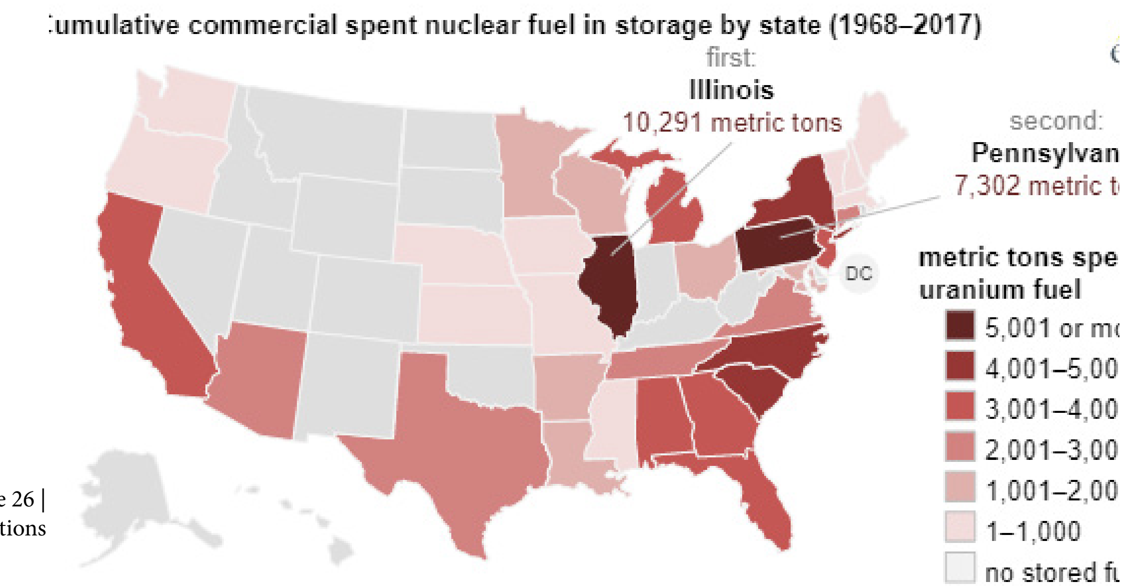


Figure 26 |
Spent Fuel Locations

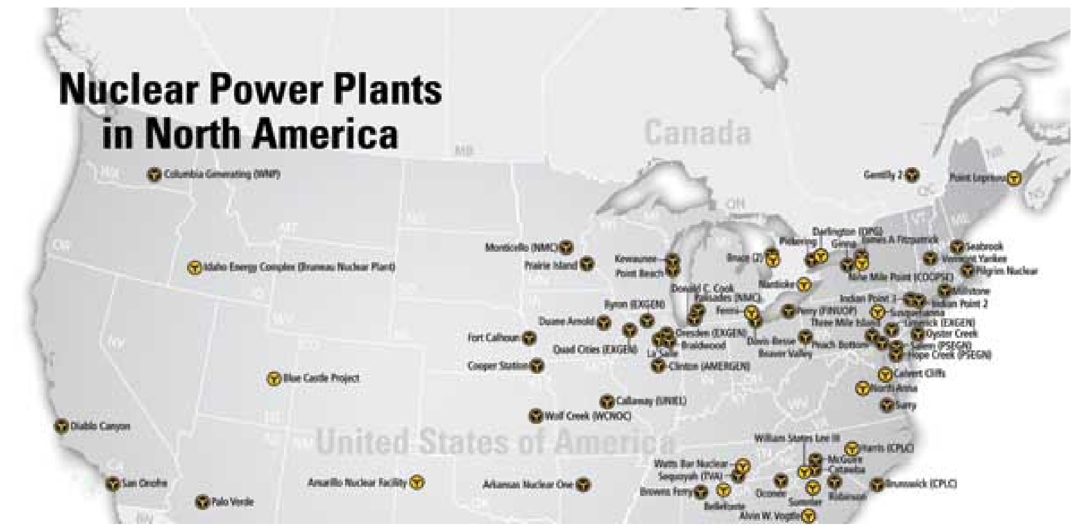


Figure 27 |
Active Nuclear Plants

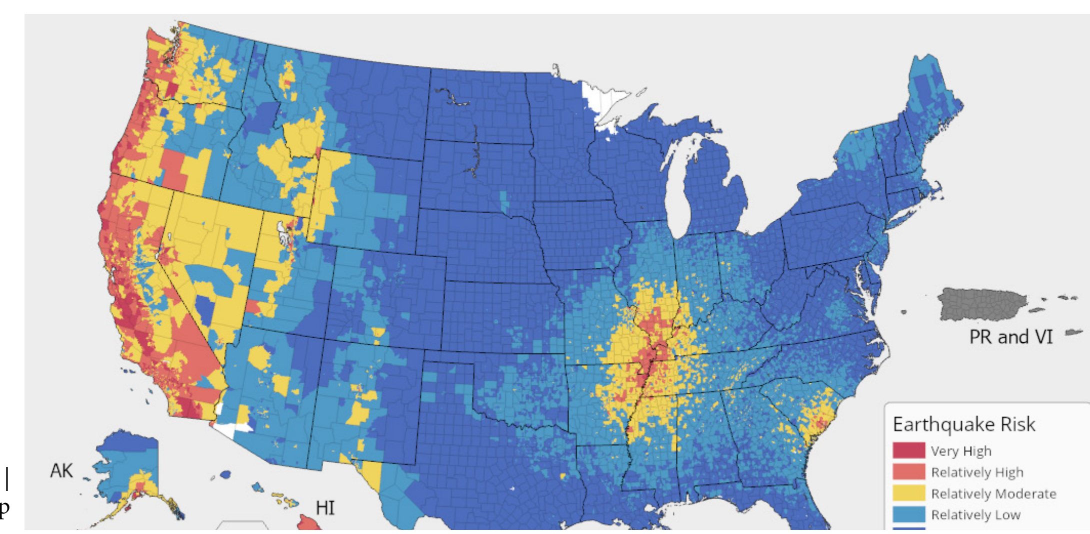


Figure 28 |
Earthquake Risk Map

Site Selection

To further narrow my site selection, I wanted my facility to be near large traffic flow to increase accessibility to the visitor center for as many people as possible in the hopes to educate and fight the stigma behind nuclear power.
Staying near to I-95 and trying to stay in a population "lul" lead me to a location along the base of the Susquehanna River North West of the small town of Havre De Grace.

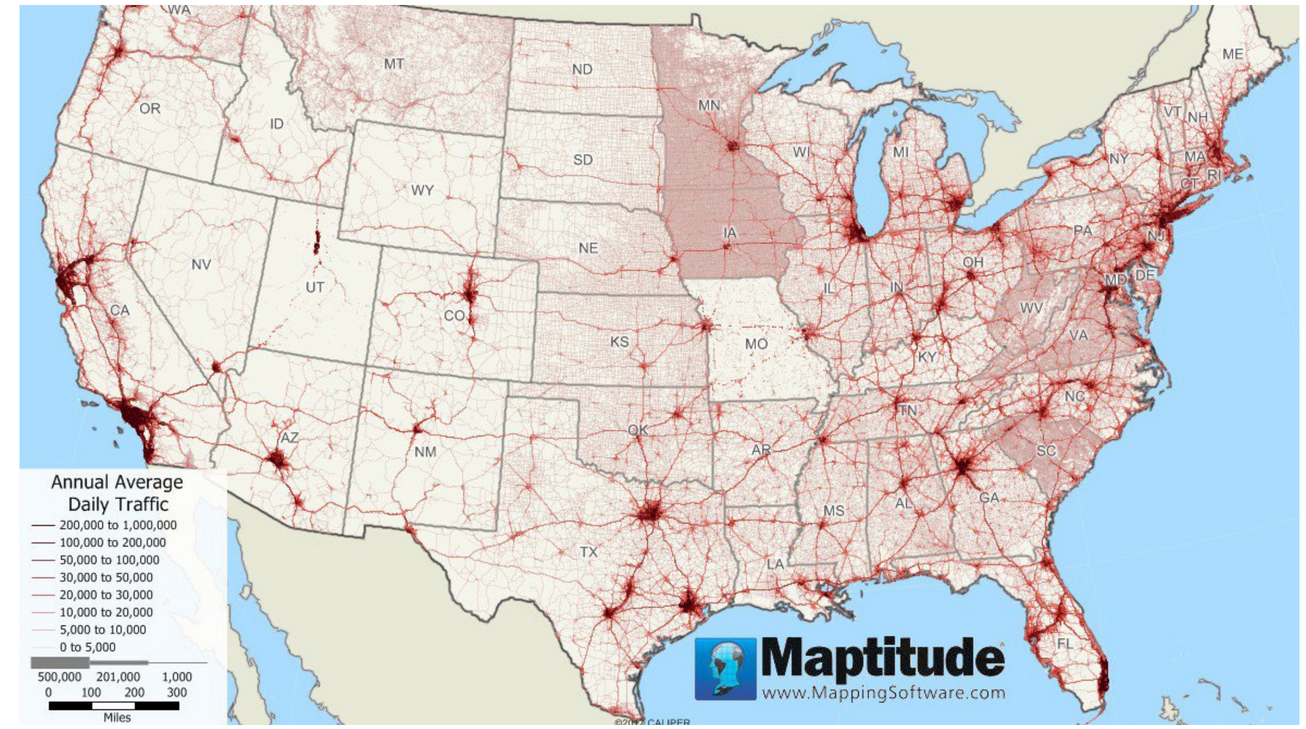


Figure 29 |
Average Traffic Map

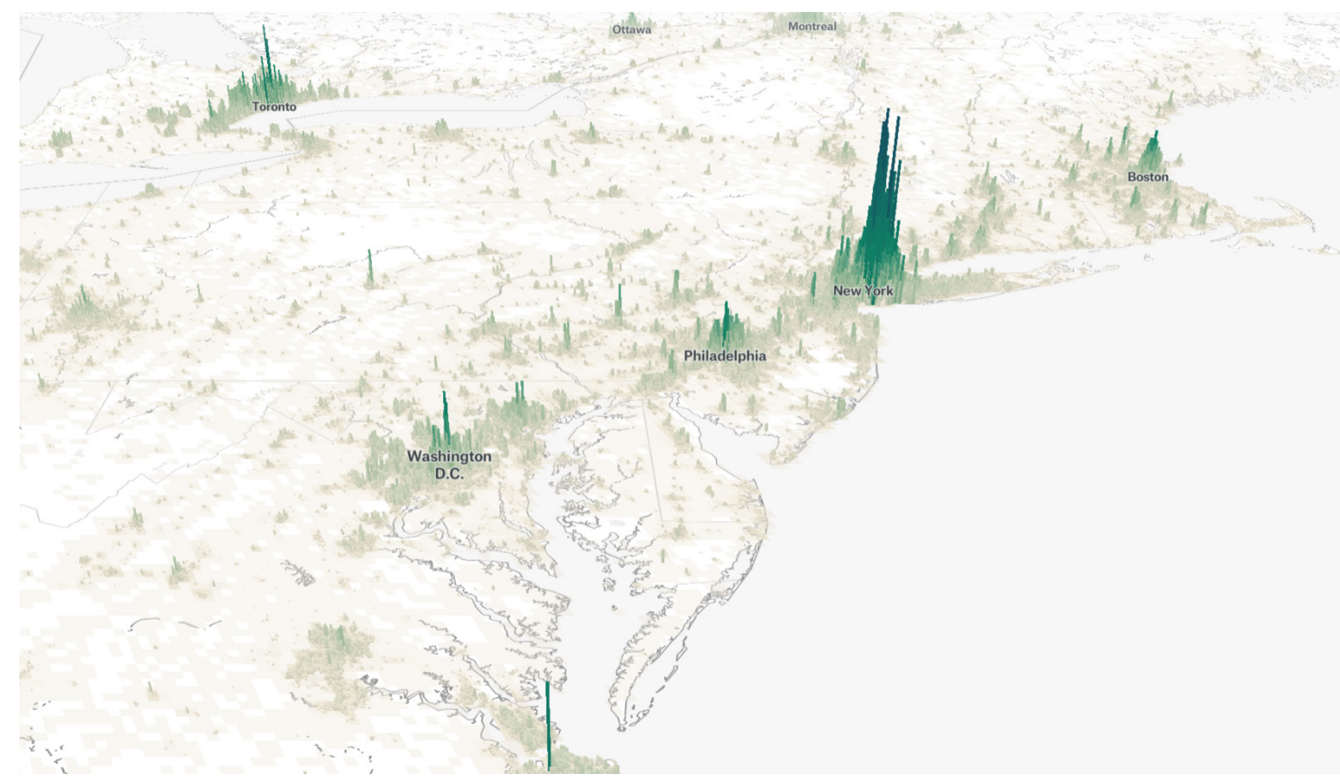


Figure 30 |
Population Density Map

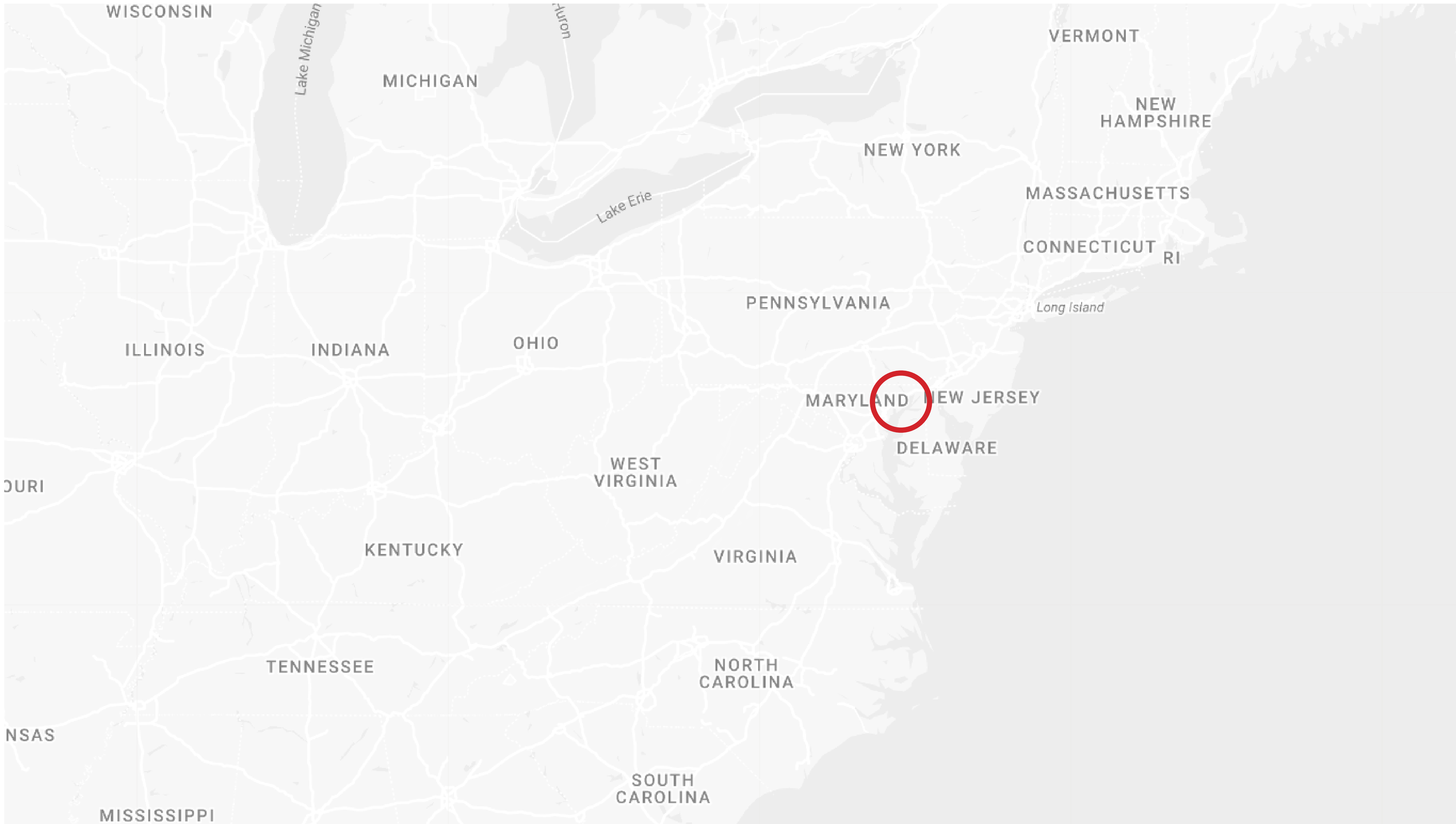


Figure 31 |
North East US

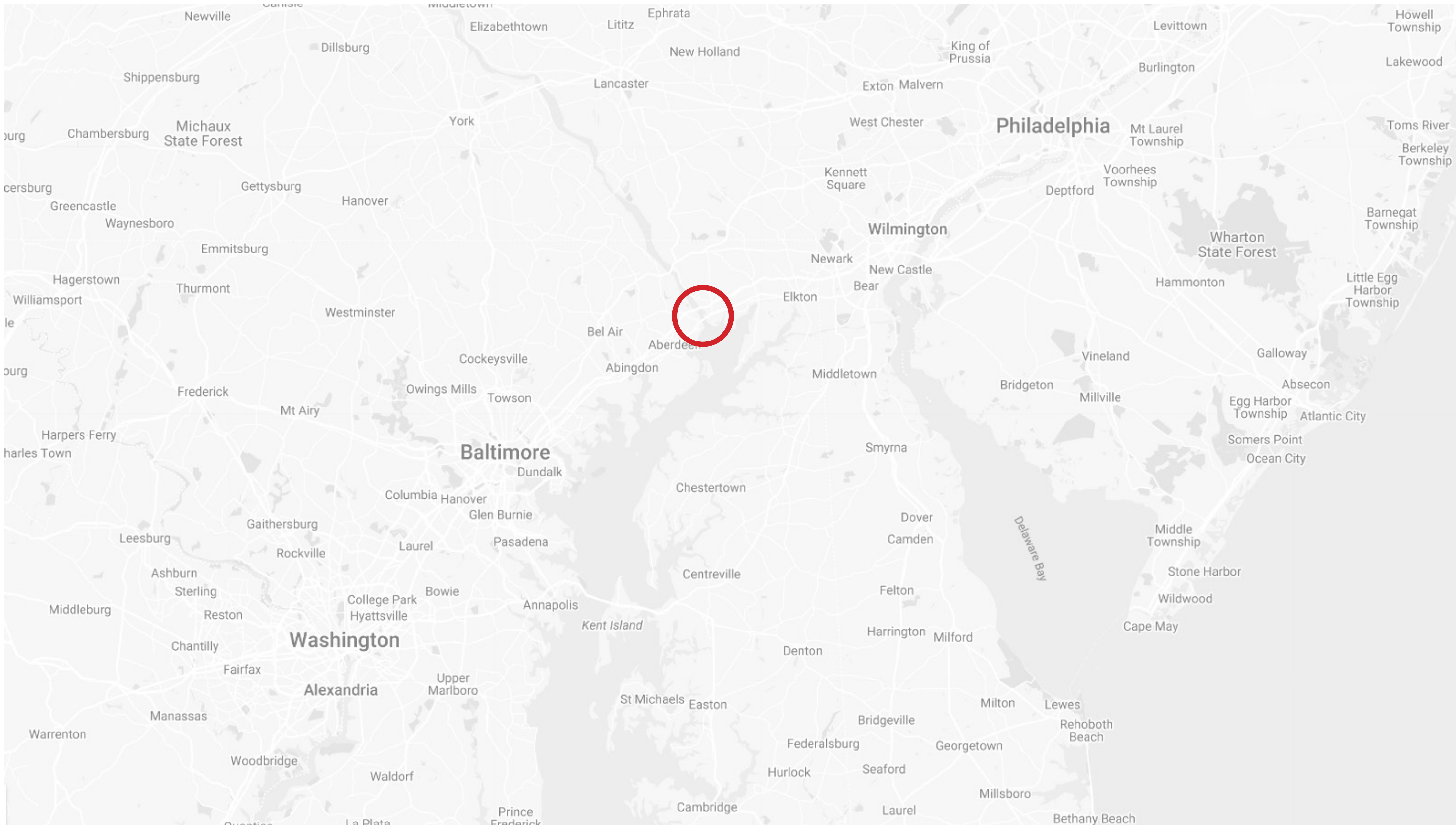


Figure 32 |
Upper Chesapeake Bay

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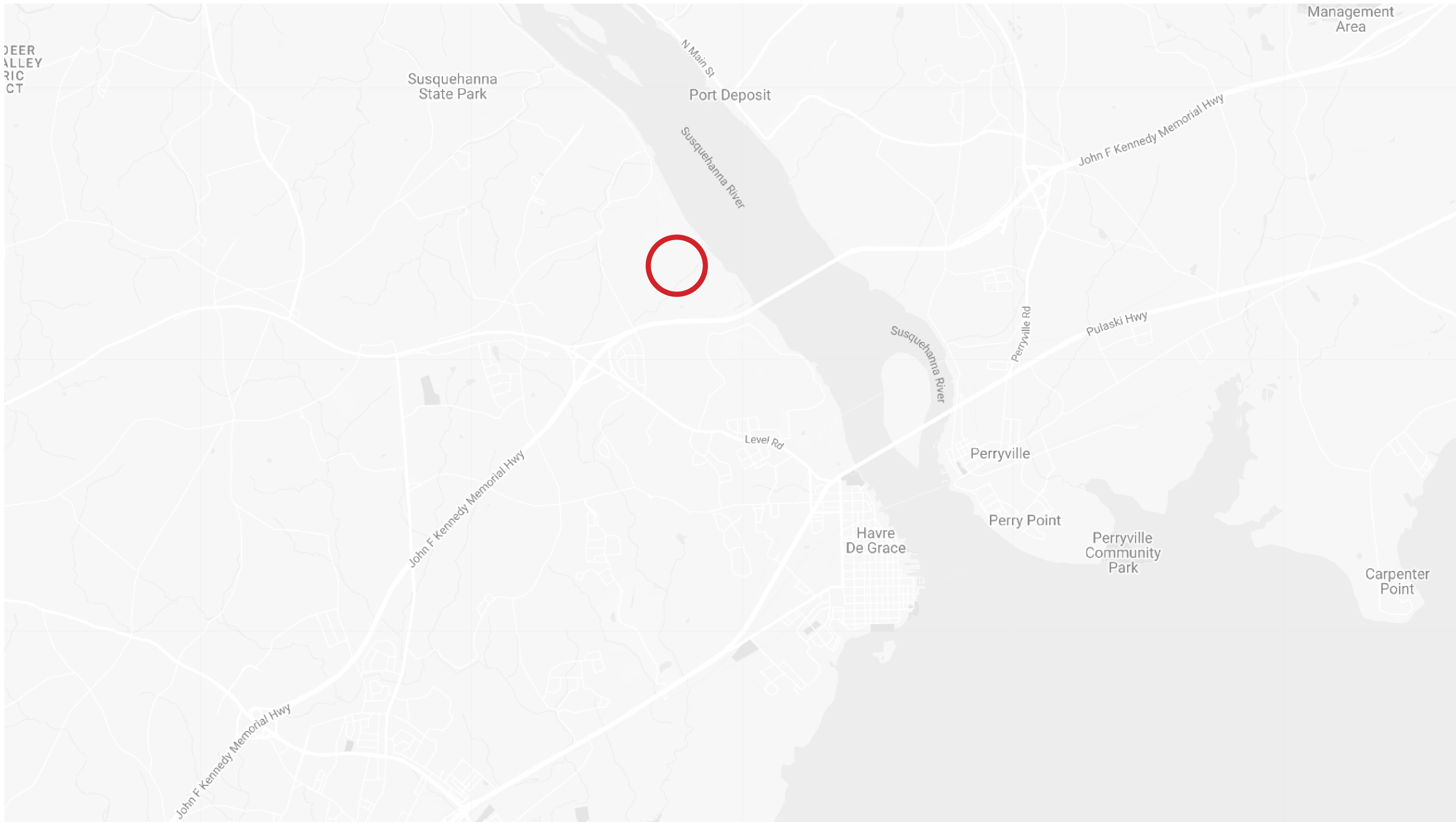


Figure 33 |
Havre De Grace

Design Solution

Figure 34 |
Exterior Aerial Perspective

Design Inspiration

- Large over hangs and “zig zags” facing south to combat sun.
- Separation of visitor center and power plant but still allowing self-guiding tours.
- Pass through to sights of the river and rock structure.
- Large garden and stage for hosting events.
- Turbine housing glass to act as “Billboard” to attract visitors from bridge.
- Pattern for turbine housing glass from nuclear reactor core for curtain system.
- Allow visitors to see into plant for better understanding of systems and education.

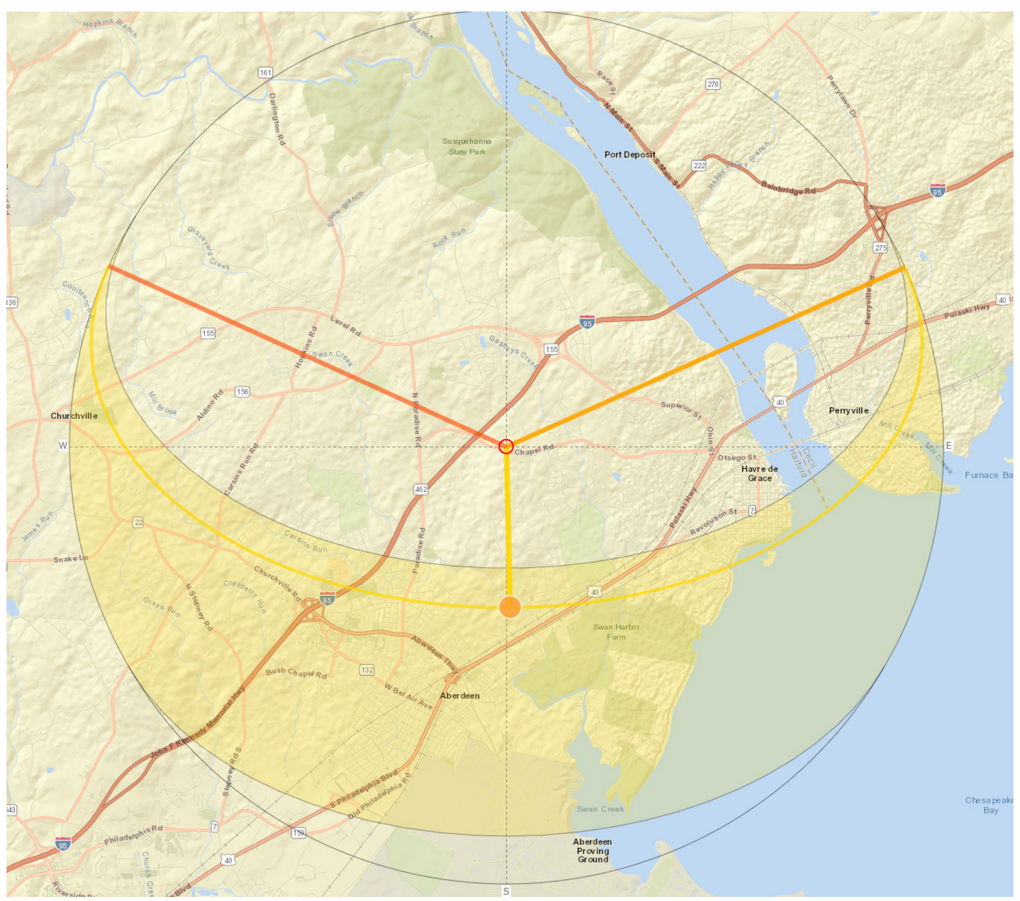


Figure 35 |
Sun Study

Figure 36 |
Nuclear Reactor

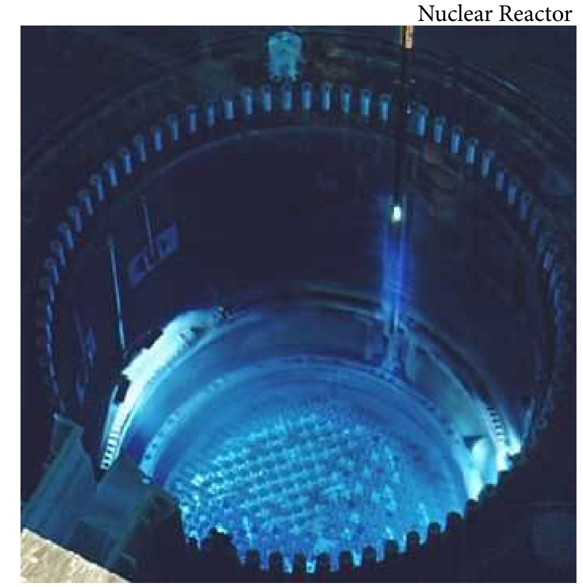


Figure 37 |
Local Cliffs

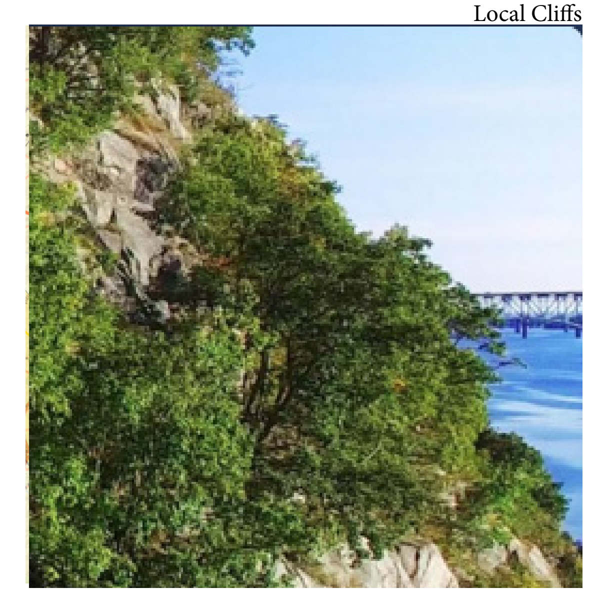


Figure 38 |
Sandstone Cliffs

Figure 39 |
Millard E. Tydings Memorial Bridge

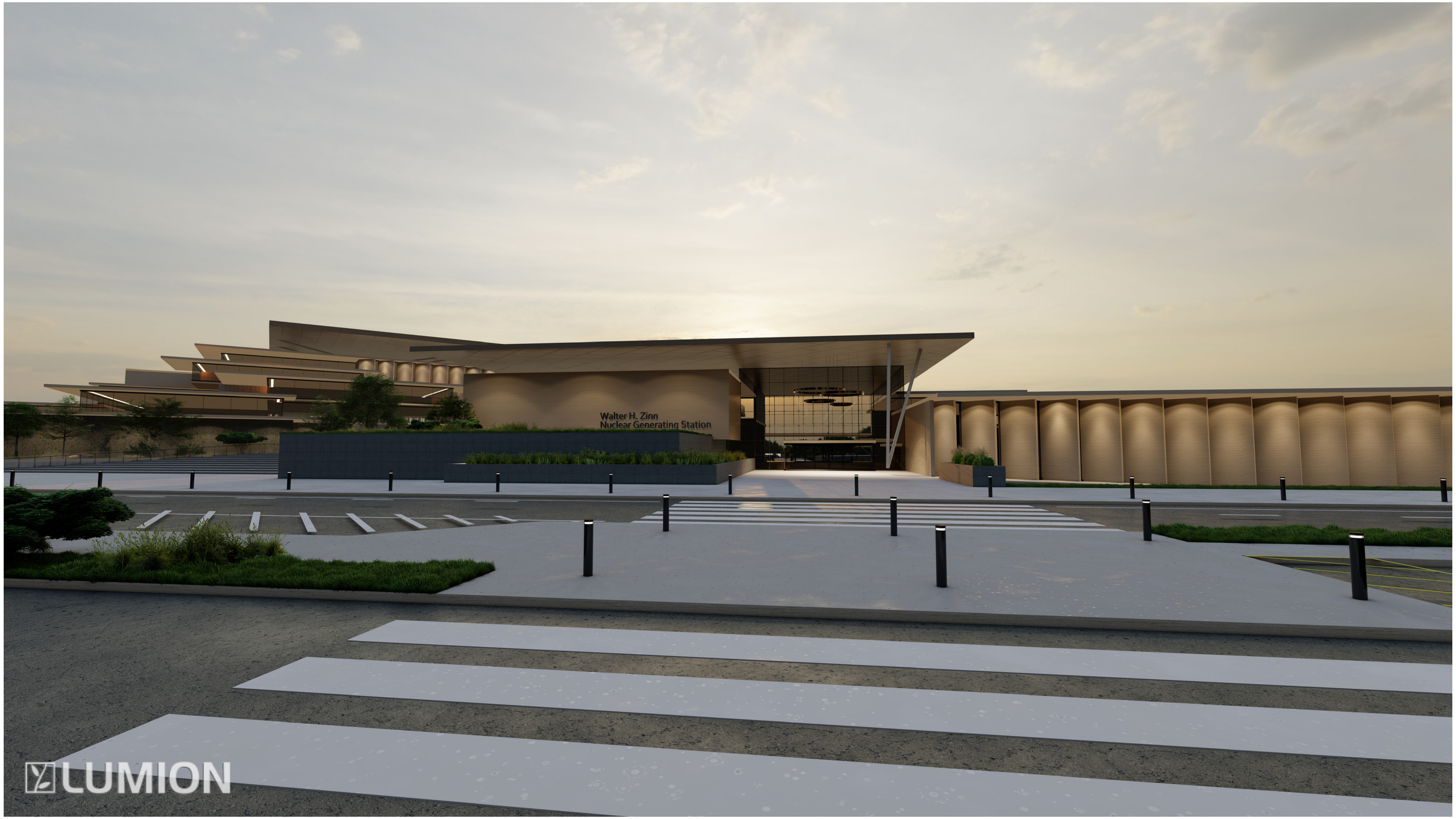


Figure 40 |
Front Entrance

Site Plan

1. Visitor Center
2. Turbine Housing
3. Power Plant Operations
4. Lawn
5. Repository Entrance
6. Diesel Generator
7. Underground Parking
8. Boardwalk
9. Auxiliary Bldg.
10. Reactor
11. Outdoor Stage
12. Reflecting Pool
13. Electrical Substation

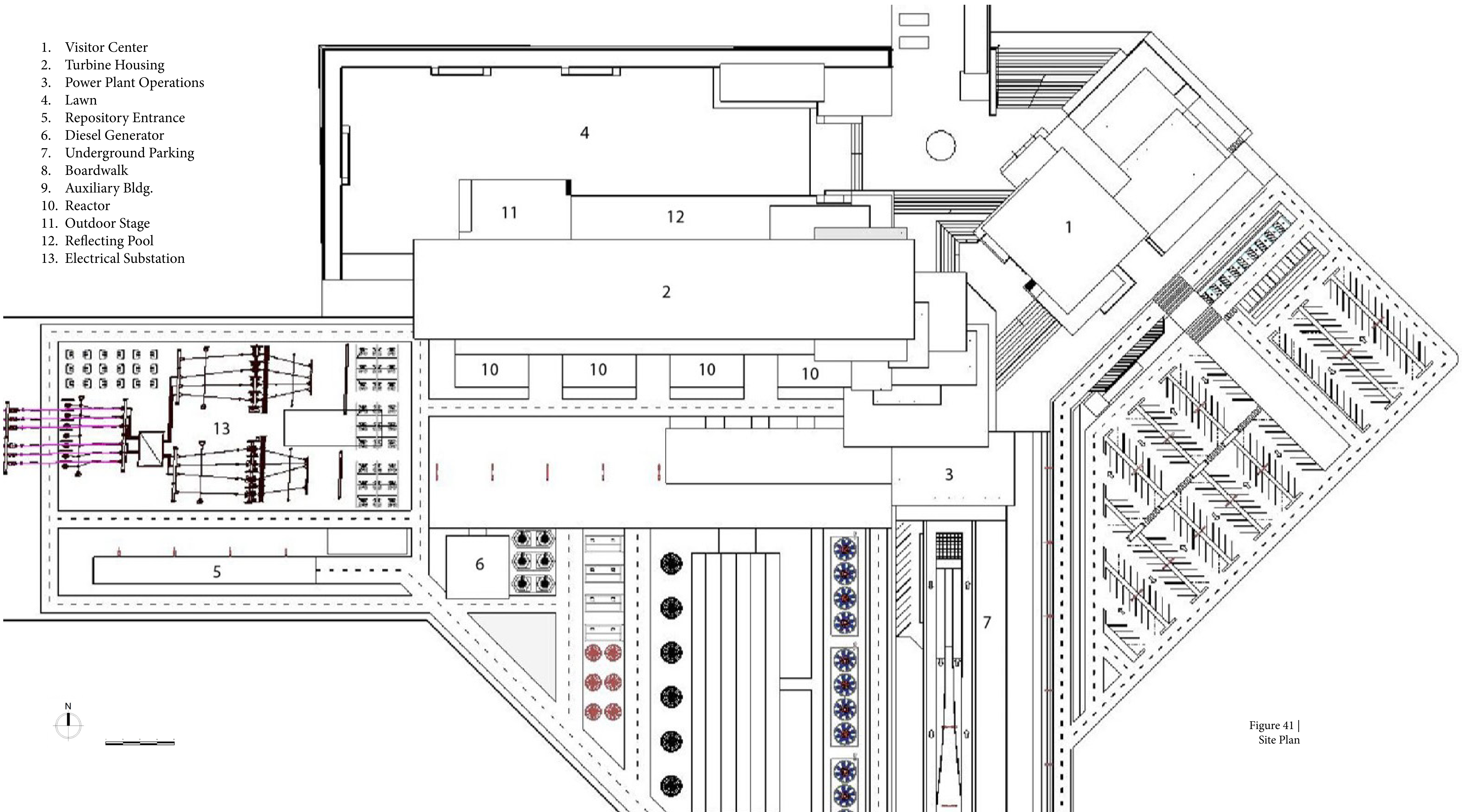
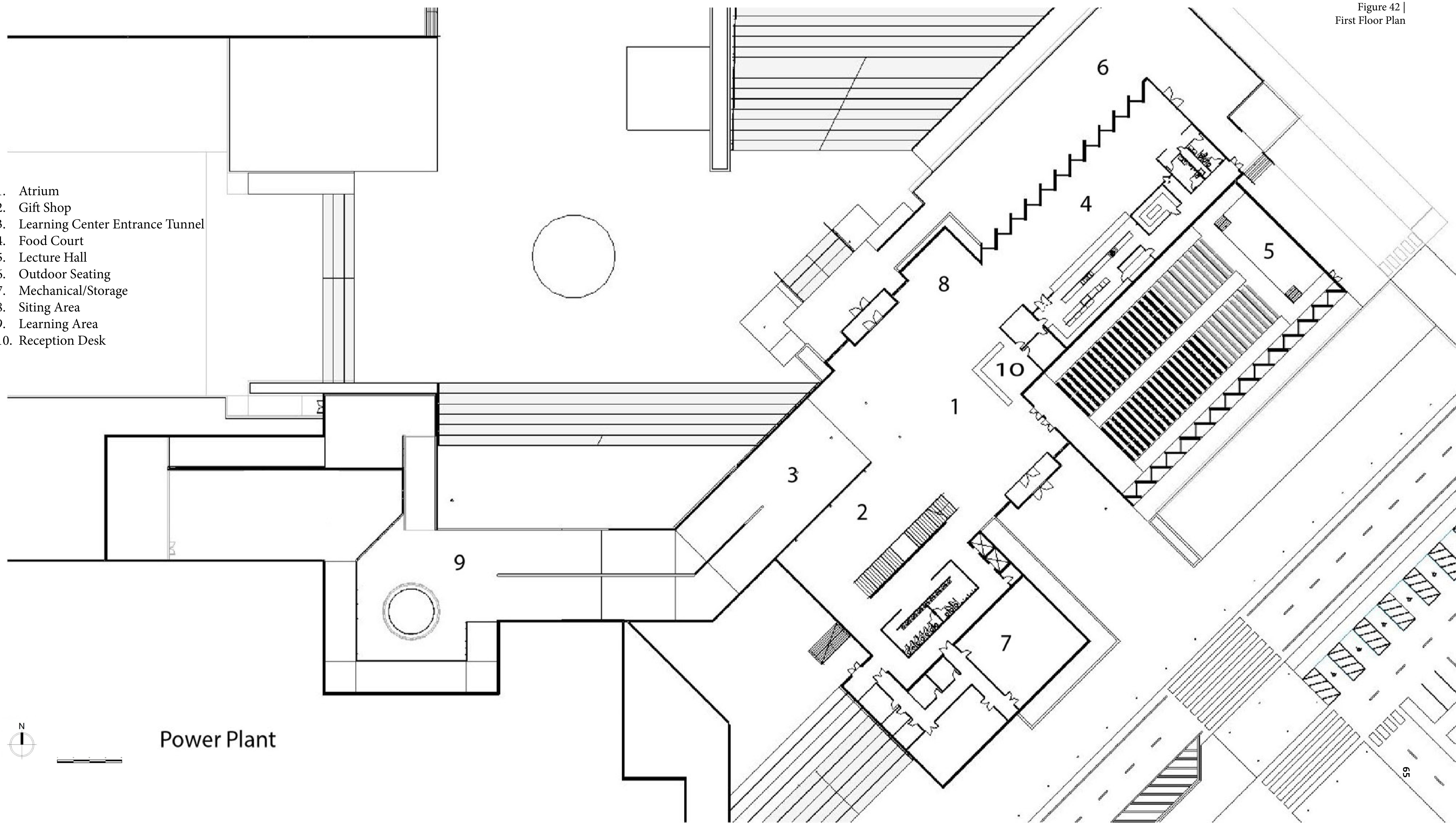


Figure 41 | Site Plan

First Floor Plan

Figure 42 |
First Floor Plan

1. Atrium
2. Gift Shop
3. Learning Center Entrance Tunnel
4. Food Court
5. Lecture Hall
6. Outdoor Seating
7. Mechanical/Storage
8. Siting Area
9. Learning Area
10. Reception Desk



Second Floor Plan

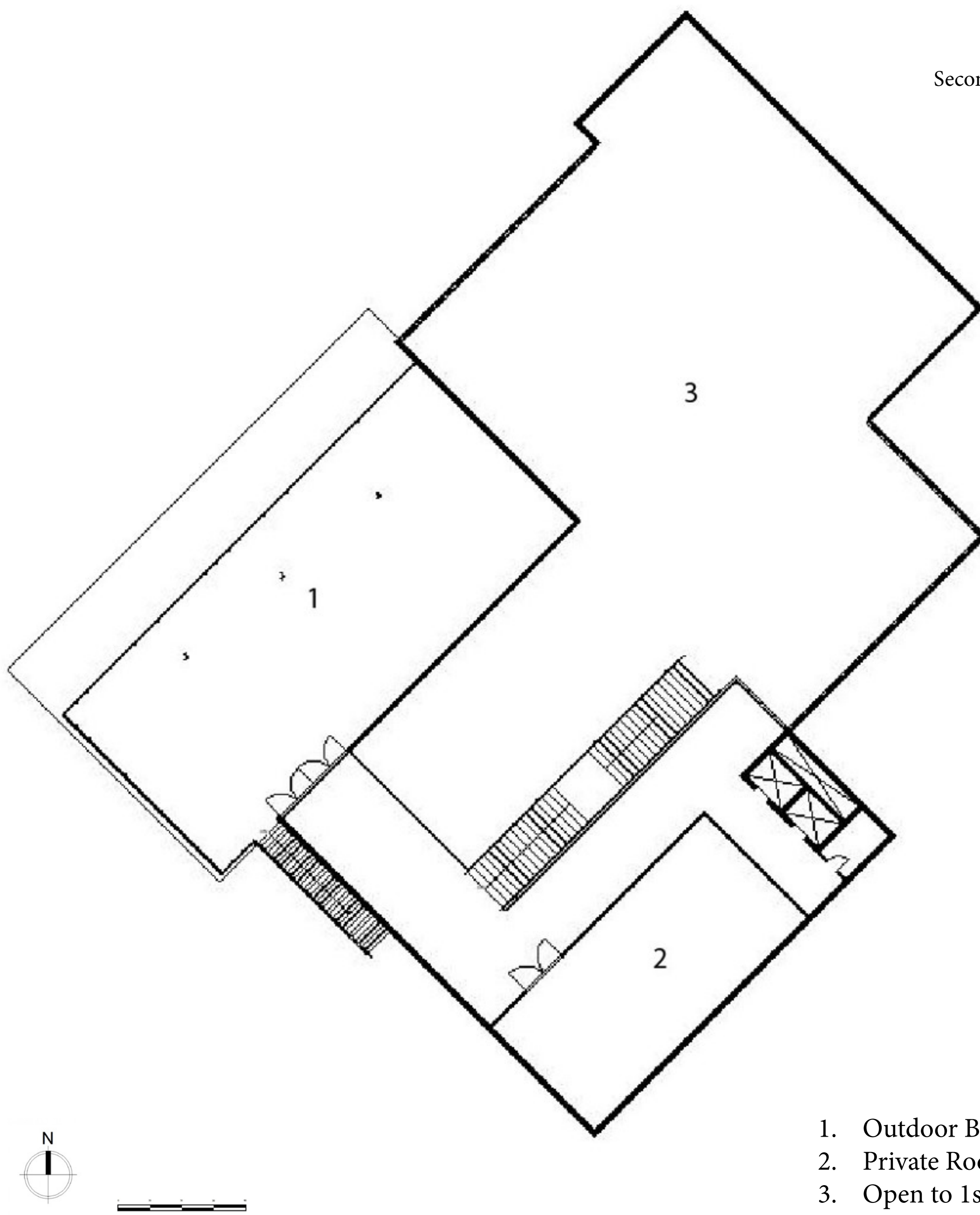


Figure 43 |
Second Floor Plan

1. Outdoor Balcony
2. Private Room
3. Open to 1st Floor Below

Figure 44 |
Balcony View

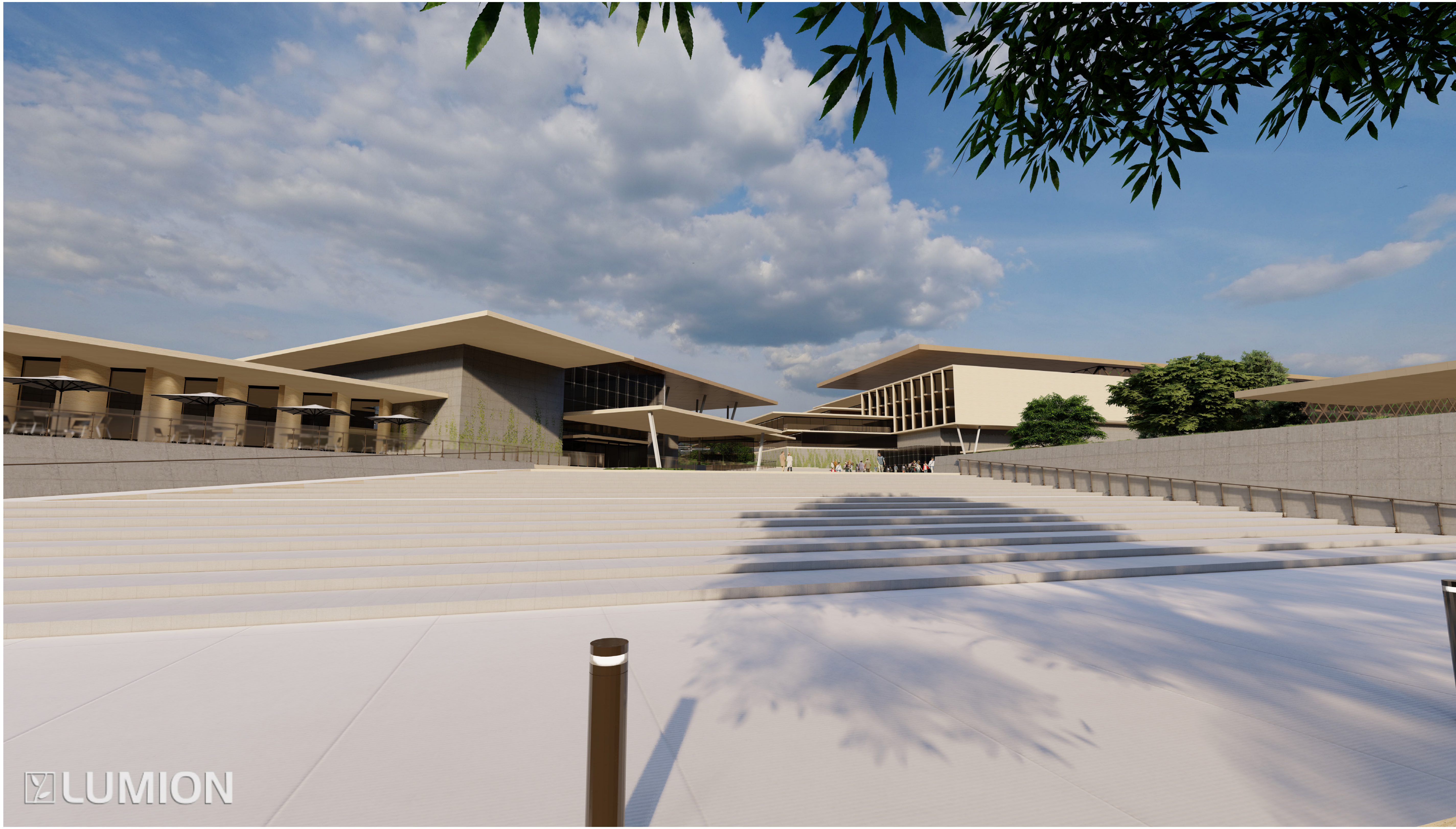


Figure 45 |
Hiking Entrance

Figure 46 |
Secondary Aerial View

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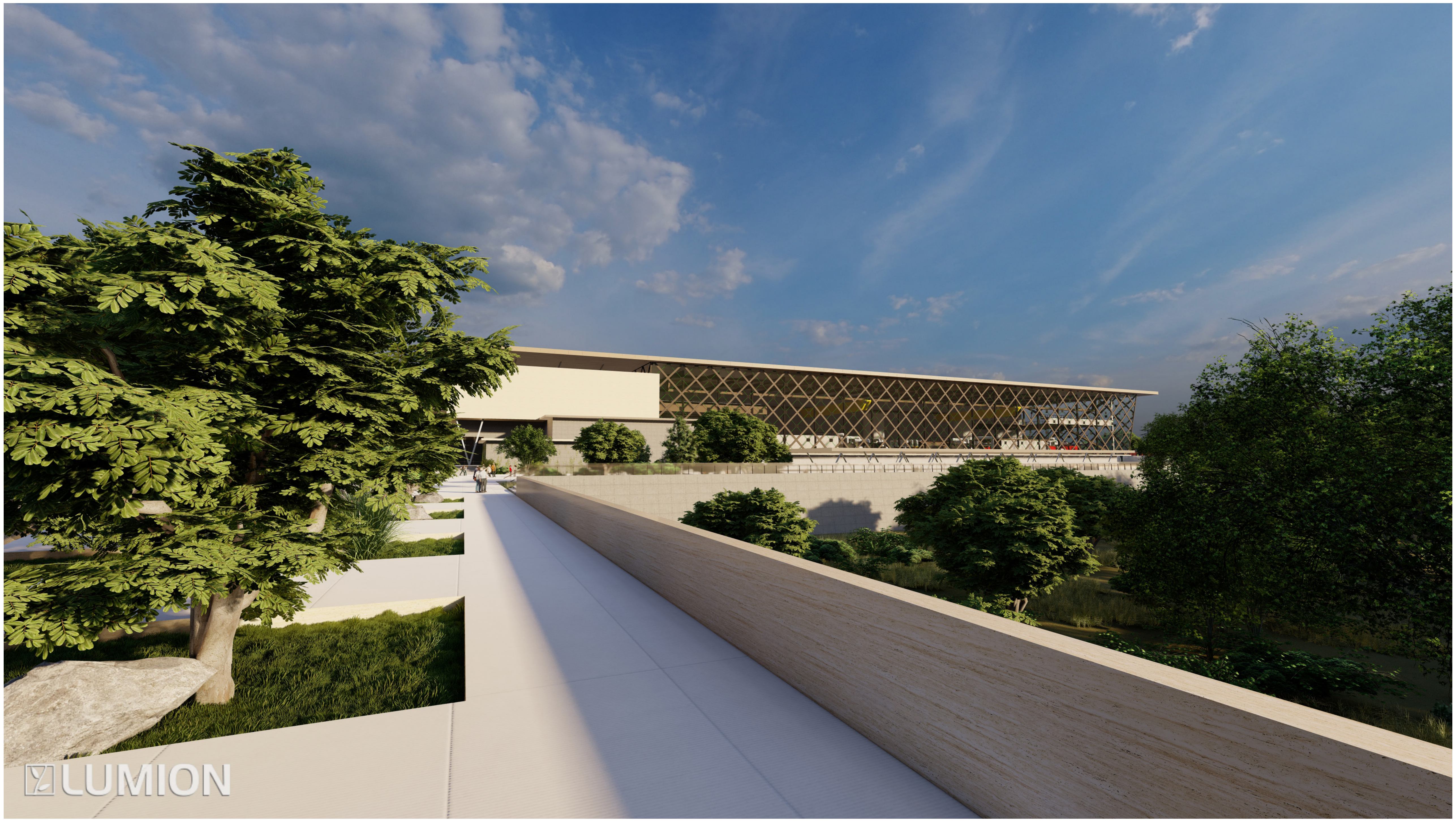

Figure 47 |
Boardwalk View

Figure 48 |
Ground Perspective

Figure 49 |
Exterior Aerial Perspective

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PREVIOUS STUDIO EXPERIENCE

Previous Studio Experience

2nd Year:
Fall 2016 | Ron Ramsey | Boat House
Spring 2017 | Milt Yergens | Marfa Dwelling & Bird House

3rd Year:
Fall 2017 | Cindy Urness | Mixed use & Medical Center
Spring 2018 | Paul Geye | Brick Facade Mixed Use & Affordable Housing

4th Year:
Fall 2021 | Amar Hussien | Miami High Rise Studio
Spring 2022 | Amar Hussien | Bal Harbor Urban Planning

5th Year:
Fall 2022 | Ron Ramsey | Advanced Architectural Studio
Spring 2023 | Ron Ramsey | Design Thesis Research Studio