Intermodal Transit Terminal: Integrating the Future of Transit into the Urban Fabric

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INTERMODAL TRANSIT TERMINAL:
INTEGRATING THE FUTURE OF TRANSIT INTO THE URBAN FABRIC

A Thesis Presented

by

GUY TANGUAY VIGNEAU

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

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Department of Architecture
INTERMODAL TRANSIT TERMINAL:
INTEGRATING THE FUTURE OF TRANSIT INTO THE URBAN FABRIC

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Thank you to the entire University of Massachusetts Amherst Department of Architecture. I have had the opportunity to work with many of the professors and staff through my Undergraduate and Graduate studies and I am looking forward to taking what I have learned to the real world.

Finally, thank you to my parents, Beth and Doug who have always pushed me to go after my dreams and have supported me throughout my education. Thank you to my sister, Sarah for being the best role model I could ask for and to Carly for being so incredibly supportive in my final year of grad school.
The very foundation of transportation relies on its ability to efficiently move people and goods through a transitional space. Transportation hubs are key to achieving this goal. However, many transit terminals are outdated or poorly designed to fit the needs of the modern world. At the core of this thesis are two overarching questions. First, how do we design intermodal transit terminals so that they successfully integrate into an existing urban fabric? Second, how do we design for innovative modes of transportation, such as hyperloop technology? This thesis explores how architectural design can recover existing transit connections within an urban context and provide new modes of transportation for a faster and more efficient user experience. Exploring the current issues within the transit sector today was a major focus of this research as well as selecting a site within an active city center. Furthermore, research into the emergence of new modes of transportation, like hyperloop technology and autonomous vehicles helped to identify potential transit solutions. Much of this research investigated the history of transit centers in addition to studying several important case studies that facilitated a solution to improving transit connections. Several
design options were explored through this research and a selected design was integrated into a final design solution to help lay the path for a more efficient future in transit architecture.
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CHAPTER 1

INTRODUCTION

1.1 Overview

This thesis document asks two core questions; how do we design intermodal transit terminals so that they successfully integrate into an existing urban fabric? How do we design for innovative modes of transportation, such as hyperloop technology? Resorting back to these two key questions was critical to the research process so that a well-developed design solution was the result. To achieve a cohesive design, background research into transportation issues of today was very important. It was also critical to look at historical transit centers as they have developed over the past two centuries with the development of new transportation technologies.

Complications in transit are wide-ranging. Heavy vehicle traffic, crumbling civil infrastructure and poorly designed transit terminals with limited transportation options are just a few of the problems we see today. New strategies within transit design are being developed to solve some of these issues. Considering technological advancements in transit like the hyperloop and the new concept of the “digital passenger”, connecting passengers to online scheduling platforms will speed up how we people get around. These are just a couple of the solutions that were explored in this thesis. The goal of this was to recognize how design can help to alleviate poor traffic conditions, improve the connections between existing infrastructure in cities and provide multiple options of transportation within transit hubs.
Transit terminals are often confusing places that result in long wait times and delays. Traveling and the movement of goods should be easy, accessible, and most importantly, time efficient. Unfortunately, this is not a reality. Architecture can support innovative transit technologies, wayfinding strategies and common-sense design approaches that can advance the way we use public transportation. The last decade has seen a rise in architecture that seeks to incorporate as many modes of transportation under one roof at a single location. This thesis will attempt to provide that architectural solution while conforming to a busy yet rapidly developing city center.

The first chapter takes a step back in time to briefly summarize the history of transportation and the evolution of transit design. This summary was used to provide a contextual background into transportation through the last few hundred years and to explore what transportation looks like today. Analyzing the evolution of transit design assisted in understanding the complex relationship between transportation and the buildings that support them. It was necessary to learn from the past to provide answers to some of the biggest issues that exist in transit architecture today and summarizing the history of this subject helped to set up the rest of this thesis.

The industrial era was a very important time for the growth of technology and transportation, which was seen across the United States and the world. The increase of locomotive trains was studied, providing many significant answers. The amazing railroad stations that were built in the last half of the 19th century and early 20th century provided travelers with the amenities necessary for their
journey across the American heartland. Rather than focusing on the technology that revolutionized travel, it was important to think about how architects and engineers worked to integrate the new technology into the city, forever changing the way civilization moves.

Processes into the research of this subject included many precedent studies, literature reviews, data collection, several primary sources and an extensive amount of analysis into site, program, overall form and structure, materials, and building systems. Precedent studies that spanned over the last century gave insight into the kind of design decisions that needed to be made. Understanding these decisions and drawing out successful anecdotes from these designs informed the design process in later chapters. Understanding the different design approaches that have been developed through the years ultimately dictated the direction of the final design.

In Chapter Two, potential solutions to America’s transportation crisis were discussed. Solving the transportation crisis will not be done through improved well-designed intermodal transit terminals but it was necessary to grasp the overall transportation crisis to provide insight into how architecture may be one solution. Literature reviews are frequently presented throughout this paper to help support the narrative of this thesis. Sources included articles, journals, websites, books, documentaries, and podcasts. Literature reviews are useful in providing potential design options, understanding what others have tried or written about in the past to help deliver the best possible answers to designing a technologically integrative intermodal transit center for today.
Chapter Three is dedicated to exploring five different transit stations and concepts throughout the world. Each of the precedents were selected based on the success of their designs. The goal was to pull successful design strategies out from each of the selected precedent studies that were then integrated into the final design. Research into innovative transit technologies and future modes of transportation were researched as well. This helped to develop a building form that suits the latest technology. This chapter began to explore different design strategies and how to adapt the intermodal terminal to the selected site as it relates to existing modes of transportation within the heart of a city. Wherever the site may be, the architecture must act as the gateway that blends new technology into the existing fabric of the city.

Several imperative sources provided information into the proposed site. These documents were reviewed thoroughly and presented in Chapter Four. Selecting a suitable site had to be decisive in the success of the design, which needed to be strategic and well researched. Aside from these important documents, diagrams that present information based on geography, topography, climate, infrastructure, population, movement etc. can be seen. This process provided important insights for later chapters when design became the main objective of the thesis. A general idea for program design that included the types of relevant spaces in the building were also explored in this portion as it relates to the shape and size of the proposed site.

Later, in Chapter Five, extensive research into the building form pushed the design into the right direction. This schematic design phase produced a form
that would integrate into the city in an orderly and thoughtful manner. A focus on
the overall form and exterior relationship of the building to the site later shifted to
the interior of the building. Circulation was key to designing a successful transit
terminal, especially when there are multiple modes of transportation involved.
With so many potential passengers moving in and out of this space, comparing
the proposed building to similarly sized transit terminals was also useful
throughout the design process.

Designing for such a large program with several modes of transportation
connecting to a single location called for a well-developed structural design.
There was a major emphasis on the structural design of the building once the
form and layout were determined. It was important to use information from
previous precedent studies as a driving force of the design. A major feature of
many transit terminals is its grand hall or concourse that is typically situated at
the center. It acts as a major wayfinding point for people to circulate in and out of.
Not to mention, such a large space could include places for people to shop and
eat as they wait to embark on their travels.

Much of the building design was complete by the end of this chapter but
not without sustainable design solutions being integrated. This facilitated in
lowering energy use and limited the overall effect on the environment.
Determining sustainable strategies that best suit the buildings performance
required analysis into sustainable materials, façade design strategies, water
collection system and the use of solar panels. All choices inherently improved the
overall design and performance of the building. Several other strategies were
explored as well, like a carport parking lot that could have been used to collect
the sun's energy.

The objective of this thesis was to deliver a well-written document that
defines an overall understanding of transit architecture, specifically intermodal
transit terminals. The final portion of the writing includes much of the final
presentation with remarks on the thesis process as it relates to the subject of
intermodal transit terminals. An overall evaluation of the completed work
concludes the paper as well as notes based on feedback from jurors. This
facilitated in finalizing the thesis document and is used to look back upon areas
that could have been improved upon.

1.2 History of Transportation

Humans have always been on the move, by foot. That is until about
60,000 to 40,000 years ago when humans began making simple rafts to cross
rivers, lakes and eventually seas. As man became more curious, their means of
travel became more civilized. Some of the first known boats were called dugouts
which were made from tree trunks. In an article titled “The Early Years: Boats,
Horses and Wagons,” author Tuan C. Nguyen states that there was evidence “of
the floating vehicles come from excavations of artifacts that date back around
7,000 to 10,000 years ago”¹ Boats evolved over time, thus improving the way
humans could travel around the globe, exploring new locations yet undiscovered
by man.

¹ Tuan C. Nguyen, From Horses to Rocket Ships: A Brief History of Getting
Around, (Thoughtco.com, 2019)
In about 4,000 BC the first evidence of horse domestication took place. A new form of transportation was born, allowing humans to travel quickly on land. It wasn’t too long after that when one of the most important inventions of human history was created, the wheel. It is believed that around 3500 BC that humans began using wheeled vehicles to transport people and goods. Nguyen says in the article that “the earliest well-dated artifact from that time period is the Bronocice pot, a ceramic vase that depicts a four-wheeled wagon that featured two axles.”

Fast-forward a few thousand years to 1769, the Watt steam engine is invented. Boats began using steam power and in 1783 when Claude de Jouffroy built the first steamship called the Pyroscaphe. The technology took some time to develop but it eventually became a mainstream form of transportation when the American inventor named Robert Fulton made it commercially feasible in 1807 (Fig. 1). Trips from places like New York City to Albany still took 32 hours to complete, clocking in at a max speed of 5 miles per hour. Freight services spread throughout the country and in industrialized countries throughout the world. Steam technology would also be used to create early automobiles and motorcycles in the latter half of the 18th century.

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2 Ibid.
3 Ibid.
In 1858, the first gasoline-powered automobile was produced by a Belgian named Jean Joseph Étienne Lenoir. It took many years for the gasoline-powered car to become a mainstream form of transportation but 20th century improvements to the technology changed all that. Another form of transportation that is still widely used today but looks very different from its contemporary was the steam-powered locomotive. British inventor, Richard Trevithick created the first locomotive in the early 1800’s called the “Puffing Devil”.\(^4\) (Fig. 2) The invention of the locomotive gave rise to a revolutionary form of transportation that

\(^4\) Ibid.
could move people and goods great distances over land. Later, a British man named George Stephenson would take the emerging technology to the next level by making it possible for the public to use.

Fig. 2: Diagram of Richard Trevithick’s Puffin’ Devil, CornwallForever.co.uk

In 1824, Stephenson helped build the first railway between Liverpool and Manchester, England. His contributions to the industry gave him the rightful nickname of “Father of Railways.” His idea wasn’t to just improve railway technology but to connect people all around the country. Since the creation of the first vessel thousands of years ago to the first locomotive, transportation has

\[5 \text{ Ibid.}\]
been improving to accommodate the needs of human beings. As humans improved their means of travel, a new building type grew out of this, the transit terminal. In the early 19th century, transit terminals would be built to support the growing railroad infrastructure. It had become clear that the railroad system was the future of transportation and there needed to be structures to accommodate travelers and cargo along their journey.

1.3 Evolution of Transit Design

The experience of walking through the doors at a place like Grand Central Terminal at the turn of the 20th century must have been difficult to describe to people who had never seen such a place before. The building was monumental at the time, acting as the welcoming center to all travels as they entered New York City. Railroad stations like Grand Central Terminal in New York were the gateway to great cities that revealed genius engineering and powerful economies. Many other railroad hubs would rise from the ground in the latter half of the 1800’s and early 1900’s. This building and many others like it left a lasting mark on the architecture of the 20th century and society all together.

The role of the railroad station became the central core of how cities and small towns grew and evolved. In Brian Solomon’s illustrated book titled “Railroad Stations”, a history of railroad stations and their impact is told through awe-inspiring images and text.
Solomon says, “Before the advent of the railway, no comparable structure had ever existed on such a large scale. Often the depot was the most important and most attractive building in a community.”

Fig. 3: Ellicott City Depot, AmericanRails.com

Thousands of railroad stations were built all around the world with most being built in the United States as locomotives and automobiles became more attractive than horse and buggy. The new and improved form of transportation was an innovation that first came to light in the 1830’s. In 1830 the first running locomotive was introduced by Peter Cooper on a rail line from Baltimore to the nation’s oldest depot in Ellicott City, Maryland (Fig.3). After that, “Railroad fever gripped the Western Nations, and from the mid-1830’s until after the turn of the century, thousands of miles of railroad were constructed every year.”

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7 Ibid.
Railway travel continued to progress throughout the 20th century with the advent of electric trains. The United States took a different path than European nations, which nationalized their railways to “maintain and improve” railroad services for passengers. “In 1981, super-high-speed (Trés Grande Vitesse) TGV (Fig. 4) trains running at 150 mph to 185 mph were introduced in France.” 8 This innovation in transit changed how people would travel in Europe, making it was easier, quicker and cheaper than air travel in the region.

Fig. 4: Very High Speed: from Turbotrain to TGV, Retours.eu

To make these trains more efficient, passenger terminals were connected to other forms of transportation, which included airport terminals. Amsterdam, Frankfurt, Geneva, and Zurich all connected to major airports and intermodal hubs specifically designed on regularly scheduled intervals for smoother

8 Ibid.
transitions. The destruction of World War II made it easier for countries like the Netherlands to build modern stations that were high-tech, integrating new technologies was critical to their success.

The United States took an alternate route in rail travel. After World War I a slow decline in passenger use of trains led to an increase in privately owned vehicle use and air travel. Solomon states, “by the early 1970’s passenger service had reached an all-time low. In 1971, Congress relieved the railroads of their growing long-distance passenger deficit by creating Amtrak to maintain a bare minimum of intercity rail service.” By the mid-1980’s most railroad companies were using rail lines for hauling cargo across the United States rather than passengers. This decline in train use across the United States led to many of the issues that we see in transportation today. More vehicles on the road meant more time spent in traffic. The once, beautiful stations that were built at the turn of the century became useless, many were “destroyed, relocated, or converted to other uses, such as maintenance depots, offices, or freight agencies, or were sold to private individuals.”

Commuter rail travel is used for short-distance service, typically to and from inner cities. There has been little change in the effectiveness of commuter rails since the 1980’s with funding by the federal and local government being limited. Solomon explains that, “Amtrak, is perpetually on the edge of oblivion, as federal funding remains continually subject to partisan scrutiny and budget

\[9\] Ibid.
\[10\] Ibid.
trimming. Only in the heavily traveled Northeast Corridor between Boston, Massachusetts, and Washington D.C., has there been any real advance toward the sort of high-speed rail service now common in most of Europe and Japan.”11 The struggle for any real change in the way Americans travel continues today. There needs to be a paradigm shift that introduces new innovative strategies in transportation and intermodal transit design to support a growing population and American economy to keep up with rest of the world.

1.4 Building Typology

In 2012, academics from Aristotle University, Pitsiava-Latinopoulou and Hellenic Institute of Transport, Panagiotis Iordanopoulos published an article on intermodal transportation hubs in *Procedia*, a Social and Behavior Sciences Journal.12 The article was titled “Intermodal Passenger Terminals: Design standards for better level of service” and discusses the critical importance of intermodal transportation hubs as a sustainable form of mobility in highly congested cities. The authors explore the provided levels of service for passengers moving through intermodal facilities and the affects that it has on the behavior of individuals as they move through transit hubs.

The goal of this research was to develop a series of categories for the various types of terminals that exist and to breakdown how they serve the public as well as understanding commuters that use transit facilities every day. This

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11 Ibid.
procedure leads the team to establish useful guidelines for each category to design better, more organized intermodal facilities that will benefit the typical behavior of a common commuter. To help enforce their argument, the authors developed a case study that they called “Reveal Preference Survey for Intermodal Terminals of the City of Athens”, which helped with examining the various modes of transportation in the city.

Pitsiava-Latinopoulou and Iordanopoulos set the stage for their argument by describing what the conventional approaches are to transportation design. This approach aims to “maximize speed and direct access by private vehicles and to minimize travel times, congestion and accidents.”13 Recently this has changed, and the focus has shifted to non-motorized transport modes that will help to minimize environmental impact. The idea of “sustainable transportation” is introduced and broken down into several factors including economic, social, and environmental. “The idea of intermodality aims to optimize travel conditions reclaiming the advantages of each mode being used while minimizing the negative impact that each one of them causes.”14

Understanding the role of intermodal terminals is imperative to successful design. The idea is to combine different forms of transportation modes into a single trip to reduce the overall cost of a trip that is using one form of transportation. There are several decisions that need to be made for the successful design and operation of an intermodal transit hub. “Inadequate
planning and design, incorrect choice of location and inefficient way of operational management can be the main reasons for delays and malfunctions in traveling.”

To improve the intermodal transportation hub, the authors created a list of design elements that a terminal should provide to be successful, although it would be very difficult to fulfill them all.

- Reliable and adequate level of service of the means involved in the operation of the terminal
- Satisfactory level of facilities serving the transfer
- Provision of low-cost travel (less than or equal to the cost of travel without transfers)
- Adequate accessibility of the site for all users (especially the disabled)
- Reduced travel time compared to that needed for the same trip without transfer
- Direct access between two different platforms for almost all platforms of different modes of the terminal

In the process of categorizing intermodal terminals, it came down to location, the mode of transportation being accessed, and what type of passenger was using the terminal. With this information, the following five categories were created: 1) Intercity terminals, 2) Commuter Transit Centers, 3) Interchanges, 4) Park and Ride Terminals and 5) On street facilities.

The planning and design of an intermodal hub needs to consider these five categories when starting from

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15 Ibid.
16 Arup and Associated Consultants, Sacramento Intermodal Transportation Facility, (Sacramento, 2004)
scratch. Some elements that are to be defined are: number of transportation modes and the type of vehicles that are going to be served, the time of expected operational use, the expected level of activity and how many passengers will be served, and the variations in transport demand. Connectivity to nearby public transportation is key to the success of a building like this: all modes need serve the same building, service facilities are located on the same block or within a reasonable distance for pedestrians to walk, and the proper protection for a traveler in the need to cross an unprotected intersection.\textsuperscript{17}

\textit{Intercity Terminals} are characterized as a transportation hub serving passengers who are traveling long distances from city-to-city. These stations typically have long waiting lines and minimal traffic throughput the day because they primarily by long distance travelers. There are four sub-categories for the Intercity Terminal: train stations, bus stations, airports, and port terminals. Each of these different modes of transportation have their own unique design and are in distinct parts of the city. For example, train stations are typically located at the center of highly populated areas whereas bus terminals tend to be located outside of areas of high traffic and more available free space for planning, “therefore for their intermodal operation it is vital to create the necessary connections of the terminal with the central district of the city and the nearby region by available transport modes.”\textsuperscript{18}

\textsuperscript{17} Latinopoulos, Iordanopoulos, \textit{Intermodal Passengers Terminals: Design Standards for Better Level of Service}
\textsuperscript{18} E. de Boer, J. van Rossum, \textit{Towards systematic design of urban bus stations, Reinforcing a weak link in a public transport chain}, (Web, Association for European Transport and contributors, 2009)
Commuter Transit Centers are used to serve passengers who are moving to and from an urban center from the greater region. These types of transportation hubs serve regular travelers who are looking to cut down travel time and to be served at all hours of the day. The terminal design in this category needs protection from poor weather conditions, service amenities like raised crossing platforms, and large pathways. A similar category is known as Interchanges, which are intermodal facilities that have several connection points. “These facilities serve predominantly everyday travelers of the network…regarding their location, it is essential to be either central districts or commercial centers of urban areas where most of the public transport routes pass through.”

The final two categories are Park and Ride and On Street Facilities, which are quite different in nature. The Park and Ride is typically found at urban transport terminals and are usually located in areas of low density for everyday commuters. On Street Facilities are used for different modes of public transport, usually bus or tram routes that are used for transferring transportation services. They can usually be found in the heart of a city and private vehicles are prohibited from using them because they can cause traffic backups. Each of the categories have pros and cons to them but to further understand the usefulness of intermodal transportation hubs, a look at Athens, Greece helps understand even further.

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19 Latinopoulos, Iordanopoulos, Intermodal Passengers Terminals: Design Standards for Better Level of Service
With a population of over 4 million people, Athens, Greece has some of the worst traffic and congestion problems in the country. This was recently improved with the development of “a network of three metro lines serving the urban area and major Intercity Terminals (Port, Airport, Railway Station), a tram service connecting the city center to the southern suburbs and suburban rail service connecting Athens International airport to the city.” In a study that was conducted at 32 of the busiest transit areas, a survey was used to understand how travelers use public transportation and by which mode of travel. After several years of study, authors Pitsiava-Latinopoulou and Iordanopoulos developed a conclusion about intermodal terminals. They stated that intermodal terminals are a key link in how passengers travel in cities and it is believed that with an improvement in design, “could lead not only to the increase of the share of commuters who use urban public transport but also the consolidation of the overall public transport system of an urban area.”

The research done in this project was clearly well done and was backed by data surveys that were held in at transit centers in the city of Athens, Greece. The study further proves that intermodal transportation hubs are continually becoming a more effective form of travel and design. Understanding the five different categories, how each of them have their own necessary elements that should be used in different scenarios and locations throughout a city is crucial to the success of intermodal station design. Analyzing where people are traveling and what sort of connections that they have to the city will contribute highly to a

20 Ibid.
project like this. Finally, the idea of a hyperloop intermodal station would fall under the category of *Intercity Terminals*, however there should be an emphasis creating a constant flow of people travelling from city-to-city with this type of travel. In understanding the future of transportation in a system like the hyperloop, travel must be made easier for more people to come and go as they please. The design of an advanced intermodal passenger terminal, like a hyperloop station, will be determined based on how many people can pass through the doors and at what rate.
CHAPTER 2
TRANSPORTATION CRISIS

2.1 Issues of Today

There are countless issues found in transportation today. In a report titled “Traffic: Why It’s Getting Worse, What Government Can Do”, Anthony Downs explores why the rise in traffic congestion continually grows in major metropolitan areas like Los Angeles, Tokyo, and Cairo. Many of the issues that cause traffic in this study are as relevant today as ever and some of the solutions that are described haven’t been fulfilled or experimented with. Downs introduces what some of the real problems are that many people face as they sit in hours of traffic in heavily congested metropolitan areas. His analysis of this issue leads him to possible solutions and how they can be implemented into everyday life to ease the growing problem.

The “Real Problem”, Downs insists, is that there are too many people that want to move at the same time every day. It is an obvious assumption, but what is at the root of this problem? He concludes that “both the economy and school systems require that people work, go to school and even run errands during the same hours so they can interact with each other.” This essential requirement of everyday life keeps society going and if altered, could otherwise cripple the economy. Many people today who drive during rush hour use privately owned automotive vehicles. This is a major reason why traffic occurs in the first place.

but with the introduction of more effective public transit this problem could subside. The fact of the matter is that privately owned vehicles are “more comfortable, faster, more private, and more flexible for doing multiple tasks on one trip than most any form of public transit.”

Traffic continues to get worse as population grows and the number of vehicles that are on the roadways increases. America’s roadway system is not built to handle the peak hours of traffic, therefore causing people to wait in long lines as drivers compete for limited space. There are several solutions that Downs insists upon. First, charging peak hour tolls and integrating electronic “smart cards” to allow more people to travel per lane is one solution. This is something that has recently become more and more common on city highways and bridges. Another solution to traffic congestion is to “greatly expand highways.” Building a roadway that can handle the peak hours of traffic would certainly help the issue, “but this ‘cure’ is totally impractical and prohibitively expensive.” To widen roadways, the government would have to demolish millions of buildings, cut down trees, destroying natural habitats, and pour millions of tons of concrete, making “every metropolitan area into a concrete slab.”

A third solution is to live with the increasingly bad congestion. This is an option but why not fix the issue with the most plausible solution, public transit. By greatly expanding public transit, vehicle traffic on roadways would subside. In the

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22 Ibid.
23 Ibid.
United States in 2000, about 4.7% of all commuters utilized public transit. This number has only risen slightly since then, in 2015 about 5% of commuters were using public transportation. The major issue with public transportation is that it is typically situated within densely settled regions, so city dwellers are more likely to take advantage of it. In 2000, 17% of the population who lived in cities used public transportation to commute to work. For people who live outside of densely populated regions, about 2.4% used public transportation. Increasing public transportation would certainly help decrease traffic but the solution is costly and relies on commuters using alternative modes of travel.

Eliminating congestion is practically impossible but making improvements to current modes of transportation, specifically public transportation. One such improvement could be to cluster high-density housing around transit stops in cities. With greater access to public transportation, it is less likely that privately owned vehicles will be used, which can be costly living in an urban region. Another improvement that seems obvious is to provide regional transportation authorities with more power and resources. Congress created the “Metropolitan Planning Organization to help coordinate ground transportation planning over all modes in each region.” The goal of this organization is to better plan public transportation in cities but if they were provided with “more technical assistance and power, more rational systems could be created.”

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24 Ibid.
25 Rob Wile, Just 5% of Americans Are Using Public Transportation to Get to Work, (Splinternews.com, 2015)
26 Anthony Downs, Traffic: Why It’s Getting Worse, What Government Can Do
27 Ibid.
Traffic congestion at peak hours of travel is inevitable within densely populated regions. It causes the average commuter to spend countless hours in their vehicles and this problem will certainly get worse in the future as populations rise. Downs lays out some practical solutions to this ever-growing issue but the one solution that stands out the most and has the most promise is public transportation. With the creation of alternative modes of public transportation that includes trains, subways, buses, bikes etc., various options provide commuters with what works best for their own situation. These modes of transportation are useful but only when located in or near densely populated regions. The idea of the Hyperloop as a new form of transportation could revolutionize what it means to live and work in very different places.

Hypothetically, hyperloop technology could transport individuals at the speed of sound through airless vacuum tubes from one city to another in minutes. Hyperloop technology is explained further in section 2.4, but this new form of travel could allow commuters to live farther from where they work, consequently easing traffic in densely populated regions. This is a solution that has yet to be proven but the technology and the means to solve the problem of traffic in cities is growing. Companies like Hyperloop One and Hyperloop Transportation Technologies are working to create the first of its kind and could soon be as common as trains within the next fifty to one hundred years. Providing a network of intermodal hyperloop stations in a region like New England could change the way people live and interact with one another as travel
times decrease. Hyperloop technology and the integration of several modes of travel at one location is discussed in later chapters.

2.2 Transportation in the Northeast

In 1961, geographer Jean Gottmann invented a term to describe large clusters of highly populated regions. “Megalopolises” is the word Gottmann coined and the name of his book that is now used to describe regions like the Northeast Corridor, which stretches 400 miles from Washington D.C. to Boston, Massachusetts. This region is sometimes referred to as the BosWash Megalopolis, and the two other regions that have been given similar nicknames are Chicago to Pittsburgh (ChiPitts) and San Francisco to San Diego (SanSan). Gottmann predicted in 1967 that “by 2000 one-half of the U.S. population would live in those three megalopolises and that any examination of U.S. population trends in the 21st century would largely be a study of BosWash, ChiPitts, and SanSan.”

Although Gottmann wasn’t entirely correct with his prediction, the three regions make up about one-third of the U.S. population (Tab. 1) and some of the fastest growing regions can be found in the south and west. Gottmann’s message remains the same however, “sprawling urban growth reflect population dynamics still at play today.”

Mark Mather, the author of Population Reference Bureau (PRB) “Reports on America: First Results From the 2010 Census” summarizes Gottmann’s

29 Ibid.
prediction, stating: “Today more than 80 percent of U.S. residents live in metropolitan areas…Within metropolitan areas, most U.S. population growth during the past century has taken place in suburban areas, rather than central cities. By 2010, 51 percent of the population lived in suburbs, compared to 31 percent in 1960…The rural population has shrunk dramatically, as rural areas have lost population or have been swallowed up in sprawling nearby metropolitan areas.”³⁰

With the population of the U.S. steadily growing and more people on the move to metropolitan areas, selecting a city with a large growing population that has major traffic congestion issues is ideal. Many areas in the south like, Florida or the ‘Research Triangle’ of North Carolina could have potential but a city that is located along a major transportation corridor connecting multiple cities would work more efficiently for the approach of this thesis. Looking into the three Megalopolises, the BosWash connection jumps out as the most significant (Fig. 5).

Fig. 5: The Northeast Corridor Population, America2050.com

³⁰ Ibid.
The population of this region makes up about 17% of the U.S. population and suffers from some of the worst traffic in the country. The region produces 20% of the nation’s Gross Domestic Product (GDP) on just 2% of the nation’s land area. There is a projected growth of about 58.4 million people by 2025 and 70.8 million by 2050.\textsuperscript{31} There needs to be a viable, innovative solution to help ease the congested traffic that runs along the Northeastern seaboard to relieve the growing population.

In the Western Hemisphere, the most highly populated region is the Northeast Megalopolis. This stretch of land encompasses Boston, including the suburbs to the north and parts of New Hampshire. It runs south through Providence, Harford, New York City, Philadelphia, Baltimore, Washington D.C. and into parts of northern Virginia. Joe Nathanson references the 1961 book that was authored by Jean Gottmann in an article from \textit{The Daily Record}, titled “Taming the Northeast Megalopolis”. “In the more than half-century since Gottmann’s publication,” Nathanson writes, “many have thought about better ways to navigate this Boston-Washington corridor, as congested highways and airways pose ever increasing challenges.”\textsuperscript{32}

Nathanson took an interest in understanding the transportation challenges of the Northeast Corridor, deciding to move across the country to study the region. After being assigned to several studies that involved general aviation and their ground transportation, he moved to Baltimore. He states that, “it seems

\textsuperscript{31} \textit{Northeast Megalopolis}, (America2050.com)
\textsuperscript{32} Joe Nathanson, \textit{Taming the Northeast Megalopolis}, (The Daily Record, BridgeTower Media Holding Company, LLC, 2017)
everyone is looking at innovative ways to move swiftly from Boston to Washington and major points in between, notably New York, Philadelphia and Baltimore.”\textsuperscript{33} Nathanson explains that as of 2012 a comprehensive planning study was launched by the Federal Railroad Administration (FRA) in coordination with the Northeast Corridor Future Project to establish ‘a vision for replacing aging rail infrastructure.’ As a result of the commission there is a “vision prioritizing a corridor-wide commitment to the existing NEC, from Washington D.C., to Boston, MA, by bringing it to a state of ‘good’ repair and provides additional capacity and service enhancements necessary to address passenger rail needs through 2040 and beyond.”\textsuperscript{34}

The cost of the improvements to the NEC has been estimated at an astounding $120-150 billion and would last over 25 years. Surely, there is a better solution to serve the busy corridor besides time consuming and costly infrastructure improvements. Another option is the Maglev or Magnetic Levitation Train, which has become popular in countries like China and Japan. Governor Larry Hogan (R) of Maryland traveled to Japan to experience the Maglev train that travels at 310 miles per hour. Hogan and his transportation secretary decided to move forward with a $2 million feasibility study looking into the connection between Washington and Baltimore. This ‘high-speed, superconducting magnetic levitation system’ would cost an estimated $15 billion, only covering 40 miles of the 440 miles to Boston, MA.

\textsuperscript{33} Ibid.
\textsuperscript{34} Ibid.
The latest option to improving the NEC is the Hyperloop. Elon Musk’s Boring Co. was granted tunneling permits in November of 2017 to begin digging under the Maryland Route 295. “While there seems to be some confusion as to what permit or permits have been issued, or are needed, there are more than a few questions about the Hyperloop technology.” The idea is so new that only a few companies out there are developing the technology, including Virgin Hyperloop One, backed by entrepreneur Richard Branson. Musk is known for his electric car company, SpaceX rockets and pulling off unthinkable tasks in short time frames. His goal for the Hyperloop is to connect New York City to D.C. with a 225-mile-long tube underground or elevated, that will shuttle passengers at a proposed 700 miles per hour in only 29 minutes (Fig. 6). Although costs are expected to be in the billions, no official report on cost estimations has been released at this time. Governor Hogan has shifted his attention from the costly

35 Ibid.
Maglev train to this innovative, sustainable, and potentially less expensive technology.

![Hyperloop illustration]

Fig.6: PriestmanGoode Unveils Hyperloop Passenger Pods, Dezeen.com

The Hyperloop may be a long shot, but the point of this thesis isn’t to investigate old technology like the Maglev, it is to look at new technology to understand how it can change the future of transportation architecture. Selecting a site along the NEC is ideal for this thesis. A location that needs plenty of transportation improvements and is located at the northernmost connection of the corridor is the city of Boston, Massachusetts. From my own experience growing up just 45 minutes outside of Boston, I know just how bad traffic can get. This city is ideal because it is a hub for science and technological innovations with a growing population. Traffic in the city is only expected to get worse in the coming years. In a Chapter 4 there will be a study on traffic in the city of Boston and how the city plans to deal with the growing development.
2.3 Intermodal Solutions

The United States is already several decades behind most developed countries around the world in transportation. Unfortunately, there is not just one solution to the crisis, but there have been effective attempts to improve passenger mobility through the implementation of intermodal transit centers in the United States within the last decade. In an article titled “All in One: How intermodal passenger transportation centers fit into the high-speed picture,” the author, Jeffrey Brubaker explores the rise in intermodal transit centers across the United States. Written in 2010, at a time when intermodal transit was breaking onto the scene as a viable option for transit hubs, the article discusses several projects under development at the time and some that were being proposed. To begin the article, the author uses a quote from President Obama in 2010, “Imagine whisking through towns at speeds over 100 miles an hour and walking only a few steps to a public transportation and ending up just blocks from your destination.”

In 2010, President Obama imagines a world where a personal vehicle is not the first option for getting around, but travel is more of a ‘fluid’ system moving people and goods between metropolitan areas using multiple mode of transportation. The future of transit would connect intercity and intracity transit, combining long-distance, regional, and local transit all under one roof. Intermodal transit systems have been around for some time now, but the scheme has

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36 Jeffery Brubaker, All in 1: How Intermodal Passenger Transportation Centers Fit into the High-Speed Picture, (Planning 76.5, 2010) 34-7
37 Ibid.
become more attractive since it combines multiple experiences for travelers to get to their intended destinations. It not only provides more options but opens the door for public transit in densely populated areas making it less necessary for city-dwellers to own vehicles.

When trains began spanning across the United States, the idea of the train station or union station became popular. Stations began popping up across the American landscape, particularly in cities in the Northeast and mid-west. This building type became an integral part of many U.S. cities acting as not only train stations but commercial centers with retail options including: stores, restaurants, medical clinics, post offices, barbershops, libraries, art exhibits, sports facilities, and theatres. Today, many of these buildings like Grand Central Station in New York remind us of their grandeur and elegance that was introduced in 20th century. However, it seems that we have forgotten about the significance of such monumental buildings that did so much for American society.

In 1991, a federal transportation policy was passed in support of connecting different transit modes. The Intermodal Surface Transportation Efficiency Act or (ISTEA) “requires that intermodal connectivity be included in metropolitan transportation planning criteria.”38 This legislation was crucial and helped set up the National Commission in Intermodal Transportation (NCIT). In 1994, the commission issued a report on the lack of intermodal terminals across the United States and cited it as a ‘major barrier to meeting the connectivity goal.’ This argument was supported by the Intermodal Passenger Connectivity

38 Ibid.
Database, which is part of the U.S. Department of Transportation. The database concluded in 2008 that only 54% of U.S. intercity rail stations were connected to intermodal hubs. Ferry terminals had just 44% and airports only 34%, according to the U.S. Department of Transportation. As for stations specifically in metropolitan areas with more than 50,000 people, only 61% had a connection to a transit service.

Since the inception of NCIT, there has been a growth in intermodal planning with California cities being at the forefront of the movement. The TransBay Transit Center in San Francisco began planning in 2006 and has only just opened part of its doors in early 2018, according to the San Francisco Chronical (Fig. 7). The goal of the project was to “connect 10 intercity, regional, and local transit services and serve 45 million passengers a year.”39 A few hundred miles south, the Anaheim Regional Transit Intermodal Center (ARTIC) has successfully been introduced to the ‘Platinum Triangle’, where three major tourist venues and attractions are located. The transit center connects two major metropolitan areas with a population of around 17 million people combined. It will eventually be the southern terminal for the highly anticipated California High-Speed Rail that is to connect to the TransBay Transit Center.

39 Ibid.
There has been a redevelopment of Denver’s Union Station that revives the ‘classic intercity station’ and will provide several new services including a regional bus facility, a FasTrack station (a 140-mile regional rail and bus transit system), and a bike repair shop. The total cost at the time of planning was estimated at $434.5 million. On the East Coast there have been similar developments in Miami for the Miami Intermodal Center, costing $1.7 billion. Warwick, Rhode Island has also introduced an intermodal center connection to T.F. Green Airport and Raleigh, North Carolina has begun planning for their own intermodal hub as well as several midwestern cities that have developed their own plans to help connect travelers. The rise in intermodal connectivity has
created a revival of great architecture and engineering, reminiscent of the grand halls that we once saw at places like the old Penn Station in New York City.

As the intermodal movement continues to grow, the public and private sectors may begin to see the importance of connectivity through design and the sustainability benefits that it offers. Cutting down on personal car use is a goal for many cities that not only decreases pollution output but also cuts down on traffic congestion. A city that is in dire need of some transportation remodeling is Boston, Massachusetts. Many commuters spend hours upon hours in traffic, the city is not easy to navigate, and it takes a lot of time to get anywhere. There has been a ImagineBoston 2030 plan put in place that suggests improvements to existing infrastructure and the introduction of new and improved bus routes.

2.4 Emerging Technology: Hyperloop

In 2013, the idea of a new mode of transportation emerged. Referred to as the “Hyperloop”, this futuristic means of travel could change cities by decreasing traffic, revitalizing infrastructure and introduce an original building type, the “intermodal transit” center. A new concept like the hyperloop may be the solution to some of the issues that we see in transit and the stations that house this mode of travel. This paper will begin to present some of the major issues in the fraught relationship between architecture and transportation. There are many questions that need to be asked and endless solutions to the transportation problems that we see today. Therefore, continually circling back to the thesis question, will help develop our understanding of how innovative design can and will inform transportation solutions.
Elon Musk’s Hyperloop idea was born out of a 57-page white-paper that was released to the public in 2013. In this document he describes a fifth mode of transportation that could revolutionize travel between cities like Los Angeles and San Francisco. Connecting the two cities in a 35-minute journey inside of an enclosed capsule traveling at speeds of 800 mph in an “almost no pressure vacuum tube.” Musk believes that the Hyperloop is safer and less expensive than high-speed trains and more efficient than supersonic jets for traveling distances less than 1000 miles. A new form of transportation creates the potential for new architectural design research into what could become the modern transportation hub within major cities that could further connect people around the world in a cheaper and quicker manner.

Elon Musk’s “Hyperloop Alpha” was an open source document released to the public to further the conversation of transportation technology and the likelihood of the Hyperloop or something like the Hyperloop could revolutionize how we travel. His view on transportation today is backed by science, proclaiming that most all forms of transportation are not sustainable or at least not yet. Musk is articulating a challenging position but as most people know, Elon Musk comes up with radical ideas and somehow makes them come to life.

The writing in this document provides a lot of fascinating points about the technology backing the Hyperloop. It is clear from the beginning that there is a whole lot of work that needs to be done to further enhance the concept to truly

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40 Elon Musk, Hyperloop Alpha, (White Paper, 2013)
41 Ibid.
make it happen. One item that is never really discussed is the Hyperloop Station, which Musk mentions needs to be addressed. What will a futuristic transportation hub look like? That is a question worth answering. The future of transportation architecture and how something like the Hyperloop could fit into an urban setting needs the expertise of an architect to design and develop a transportation hub of the future.

There are no built examples, which is what makes this thesis such an exciting challenge. The technology is being improved by companies like Hyperloop One and Virgin Hyperloop, so within the next decade there may be multiple routes around the world that will further prove the concept. Bjarke Ingels Group or BIG Architects have already developed concept designs for a Hyperloop station in Abu Dhabi at the foot of the world’s largest building, Burj Khalifa. There have been a lot of discussions about the Hyperloop since this papers release and the backing for the concept only continues to grow.

There has been much skepticism about Hyperloop technology and whether it is feasible or not. The true cost and performance are a couple of the major fears but according to Musk and the many people and companies that are further developing the idea, believe that it could transform the way we travel, making it cheaper, safer, and far quicker. Within the next few years research will continue to be run on tests tracks in California and Nevada deserts, investors will continue to pour money into start-ups and architects will have the thrilling opportunity of taking on a new revolutionary transportation hub at the heart of cities.
CHAPTER 3

PRECEDENT STUDIES

3.1 Grand Central Terminal

Grand Central Terminal is one of the world’s most recognizable works of architecture in the world, let alone the world’s most famous train station. The building was built in 1913 in the Beaux Arts style, which draws upon principles of French neoclassicism while incorporating Gothic and Renaissance elements. It was a majestic beacon for the city of New York and a symbol of power to all those who traveled to and from the city. There are 44 platforms that serve 63 tracks, making it one of the largest and most complicated train depots in the world (Fig.8). Those who have passed through the doors into the main hall will notice “a celestial ceiling mural and the iconic four-faced clock, worth an estimated $10-20 million.”

Fig.8: Historic Grand Central Terminal Exterior, ArchitecturalDigest.com

Grand Central Terminal was an engineering marvel of the day. Once you strip away the limestone facings, painted surfaces, and underground tunnels, it is obvious why this building is compared to structures like the Eiffel Tower and Brooklyn Bridge. The significance of this awe-inspiring engineering, Anthony Raynsford explains, “appears in human form: the hurrying masses that continually pour across the floor of the main concourse and circle the information desk. The crowd is both dwarfed and amplified by the enormous arched windows and the 110-foot vaulted ceiling with its zodiac motif. As an urban monument, Grand Central Terminal stages an elaborate spectacle whose mythical object is the metropolitan crowd; as a piece of engineering, it orchestrates an immense flow of human circulation.”

Fig. 9: Grand Central Terminal Grand Hall, ArchitecturalDigest.com

Grand Central Terminal was one of a kind. A building so large and so elegant that could be used by any person in the world, a democratic space full of movement and forward-thinking. The true genius of the building is not the building itself. Technology improves, new materials are used to stand taller and larger. The true genius lies within the concept that a building can provide passage to anywhere in the world to anyone who chooses to embark.

This for-the-people ideology would not be supported with a weak circulation pattern. It was critical for architects to design a building with movement in mind. The design for Grand Central was largely based on circulation issues as well as “the crowds themselves as objects of spectacle within the terminal.”44 Instead of being regarded as an independent object, Grand Central was designed to become part of the industrial apparatus of railroads. The author writes, the station buildings and their interior circulation spaces are herein construed both as architecture and as machinery, analogous in function to switching yards and train tunnels.”45

The building ran like a fine-tuned engine. A beautiful orchestra of movement, with people going up and down, left and right, side to side. Grand Central Terminal has inspired every single transit terminal hereafter. Through the past 100-years since the erection of Grand Central Terminal, we have seen some truly inspiring works of architecture that help people to move from point A to point B and everywhere in between. The standard for designing a transit

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44 Ibid.
45 Ibid.
terminal grew from the work of architects, Reed & Stem, Warren & Wetmore, laying the blueprints for what a transit terminal should look and feel like. This building will continue to drive the urban centers of today as architects look to the past to drive the future cities tomorrow.

3.2 Berlin Central Station

Berlin’s Hauptbahnhof or Berlin Central Station opened in 2006 at the cost of $850 million. Design and construction took 12 years to symbolically reunify eastern and western Germany after being divided many years as a result of the World War II and the Cold War. The rail station became the largest and most modern in Europe, linking cities across Europe to the north, south, east, and west to a central location. Berlin Central Station became a major railway intersection to ultimately unify a previously divided city. Besides being a symbolic work of architecture, the design is grand with several large volumes intersecting to create an all-encompassing structure. (Fig.10)

Fig.10: Berlin Central Station, ArchDaily.com
An east-west oriented viaduct spanning 1,000 meters or 3,280 feet is the first volume you see as you in the image above. This train hall is located 10 meters (32 feet) above ground and has 320 meter (1,050 feet) wide vaulted glass roof that covers all the platforms below. North-south oriented lines enter through a 4-kilometer (2.5 mile) tunnel and met by a 160 meter (525 foot) by 15 meters (50 foot) below ground volume. Two, parallel 12-story office buildings straddle the east-west concourse and a 213-meter (700 foot) by 41.2-meter (135 foot) entrance hall provides access to the stations three levels. The three levels are made up of commercial spaces, parking areas, and train services. You can see the main form of the building in the image below. (Fig.11)

Fig.11: *Berlin Central Station Structure*, ArchDaily.com

 Architects and engineers were able to skillfully integrate circulation into the overall form with escalators and elevators that connect the eight train platforms to each other. Since the structure has so many layers, a filigree glass and steel façade shell were used to allow light into the lowest levels of the station. To create such long spans, attention to structural detail was key: “despite its
considerable size the train hall appears light and transparent. This outcome was
achieved through the use of an innovative structural system and modern
materials. To create the most transparent roofing structure possible, a grid shell
was developed rather than a traditional purlin roof. The grid shell system
minimized costs by exploiting the hall’s curvature to create an extremely efficient
structural system.”46

Effective design strategies were used throughout this building, particularly
on the roof structure to meet the spatial requirements for train platforms below
and to span far distances. A cable suspension system was used above and
below certain parts of the frame of the roof to help improve the bending moment
of the structure. Special radial spherical plain bears were developed to support
the glass roofing to prevent damages caused by the vibrations of train traffic
below.

Berlin Central Station is one of the most significant train stations in the
world. About 300,000 travelers arrive at the 70,000 square-meter (230,000
square-foot) transit terminal each day. The building is also supported by a 15,000
square-meter (50,000 square foot) office, retail and restaurant spaces. It is a
remarkable work of architecture and transit design that is critical to analyze in this
research. Architecture firm, Gerkan, Marg, and Partner of Hamburg, Germany
integrate the crisscrossing rail lines into a modern transit center that anyone
traveling would enjoy visiting.

46 Dr. Ing Hans Schober, Berlin Hauptbahnhof, (Schlaich Bergmann and Partner,
2006)
3.3 Anaheim Regional Transit Intermodal Center

Solutions to the transit issues have been proposed but one project that has been successful in this endeavor can be found in Anaheim, California. In an article from Civil Engineering News, author Robert L. Reid explores the efficiency of an intermodal transportation hub located at the intersection of several sporting venues, recreational facilities, and entertainment centers in Anaheim, California.

Fig.12: Anaheim Regional Transit Intermodal Center, STVInc.com

“Anaheim Mass Transit Center Will Feature Soaring Shell Structure” is the title of the article and it outlines the value of interconnected transportation hubs (Fig.12). The 67,000 square-foot building provides access to ten different modes of public transportation including, “Amtrak passenger trains, the local commuter rail network known as metro link, various bus services, resort shuttles, taxis, and bicycles,” and eventually a “southern terminus of California’s high-speed rail
system and possibly a terminus of a proposed streetcar line.”\textsuperscript{47} The $184-million facility is an impressive assemblage of transportation devices that makes transferring from one mode of travel to another as efficient as possible.

The design for the transportation hub, nicknamed “ARCTIC”, is an elongated shell that reaches 115 feet at its highest point, 250 feet long, and 180 feet wide. The architecture is expressed through structural elements, arched steel supports create a diagonal grid that is encapsulated by a material known as ethylene tetrafluoroethylene (ETFE), a material that has grown in popularity in recent years because of its insulating capabilities. ETFE allows plenty of light through its pillow-like structure to help illuminate the busy transportation center, which also features stores, ticketing booths, offices, and other necessary amenities and services. The expressive nature of the structure draws visitors into a great, open space, that designers have named the ‘gateway’ to Orange County. Bruce Gibbons, the senior principal of Thornton Tomasetti, compares the grand space to “the great transit halls of Western Europe.”\textsuperscript{48}

ARCTIC also features sustainable design amenities that are intended to achieve a LEED platinum standard, the highest honor awarded by the LEED council. The terminal takes advantage of natural ventilation with operable louvers at either end of the structure to help control air through the top of the shell. A radiant floor slab at the base of the building will absorb solar radiation during the

\textsuperscript{47} Robert L. Reid, \textit{Anaheim Mass Transit Center Will Feature Soaring Shell Structure}, (Civil Engineering 83.1, 2013) 16-22

\textsuperscript{48} Ibid.
day and release warm air during the cooler evenings to heat the building. On very hot days, chilled water is to be pumped through the floor slab to cool the building. Keeping members of the public comfortable as they pass through the terminal is a critical design goal of the architects at HOK, the leaders on the project. Some other sustainable features include reclaimed water to be used for cooling towers, toilets, and other non-potables, as well as “10,000 square-feet of photovoltaic cells located on carport canopies in the site’s southern parking areas.” There is also a storm water collection system with a filtration container that allows runoff to be captured as potable water and recycled for further use or sent into a nearby river.

What makes ARCTIC so successful is its location in Anaheim, known as the Platinum Triangle. There are several popular destinations in this area including Angel Stadium, where the Los Angeles Angels of Anaheim play, the Honda Center, where the Anaheim Ducks play, and a transportation connection to nearby Disneyland. Without so many amenities located in close such proximity to ARCTIC, the transit hub would be obsolete. In selecting a site location for an intermodal transit hub, there must be several valid reasons for selection. In the case of ARCTIC, a popular destination was picked based of the current attractions in the area and easy access to other modes of transportation made it an even better choice. The less infrastructure needed for connecting different modes of transportation, the better the site.

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49 Ibid.
An urban center is an obvious choice for a transportation hub but besides having great real estate, the design of the structure itself is crucial. ARCTIC features an enormous shell-shaped design that utilizes impressive structural engineering feats to create an open environment within. This type of transit hub, as mentioned in the article, is reminiscent of Western European transportation centers. The design allows for pedestrians to move freely about in a wide-open space and eases the anxiety of travel while also providing important amenities and services for people passing through. Developing a design scheme that is structurally focused is an intriguing approach. It is a concept that several other notable transit centers have done in recent time, most significantly the World Trade Center Hub in New York City. Santiago Calatrava, the famed engineer-architect, designed the hub with the same conceptual method.

A LEED Platinum building is not an easy feat to achieve but the designers on this project committed themselves to doing so. The most important feature that helps towards this goal is the buildings east-west orientation, which helps maximize southern exposure. This is one of the most basic design moves that you can do to improve passive solar design, taking advantage of the suns energy to heat and cool a building. The use of a thermal slab at the base of the building is also a method in passive design that help absorb heat in the building is released when the temperature drops. These are crucial practices used to improve a buildings overall performance throughout the year. Learning from each of the significance of location, structural design approach, and sustainable design
systems that were utilized in ARTIC will significantly help in determining the best approach to designing an intermodal transportation hub.

3.4 Tokyo Station City

In the past few decades, several developed Asian countries have led the way in the design of state-of-the-art transit stations. Japan is one of those countries that has been redeveloping their railway stations to accommodate for new spaces that account for consumption and leisure. In this case study we will be looking at one such example, the Tokyo Station City (Fig:13).

![Tokyo Station City](TokyoStationCity.com)

Fig.13: Tokyo Station City, TokyoStationCity.com

This project has redeveloped what was once an outdated railway station into a building that has become an important urban center for the city of Tokyo. With the experimental introduction of new businesses, shopping centers and entertainment venues, “the station redevelopment, along with related investments in the surrounding space represent a distinctly Japanese approach to transit-oriented development.”

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In an article titled, “Tokyo Station City: The railway station as urban place”, authors John Zacharias, Tianxin Zhang and Naoto Nakajima, study the relationship of transit-oriented developments to urban centers. Their exploration takes them to Japan where you can find some of the largest and most complex transit stations in the world. Their role in urban Japanese transportation is critical in connecting to suburban regions and to other cities. In this case study, the primary mode of transportation is rail, not intermodal. This is because Japanese subway and trains have become the most effective way to transport people who live outside of the city whereas, many transit-oriented developments in North America tend to offer several modes of transit that are either road-based or rail. Some 86% of all travel in Tokyo is by rail and just 61% New York. 51

The transit centers of Japan have become something more than just a place to catch a train. Their role has developed into something more, ‘cultural symbols, social communication hubs and business centers.’ Since the redevelopment of transit centers has started, the trend in Japan is to combine many industries into a new urban center that is located within the heart of the city. Transit-oriented developments of North America are missing grouping of “commerce, leisure, media, fashion, information…so as to make the stations important spaces for creation and innovation.”52 Design of these facilities has paid special attention to lighting and the social ambiance, as to provide people who are passing through an inviting spaces to rest, shop or eat.

51 Ibid.
52 Ibid.
Zacharias et. al. breakdown their understanding of the new transit-oriented development model.\textsuperscript{53} First, a discussion into why there is an increased investment into improving transit-oriented developments and the spaces that support it. Second, programs are then analyzed to understand their overall contribution to creating a new urban place. Third, developing an understanding of the relationship of the spaces to the station and surrounding development. Last, the authors discuss urban center and how the new model for a transit center will affect the adjacent buildings in the city center.

In 2000, railway companies began investing in the properties surrounding major stations including the Tokyo Station City. The redevelopment of this station would provide a new pedestrian system that would connect the new commercial and public leisure spaces together. “The common goal of a Japanese railway station development is to enhance the station commercial function among many others, making the station a powerful magnet for visitors.”\textsuperscript{54} The consequences of this type of redevelopment were positive, in fact land value increased significantly in the surrounding areas. In the case of Tokyo Station City, there are several major landmarks close by including Imperial Palace, and the Ginza and Nihonbashi commercial areas.

Tokyo Station City is one of Japan’s busiest railway stations, ranking fifth among the East Japan Railway Company with 380,000 passengers a day. More than 30 lines, both rail and subway converge onto this busy station. It has three

\textsuperscript{53} Ibid.
\textsuperscript{54} Ibid.
major entrances and many platforms that are both above ground and below
ground. This extremely complex configuration of the made this redevelopment a
tricky project but the railway companies felt that ‘place-based’ activity and
consumption was necessary to link travelers to different parts of the station. This
design helped to begin reinventing how many people around the world view transit centers. Tokyo Station City has become a symbol of the city with its
unique modern integration into a 20th century station, improved connections for pedestrians to travel and an urban center that is crucial to the success of a continuously growing city.

3.5 Hyperloop Station Concept

Hyperloop technology is in the early stages of development but that isn’t
stopping architecture firms like UNStudio. The Dutch firm has developed a modular design concept for what a hyperloop station could look like soon (Fig.14).

Fig.14: UNStudio Hyperloop Interior Concept, Dezeen.com

With the integration of cutting-edge technology in combination with multiple transportation options, the studio has produced what could be the center of a new European hyperloop system, beginning in Amsterdam and ending in
Frankfurt. This line could transport passengers in just 51 minutes, cutting the typical 4-hour train ride down significantly.

In an article titled “Architects Unveil Design for Europe’s Network of Hyperloop Stations” from MyModernMet, Jessica Stewart describes the benefits of the new form of transportation. “Hyperloop technology is a solar-powered system that could allow passengers to travel at ultra-high speeds over land, making it an environmentally friendly alternative to flying.” An introduction of hyperloop technology would have the capabilities of cutting down time and cost of traveling between cities like Amsterdam and Frankfurt that are 280 miles apart. This would help bridge the gap between distances and culture, an exciting future that could be on the horizon.

UNStudio’s concept was revealed at the HyperSummit in 2018, which discusses the possibility of bringing a European hyperloop network to the continent. Their design uses a tessellated modular system that can adapt in size to the needs of any location, operating as transportation hub and meeting place. With this goal in mind, architects developed a design that could be flexible and suit the needs of passengers with the introduction of programmatic elements like luggage storage, daycare, hotel, offices, and multiple modes of transportation to connect to the existing city infrastructure. UNStudio explains: “Global urbanization, population growth, and urgent environmental concerns create infrastructural challenges that cannot be resolved with our current modes of

55 Jessica Stewart, Architects Unveil Design for Europe’s Network of Hyperloop Stations (MyModern.com, 2018)
transport. A sustainable alternative to air travel is therefore imperative. Just as each hyperloop line will draw power from solar panels on the tube, each hyperloop hub must also act as a battery to sustain itself.56

UNStudio focused on using sunlight to illuminate the entire terminal by designing large glass panels that also protect passengers from the elements. The canopy collects energy through solar panels and utilizes a water collection system that is to be used within the facility. With the additional energy created by the transit terminal and hyperloop tube solar panels; electric vehicles, electric buses, and bike stations could be powered. Making this transit hub a sustainable and effective means of travel. To improve the overall design, UNStudio placed amenities at strategic locations throughout the building that includes five areas to meet the needs of travelers: green, culture, work, health, and travel. (Fig.15)

Fig.15: UNStudio Hyperloop Station Program Concept, Dezeen.com

56 Ibid.
Hyperloop technology is emerging as a plausible means of transportation and many organizations, cities and countries are taking this very seriously. This precedent shows the capabilities of a hyperloop transit terminal and how it can positively impact the way we travel and use sustainable energy. Designing for a specific site will have its own challenges however drawing design elements from what is working well with this precedent is necessary to the overall success of this thesis.
CHAPTER 4  
SITE INVESTIGATION  

4.1 Future of Boston  

Boston, Massachusetts has countless issues with their transportation system. Highways are always crowded during rush hour; the Subway T is outdated and there have only been minor improvements to Boston’s North and South Stations in the past few years. This region could use a healthy upgrade that includes a new form of transportation and a high-tech intermodal transit terminal. Boston became the first city in the world to have a Subway line and perhaps they are the perfect city to have a Hyperloop line.

In the diagram below, some of the busiest train corridors and highways networks are shown along with general populations of major cities in the Northeast (Fig.16). The population of this region is expected to rise, and traffic will only get worse.

Fig.16: Northeast Transit Routes
A proposed Hyperloop route running from Washington D.C. to Boston could help to alleviate traffic, providing an alternative for millions of travelers who want to stay off the road or out of the air. The image below shows a proposed Hyperloop route along the Acela rail line (Fig. 17). Using an existing rail line would help to cut costs, without having to make way for a whole new system. The line could be underground or elevated to avoid existing infrastructure still in use.

Fig.17: Northeast Hyperloop Route

Zooming in even further to the city Boston. Primary and secondary highways crisscross the Greater Boston region, stretching west to the cities of Worcester, MA and Springfield, MA. The diagram below shows the busy highway system along with Commuter Rail lines and busy Train Routes (Fig. 18).
Over 200,000 people are using the subway system in Boston daily and nearly 500,000 are using the Commuter Rail system. The transportation system is reaching a breaking point and needs to expand or come up with innovative solutions.

In a document titled “ImagineBoston2030”, the city lays out a plan for the next decade with feedback from 15,000 residents. The article states, “today, Boston is in a uniquely powerful position to create quality jobs, strengthen our competitive economy, add the housing our city needs to become more affordable, and prepare for climate change.”

The city is using this document to continue improving a productive economy, plan for a growing population, provide

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\(^{57}\) Imagine Boston 2030, (City of Boston, 2017)
more equality for people of color, affordable housing, adapt to a changing climate, and introduce transformative technology.

The plan looks to “identify three types of places for growth and enhancement.” These include existing neighborhoods that need enhancement, commercial cores that encourage mixed-uses, and edge neighborhoods that are to be expanded. One neighborhood that is discussed is the South Boston Seaport District. This area is expected to have a large development in mixed-uses located on the Waterfront. The Seaport District in Boston has seen significant growth to its economy and population since the mid-2000’s. Right now, there are a lot of unused areas or open parking lots that could be optimal locations for a Hyperloop terminus and intermodal transit hub.

### 4.2 Seaport District

The South Boston Seaport District has seen a tremendous rise in the past 15 years. The image below shows the Seaport District from 2006 as barren wasteland of parking lots (Fig.19).

![Image of the Seaport District in 2006](Fig.19: Boston Seaport District 2006, BRAdivisors.com)

58 Ibid.
The amount of construction that has taken place is clear as you compare the 2006 image to the 2018 image below (Fig.20). A lot has changed in this area and it is only expected to grow.

Fig.20: Boston Seaport District 2018, BRAdvisors.com

In a document titled, “South Boston Waterfront Sustainable Transportation Plan”, the introduction states, “the South Boston Waterfront is a truly unique place with tremendous, still to be realized, potential for the future.”59 The document summary continues, “At the heart of the City of Boston, it is home to an active, growing industrial port, an emerging, residential area; first class convention center, cultural and recreational resources that attract visitors from throughout the nation and around the world; and, an emerging center for innovation in the finance, legal, biomedical research, and technology sectors.”60 There seems to be no better place in the city of Boston to put a new, high-tech intermodal transportation terminal that plans for the exciting years to come.

59 South Boston Waterfront Sustainable Transportation Plan, (Mass.gov, 2018)
60 Ibid.
There is a laundry list of goals that comes out of this document including: improve all access and mobility for all, support economic growth and vitality, reinforce sustainable policies and programs, enhance the public realm, contribute environmental and health benefits, and invest smartly for the future. With that said, it is quite the challenge the city is taking on. The existing transportation is weak with the Bus Rapid Transport or Silver Line Transitway running through the neighborhood as the primary public transit. There are several city bus lines that run through the area, but transit connections are weak here and do not provide access to many parts of the region.

The graph below shows the growth in population and the amount of employment that is expected for the neighborhood (Fig.21).

Fig.21: Population/Job Growth,
SouthBostonWaterfrontSustainableTransportationPlan.com

In all, Boston is preparing for its population of 710,000 to increase to 724,000 by 2030, about 1/3 of that growth will happen in the Seaport District. The document states that transportation, “if left unaddressed, existing and future access and
mobility challenges could thwart economic growth and threaten the long-term vitality of the South Boston Waterfront."61

An important conclusion that is draw from this document is that there needs to be a multimodal or intermodal transit center that helps to address the growing need for transportation and connections. It is stated that to further enhance the connection, a “complete design of multimodal accommodation along Summer Street,”62 is necessary. This makes the argument for an intermodal transit hub straightforward since the city is already proposing that this is necessary for the future success of the neighborhood, “there is a need to create mobility hubs that bring together multiple transit modes and parking in the Waterfront.”63 Choosing a strategic site in the area is very important. It must be in an area that can integrate into the existing urban infrastructure and centrally located for easier access.

61 Ibid.
62 Ibid.
63 Ibid.
4.3 Site Location

A large site located at 85 Fargo Street, South Boston, MA adjacent to summer street was selected as the site location for an intermodal transportation hub. The image below shows its location in light blue (Fig.22).

![Site Location](image)

Fig.22: Site Location

It is a 900,000 square-foot property that is currently used as an industrial site for parking large trucks and vehicles. It is within a mile walking distance of the Boston Convention Center, Boston Design Center and many future developments like Seaport Square and Innovation Square. This site was carefully selected and works logically with the surrounding transportation of the neighborhood. The two diagrams below reveal its proximity to local transit and attractions (Fig.23 & Fig.24).
Fig. 23: Transportation Routes

Fig. 24: Transportation Hubs
The top diagram shows some of the major highways, primary and secondary roadways, and railways that enter South and North Station. The bottom diagram shows transportation hubs. You can see that downtown Boston has South Station and North Station, which have commuter rail lines and bus transit. There is a deficit of any rail or major bus stations in the Seaport but there are two waterfront ferry and cruise terminals.

The diagram below shows a transportation connection proposal that uses the AMTRAK line or Acela Line that was previously talked about as a plausible Hyperloop route (Fig.25). An elevated Hyperloop route could run along this existing infrastructure (shown in yellow) into the city of Boston. It would then turn into the Seaport District and follow along the old, unused Track 62.

![Transportation Connection Proposal](image)

Fig.25: Transportation Connection Proposal
The Hyperloop would run right through heart of the district for all to see and then reach the terminus point of the site shaded in light blue. Another proposal that would also add value to this site is a Red Line Subway extension (shown in red). There are no subway lines in the Seaport so this could be an extremely useful proposal that would connect downtown Boston to the South Boston neighborhood.

The proposed site would then have a Hyperloop terminus as well as a Red Line Subway station. In addition to these two modes of transportation would be a Bus Rapid Transport or Silver Line connection. Currently the Silver line runs between North Station and Logan International Airport in East Boston.

Fig.26: Seaport District Transportation
This would be a useful stop for people who want to use public transport that need to get to downtown Boston or to the largest airport in New England. A city bus line also runs directly in front of the site making this location perfect for a city bus stop. These transit lines are shown in the diagram above (Fig.26), the diagram below shows the surrounding attractions located nearby (Fig.27).

Fig.27: Seaport District Attractions
4.4 Site Analysis

After locating a strong site location, analyzing the site was very important to get a better understanding of the area. The first item of analysis was the climate. Boston has a humid continental climate, large seasonal differences, and precipitation throughout the year. On average there is 42.2” of rain per year and 41.8” of rain per year. The average temperature is 51.3°F with the warmest month being July and the coldest month being January. Boston’s climate deals with warm and cold temperatures, rain and snow. Designing a building that is adaptable and can handle of these different elements was key to the success of the building.

In terms of demographics, the South Boston Waterfront Sustainable Transportation Plan states that the population of South Boston was 38,206 in 2018. The population of the neighborhood grew 25% from 2000 to 2015. Since 2000, there has been a 37% population growth aged 25 to 34. This growth has helped the neighborhood economy significantly with a 10% growth in the number of payroll jobs from 2011 to 2014. Between 2010 and 2016 the housing industry saw the construction of 2,723 new units. The media age is 30.5 years and the race breakdown include 78% white inhabitants. Black or African Americans make up 5%, 10% Hispanic, 5% Asian, and 2% other.

The site topography is extremely flat, having been part of Boston Harbor until it was slowly filled in the past two centuries. The image below shows 1’
contours but most of the height differential happens at the coastline, dropping down nearly 15 to 20 feet to sea level (Fig.28).

Fig.28: Topography

The land use of the Seaport District is mostly government owned or institutional. This makes up nearly 50% of the land use in the area. About 10% is strictly commercial land, about 40% is dedicated to residential land use. The remaining 10% is divided between mixed-use and industrial areas. According to the ImagineBoston2030 plan, this is likely to change, mixed-use areas are expected to increase. This makes the land-value go up if you have residential and commercial areas combined. The diagram below shows the current land use breakdown of the neighborhood (Fig.29).
Fig. 29: *Land Use*

The existing buildings and infrastructure of the Seaport District play a major role in the site analysis. Understanding the current layout, building sizes, building heights help to set the scale for an intermodal transit terminal. Several buildings close by have a huge building footprint, others are smaller in footprint but taller in height, and to the south in the South Boston neighborhood you can see most of the buildings are small triple-deckers. The site itself only has a few small structures, which makes this an ideal site for new construction. These diagrams can be seen below. (Fig. 30)
Fig. 30: *Existing Buildings and Infrastructure*
CHAPTER 5
DESIGN PROCESS

5.1 Program Breakdown

The program breakdown for this 20-acre site or 900,000 square-feet was divided into three. First, the building makes up about 300,000 square-feet. This number was driven by the size of the site in consideration with precedent studies. Anaheim Regional Transit Intermodal Center and the Berlin Central Station both shared similar site constraints and appropriate programmatic elements. After finalizing the size of the building, it was important to consider transportation infrastructure as well as parking, this was also given 300,000 square-feet. Another 300,000 square-feet was dedicated to green space or landscape that would help to integrate the building into the surrounding landscape.

Once the site was divided into thirds, dividing the building itself into percentages and square footages came next. Precedent studies were used to come up with programmatic elements that would help to improve the transit terminal experience. Certain spaces that were introduced to the building included: security checkpoints, ticket counters, circulation space, waiting areas, workspaces, retail, restaurants, attractions and restrooms. Below is a full breakdown of all the spaces included in the building program. The diagrams assist in understanding the program relationship and how the spaces may be rationally organized (Fig.31 & Fig.32).
• Site: 300,000 SF (Urban Connection & Landscaping)
• Transport: 300,000 SF (Transit Services & Infrastructure)
• Building: 300,000 SF (Floor Space)
• Concourse: 25% (70,000 SF)
  • Security Checkpoint 20% (15,000 SF)
  • Ticket Counters 15% (11,250 SF)
  • Circulation 50% (37,500 SF)
  • Waiting Area 10% (7,500 SF)
  • Restrooms 5% (3,750 SF)
• Commercial: 25% (70,000 SF)
  • Retail 25% (18,750 SF)
  • Restaurants 25% (18,750 SF)
  • Attractions 15% (11,250 SF)
  • Circulation 30% (22,500 SF)
  • Restrooms 5% (3,750 SF)
• Hyperloop Terminal: 20% (60,000 SF)
  • Circulation 30% (18,000 SF)
  • Waiting Area 40% (24,000 SF)
  • Workspace 20% (12,000 SF)
  • Restrooms 10% (6,000 SF)
• Subway Red Line: 10% (30,000 SF)
  • Circulation 30% (9,000 SF)
  • Waiting Area 40% (12,000 SF)
  • Workspace 20% (6,000 SF)
  • Restrooms 10% (3,000 SF)
• Pick Up/Drop Off Terminal: 7.5% (15,000 SF)
  • Circulation 30% (4,500 SF)
  • Waiting Area 60% (9,000 SF)
  • Restrooms 10% (1,500 SF)
• Regional Bus Terminal: 7.5% (30,000 SF)
  • Circulation 30% (9,000 SF)
  • Waiting Area 60% (18,000 SF)
  • Restrooms 10% (3,000 SF)
• Silver Line (Bus Rapid Transport) Terminal: 2.5% (15,000 SF)
  • Circulation 30% (4,500 SF)
  • Waiting Area 60% (9,000 SF)
  • Restrooms 10% (1,500 SF)
• City Bus Terminal: 2.5% (30,000 SF)
  • Circulation 30% (4,500 SF)
  • Waiting Area 60% (9,000 SF)
  • Restrooms 10% (1,500 SF).
Fig. 31: *Program Relationship*

Fig. 32: *Program Organization*
5.2 Linear Circulation

In a 2014 journal titled, “Examining influence of merging architectural features on pedestrian crowd movement”, authors Nirajan Shiwakoti, Yanshan Gong, Xiaomeng Shi, and Zhirui Ye explore and conducted experiments on an architectural feature called ‘merging corridors.’ The authors have academia backgrounds and are researchers at RMIT University, School of Aerospace, Mechanical and Manufacturing Engineering in Victoria, Australia and Southeast University in the Jiangsu Province of China. This study features a controlled laboratory walking experiments to help understand the impact of merging angles within the floor plans of public infrastructure. The goal of this study is to develop and test pedestrian crowd simulation models to help inform designers, architects, and planners.

To produce the best possible design for multimodal transportation centers, shopping malls, stadium, and concert venues, special attention to the way people move, specifically merging, will ensure efficiency and safety of pedestrians as they move through public spaces. Merging points can cause delays and discomfort as people weave their way in and out of pedestrian traffic, thus reducing the speed at which people can move through a space. As noted in, previous studies on documented crowd disasters have highlighted that sudden change in the egress direction in a restricted passage due to merging and turning could initiate trampling and stampede as people rush to escape.”64 There is an

64 Nirajan Shiwakoti et al., Examining Influence of Merging Architectural Features on Pedestrian Crowd Movement, (Safety Science, 75 Vol., 2015)
understanding that merging flows of people do clearly cause issues, especially in an evacuation. Nevertheless, there is little data about the merging process and this study aims to explore this issue through the collection of data and analysis.

In this first part of the paper a literature review of crowd movement is conducted. Researchers have used “mathematical modelling, simulation and empirical approaches”65 to investigate the complexities of how people move and make decisions in a space. Many studies use animal models that could have alternative motives from humans moving through a space. Other studies used mathematical models that may not fully articulate the decision-making process of individuals. The authors conclude that research on the subject is limited. In an experiment by Tajima and Nagatani (2002), an “applied lattice-gas model of biased random walkers” simulated pedestrians merging in a t-shaped channel. In this scenario, clogging occurred at either channel or both channels. In most of these studies it was concluded that complex architectural configurations may result in inefficient egress.

A series of experiments were conducted with 22 participants that included 6 females and 16 males between the ages of 22 and 26. Three merging angles were used (60°, 90°, 180°), each conducted 6 times, totaling 18. A normal walking pace was the standard speed of each pedestrian, rather than a slow jog, which might have given some competitive advantage. The layout of the experiment used two corridors that were each 7 meters-wide that merged into one common corridor that was 6 meters-wide. To create a more realistic

65 Ibid.
situation, 12 participants merged from one direction and 10 came from the other. No information was provided to the participants about the aim of the research and the men and women were told to walk to the merge point. To make sure that the entire experiment was recorded properly, four synchronized video cameras were set up.

Once the experiment was completed, there were several interesting results that helped the researchers understand the movement of the participants. In the first part of the results, the trajectories of the participants were analyzed. The two streams of pedestrians tended to stay on the original side that they had begun on to avoid any sort of collision at the merging point. When the angle was switched from 60° to 180°, things got a bit more interesting. The 180° corridor was more chaotic and demonstrated that this merge was more complicated, causing some participants to have to weave in and out of one another. “The trajectories analysis demonstrated that pedestrians usually try to exhibit self-organized behavior by avoiding conflicts…despite their desire to stay on their current path, at the merging areas turning and weaving occurred, (demonstrated by the conflicts in trajectory).”

The next analysis looked at speed. The merging process was broken into three different sections called: merging initiation point, merging area, and merging completion point, seen in the image below. An interesting trend appeared in the data, a visible change in speed can be seen in the time and distance diagram below (Fig.33 & Fig.34). As participants made their approach to

66 Ibid.
the merging point, all began to slow down significantly as to not run into other walkers. Immediately after the merge had occurred, participants then sped back up, perhaps not know that they were in fact moving more rapidly than before.

"It can be clearly seen that on the merging area, there is drastic change in speed as compared to after merging," with the greatest reduction in speed at the 180° merging corridor (Fig.35). A reduction in speed of about “25% and 34% respectively for 90° and 180° merging corridors for normal walking” speeds, which can also be seen for slow running.\footnote{Ibid.}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{linear_circulation.png}
\caption{Linear Circulation (A), Nirajan Shiwakoti et al., \textit{Examining Influence of Merging Architectural Features on Pedestrian Crowd Movement}, (Safety Science, 75 Vol., 2015)}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{irregular_circulation.png}
\caption{Irregular Circulation (B), Nirajan Shiwakoti et al., \textit{Examining Influence of Merging Architectural Features on Pedestrian Crowd Movement}, (Safety Science, 75 Vol., 2015)}
\end{figure}
This study proved that an architectural feature like merging corridors is a major component for public infrastructure, especially transit stations, shopping malls, and stadiums. These controlled experiments helped to prove that the speed at which people move through merging corridors will need to be adjusted to not conflict with the trajectory of other individuals. Merging angles in floor plans are a common feature that many architects and planners use to control the flow of pedestrian traffic. The research provided here shows that by minimizing the use of angles should minimize the amount of time spent adjusting the speed at which people have to adjust as they move through a merging corridor. The
researchers agree that further studies must be done with a larger group of participants and more merging angles to be considered.

The design of merging corridors is extremely important especially when massive amounts of people are moving in and out of a building like a busy transit center. By minimizing the number of angles that pedestrians must navigate through, the amount of time spent at busy merging points will be decreased. If an intermodal transit center offers several forms of transportation, then how can the design of the building most efficiently allow people quick and safe movement from one space to the next? Perhaps a building that is designed in a linear fashion that effectively connects and merges pathways in the same way that vehicles on highways are connected to off ramps. A sectional design approach is a strong strategy for creating visual connections throughout a busy transit center that will help minimize certain intersections that may happen when designing in plan.

5.3 Expressive Structure

In Cecil Balmond’s book titled Informal, he explores the engineers desire for regularity in the design of structure. He argues that the engineer uses rigid forms, and this standard design is found in most structures. Engineers are not exposed to the same type of design exploration that architects endure. Balmond believes that structure doesn’t have to follow a pattern but can be used as an architectural device. This is important because it argues against the common belief that structure must be synchronized, when in fact there are opportunities where structure may be expressive, reflecting within a space. Balmond states,
“The formal marches to strict rhythms,” then asks, “why the necessity to space out structure equally, like soldiers marching on a parade ground?”

The chief critique that goes against Balmond’s idea of structure is of course, that structure should not be expressive, rather it should perform its function and support all that is comprised of a building. His thesis is bold and takes a previously un-talked about topic and makes it the subject of his own research. He develops an idea that combats this previously held notion of structure, thus creating a new paradigm within structural design and the role of engineers. Cecil Balmond is an interesting character who studied to become a structural engineer but has the creativity like that of an artist or architect. His book, *Informal* is an exploration of his theory of what structure should be and how engineers and architects can work together to inform one another to design well-rounded architectural design.

*Informal* is laid out in a thoughtful approach, targeting his four proposals of structural design: Brace I, Slip II, Frame III, and Juxtaposition IV. In each of his proposals he supports his thesis by arguing that engineering solutions can influence and improve the aesthetics of a building. Brace is focused on the design of a truss and the belief that the truss doesn’t need to follow along a uniform pattern of triangular configurations. In Slip, Balmond believes that columns being placed in such an orderly fashion takes away from the movement of a space when columns can be placed in a free-flowing pattern. Frame is concerned with building loads that can be forced in a diagonal direction with

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larger forces in the opposite direction supporting the load. The materiality used in each of these forms may be defined separately with concrete or steel for example, this is Juxtaposition.

There are many individuals in the architecture community that have found his work to be a significant influence on the philosophy of structural design. Well-known architects like Philip Johnson, Rem Koolhaas, Daniel Libeskind, James Stirling, Ben van Berkel, Toyo Ito, and several other celebrated architects have worked with Balmond on gravity-defying projects. His thinking has brought about masterpieces of architectural design, he worked on the Sydney Opera House in the early 70’s, which gave him an epiphany. He states in a New York Times article, “I realized that engineering was more than calculating. I became intrigued with the way that forces shaped things, the way you assemble structures in a series, the idea that we could help shape things – all that was in the air.”69

His epiphany led him to some of the greatest architects of the time to try and achieve something grand and new. An architect and engineering collaboration with Rem Koolhaas that helped produce an early design was the ZKM Center for Art and Media Technology. The building was a series of multi-story voids with a lecture hall, museum of contemporary art, library, media theatre, and video labs. Balmond’s idea was to create a series of Vierendeel trusses that could be stacked forming triangulated units to support the structure. Koolhaas said in an interview, “we were saying that simply making an endless

variation of new forms was too superficial, instead of making un-sober forms, we became interested in making unstable engineering behind sober forms.”

Balmond explains the architect – engineer relationship in *Informal*, discussing the importance of the relationship that can lead to incredible collaborations of thought and creativity.

Before Balmond began his career at the world-renowned engineering firm, Arup, there was a clear distinction between architecture and engineering. Once this line began to be blurred, Balmond’s career took off and has led him to today, collaborating on thousands of projects across the globe that all share a common thread, defying gravity. *Informal* was published in 2002 to provide a guide for engineers and architects alike, to work together, it has since become a critical reading topic for students in the field all over the world. At the time he wrote it, his work was known to many, but his thinking was not. A framework for structural design is laid-out, however, the framework is not nearly as set-in-stone as many had come to understand of engineering.

Civil engineering schools teach that structure needs to be orthogonal, rigid, stiff, boring, and sturdy. All of these items are important to understanding the fundamentals of structural design but the more you understand how a form works and what materials are being used, the quicker you realize that structure is capable of much more. This is a key argument that is the foundation of Balmond’s thinking, and evocative to others in the field. A paradigm suggests a shift in thinking from a known understanding of a subject to something new and

70 Ibid.
profound. Balmond is not only explaining this shift in thinking to others in his book, but he is laying the guidelines for architects and engineers to take on this role that he has. This book is meant to inspire anyone interested in structural design to do what he has done, and that is exploring what was previously believed to have been impossible through design.

In conclusion, Cecil Balmond’s work in the field of engineering has intertwined with architecture and promoted a fresh experience into design thinking. His book is a critical read for anyone involved in creating beautiful design through architecture and represents the direction in which the future of building design will be heading. With the advent of new technology, improved materials and building information modeling, which enhances our understanding of how buildings work, the possibilities are infinite. This is the beginning of a new era of engineering and architecture that will inspire many to look at Cecil Balmond’s work as the epicenter of this phenomenon.

5.4 Design Integration

Using everything that we have learned from previous chapters, the design process began as most projects do, sketching on paper. The images below show some of the early sketches that were produced, these evolved into digital designs (Fig.36-Fig.39). There were three designs that were developed further and eventually one was selected to move forward with.
Fig. 36: Sketch Ex. 1

Fig. 37: Sketch Ex. 2

Fig. 38: Sketch Ex. 3

Fig. 39: Sketch Ex. 4
In each of the designs there were five key elements to keep in mind: Future transit, linear circulation, expressive structure, urban connections, and sustainable design. Eventually, three forms were selected with the help of my advisor. These three forms were explored through sketches and digital representations, as well as models. They can be seen in the images below (Fig.40-Fig.42).

Fig. 40: Concept 1
Fig. 41: Concept 2

Fig. 42: Concept 3
The form above reveals a long-linear design. The proposal would allow for the Hyperloop terminus to enter the upper portion on the north side and the subway would run below ground on the south side. This would allow for buses and ground transportation to run underneath the belly of the building and the upper portion would make up the main concourse running parallel to the site boundary. Now that a concept was created, the next step was to figure out how everything would fit within. The following page shows how the program would connect and the relationship between spaces is formed in a coherent manner (Fig.43).

**Fig.43: Program Diagram**

The Subway or Red Line would be below grade at Level 0 shown in purple. Level 1 consists of all ground transportation including: vehicle Pick Up &
Drop Off, City Bus, Silver Line (BRT), Regional Bus, and a main entrance shown in yellow. Also shown in yellow and red on Level 2 is the main concourse and commercial area, which is important to the success of a transit terminal and found in every precedent study in this research. Finally, Level 3 is the Hyperloop terminal, all terminal would connect to the large concourse space and commercial areas. The diagram below shows how circulation would look in the building and a site integration plan (Fig.44-46).
Fig. 44: Program/Circulation Section

Fig. 45: Site Integration
CHAPTER 6
DESIGN PROPOSAL

6.1 Final Presentation

The following pages will include the final thesis proposal. This includes site diagrams, site plan, exploded axonometric drawing, floor plans, elevations, circulation diagrams, sectional perspectives, and renderings. The first page is used as introduction to the project that asks the two key questions that were used at the beginning of this document. A response to these two questions is provided along with the many drawings that were produced. This portion of the presentation is summarized in the text below:

- The Seaport Intermodal Terminal integrates the future of transportation, linear circulation patterns, expressive structural elements, sustainable design, and a seamless connection to the existing urban infrastructure.

- **Future Transit**: Hyperloop terminus connects the city of Boston to New York City and beyond
  - Hyperloop is sustainable and uses vacuum tubes to move across many miles in a shorter amount of time than current transportation offers
  - Located in the heart of the Seaport district in Boston
  - Regional bus terminal, a connection to the Silver Line or Bus Rapid Transport system, a connection to the city Bus system, a proposed Red Line Subway connection,
automobile pick up and drop off location, bicycle and pedestrian pathways

- **Linear Circulation**: A linear circulation pattern helps to minimize confusion and direct people in an orderly fashion throughout the station
  - Gives the building it’s long, linear shape that adapts to the city infrastructure and the site

- **Expressive Structure**: An expressive exoskeleton structure allows for large spans, open areas for movement
  - These structural elements can be seen from the exterior and within the building as pedestrians walk through the main concourse past retail and to their next destination

- **Sustainable Design**: Sustainable design includes solar panels that are located on a south facing roof for optimal performance and includes a water collection system
  - Aluminum mesh screening facade helps to minimize solar exposure without blocking views to the outside
  - Vast array of solar panels that minimizes energy costs
  - Water collection system located on the south side of the building to be used for watering green space

- **Urban Connection**: The location is key to integrating into a developing neighborhood
• Provides people the opportunity to use various modes of transportation
• Large green space for people to enjoy as they come and go.
Intermodal Transit Terminal
Integrating the Future of Transit into the Urban Fabric

How do we design intermodal transit terminals so that they integrate logically into an existing urban fabric?

How do we design for innovative modes of transportation, such as hyperloop technology?

The proposed Seaport Intermodal Terminal in South Boston integrates the future of transportation: lower emissions patterns, expressive structural elements, sustainable design, and a numerous connection to the existing urban infrastructure. A terminus

Presentation Board 1

Exploded Axonometric View
Scale: 1/64"=1'0"

Fig. 46: Presentation Board 1

Fig. 47: Presentation Board 2
Fig. 50: Presentation Board 5

Fig. 51: Presentation Board 6
Fig. 52: Final Massing Model 1
Fig. 53: Final Massing Model 2
Fig. 54: Final Model 1
Fig. 55: Final Massing Model 1
Fig. 56: Final Model Interior 1
Fig. 57: Final Model Interior 2
CHAPTER 7

THESIS CONCLUSION

7.1 Final Remarks

The architecture thesis process is a long and arduous ordeal. From the very beginning of my research I wanted to find a topic that I could feel passionate about. It needed to be something that I could look back at in a number of years and feel proud of what I accomplished. Selecting a topic was one of the most daunting tasks because it could make or break your thesis. I have always loved large buildings, especially stadiums but I had found a great enjoyment in walking around in transportation terminals. Whether it be an airport, train station or a simple bus terminal, there were so many elements and the end goal was always clear, to move people and goods.

I decided early on that I would begin researching transit terminals to develop a new type of terminal for my thesis that was forward-thinking. Intermodal terminals had been on my radar and I decided it would be in my best interest to study how these places work. With that said, I wanted to introduce a new form of transportation that doesn’t exist but is likely to exist within my lifetime, hyperloop technology. The hyperloop was an exciting futuristic idea to me, I imagined myself traveling from city to city in a short matter of time to end up in an amazing, state-of-the-art intermodal transit facility that could whisk me away to my next destination.

My early research gave me a great amount of insight into the history of transportation and transit terminals. Next, I investigated some of the biggest
issues in transportation that we see today. It was clear that there needed to be something done in the transit sector, providing a new mode of transportation was one solution that I developed. On top of that, providing a new building typology called an intermodal transit terminal, which could integrate into the existing transportation infrastructure was critical. This early development helped me to set my sights on different precedent studies that would help to solve problems that I would run into during the design process.

Five total precedent studies were used to enhance my design. Each were selected for particular reasons and each have innovative ideas that were brought into my own design. The five keys to my intermodal transit terminal included: future transit, linear circulation, expressive structure, sustainable design, and integration to an existing urban fabric. These elements helped to support the argument for my thesis during the final thesis orals presentation and in this document. With these elements in mind and using what I had learned from past research, the final design was created and proposed. The title was “Seaport Intermodal Terminal”, which was developed to introduce a future mode of transportation within an intermodal hub located in an upcoming and coming part of Boston, Massachusetts.

In conclusion, I was proud of the work that I did for this thesis research. The final proposal was complete and had many exciting features but as always, with any design there were flaws. The sheer scale of an intermodal transit terminal may have caused for some limitations, since it made it difficult to focus my energy into very small details of the project. If I had the chance to do it again,
I may have looked into designing an intermodal transit terminal at a smaller scale. But for this project I wanted to go big, I wanted to make it massive and introduce the Hyperloop into a building, something that has only been done in concept.

There were so many different elements to take on and without the help of a project team it was difficult to keep track of everything involved in designing a successful transit terminal. Some parts that were well-received by reviewers and advisors was the idea of providing so many different transit options in one building as well as creating a design with a large-open concourse that was reminiscent of buildings of the past. Although this building may never exist, it was a project that I felt passionate about and helped me narrow my interests down to truly understand what it is that I want to do within the field of architecture.

From the very beginning of this research, I was told that once you enter the real-world, you will never have an opportunity to design whatever you want, with no client and no budget. From then on, I was enthralled with going big and designing something out-of-this-world. It was a project that I was intrigued by from start to finish and truly couldn’t wait to produce a finished product. I am excited to show this vision of a future intermodal transit terminal to family, friends, and professionals. Perhaps one day, a building with like this will exist but for now I will enjoy the hard work that I put in over the past year and take what I have learned to continue to move forward in my career.
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