The Under Wing Home

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THE UNDER WING HOME

A Thesis Presented

by

DAVID ANDREW HARRINGTON

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

MASTER OF ARCHITECTURE

May 2014

Department of Art, Architecture, and Art History
THE UNDER WING HOME

A Thesis Presented

by

DAVID ANDREW HARRINGTON

Approved as to style and content by:

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Kathleen Lugosch, Chair

________________________________
Ray K. Mann, Member

________________________________
William T. Oedel
Chair, Department of Art, Architecture
and Art History
DEDICATION

I dedicate this thesis to my grandfather, John F. Harrington, who loved to fly, and who built his family home with his own hands. I also dedicate this to my grandfather, “Bud” Griffiths, who built many homes and taught me how to build a birdhouse.

They both inherently gave me a love and appreciation for architecture.
ACKNOWLEDGEMENTS

I would like to thank Kathleen Lugosch for her ability and willingness to help turn my ideas and abstractions into the final project. Kathleen allowed me to hang onto what was important to me, and ultimately enabled me to see how to successfully make the project work.

I would also like to thank Ray Mann, for always seeing things from a different and interesting perspective. Your enthusiasm puts a great deal of excitement and intrigue into the project.

Thank you to all of my classmates, in studio. Many late, and sleepless delirious nights have made a permanent mark in my memory. Good music, and good laughs turned our concrete bunker into a lovable workspace.

I wouldn't have been able to do any of this without the unconditional love of my mother and father. Thank you for showing me what it takes in all aspects of life and for the extra encouragement to pursue architecture.

I would like to acknowledge the blue-eyed girl who sat next to me on the first day of school, and every day of class thereafter
It is quite astonishing that most homes being built today fail to adequately respond to natural disasters. Looking within the last decade, the data indicates that these disasters are more frequent than they once were, and are affecting a larger geographical area. Many believe that these patterns will only escalate. The magnitude and frequency of these tornadoes and hurricanes are hard to ignore. The power and destruction inflicted has affected most Americans in a multitude of ways.

We simply cannot continue to build homes using typical methods of construction in these disaster-prone areas. To re-build a home in the same manner on top of a post-disaster site is the definition of insanity.

This thesis aims to bridge the gap and merge the benefits of the safety associated with living in a concrete bunker and the perception of quality of space associated with living in a glass home. An analysis of feasibility and difficulty of construction, and cost will help set parameters early on in the design phase. The goal is that the resultant home could be deployed in both pre and post disaster areas. The challenge, I am addressing, is designing a home that is impervious to tornado and hurricane while offering a delightful space of dwelling.
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CHAPTER 1

THE PROBLEM

Natural Disasters

Natural disasters including: fire, earthquakes, tornadoes, and hurricanes, have affected nearly 10 million people causing 4,107 reported deaths and over 7,000 injuries. In the last decade, there has been 445 billion dollars in reported damages in the U.S. On average, 300,000 homes are destroyed annually. That is more than 60% of the number of new single-family homes built in 2012. We have the technology to build homes that withstand these disasters, but many of the new homes fail to meet the criteria of resisting these disasters. Why?

Drafting a Response

The construction industry is hard to change, and it is even harder to facilitate change on a public level. Many new homes suffice for today, but will they tomorrow? Cultural influences and life styles cast the mold of our limitations. How will tomorrow’s family perceive homes of today? History shows it would be foolish to predict that there is a timeless, universal answer. There are inherent qualities and characteristics existent in century old houses that are present in today’s homes. Perhaps, by building around these qualities and combining them with emerging building technologies, we can build a robust and desirable home. The diagram in Figure 1 illustrates the approach I am taking in creating a response to the problem. The public’s perception, choice of materials, methods of construction as well as ease of assembly, cost, Return on Investment (R.O.I.), and an evaluation of the solution will be the framework shaping the final product.
Figure 1: Image created by author
In Harm’s Way

There are two tornado predominant regions within the United States. One is in Florida and the other, known as "Tornado Alley," is located in south-central United States. Florida has high frequency of tornadoes because of the region’s almost daily thunderstorms. Several tropical storms or hurricanes impact the Florida peninsula each year. When these tropical systems move inland, the embedded convective storms in the rain bands often produce tornadoes. While any tropical storm or hurricanes can be disastrous, the tornadoes yielded from these storms are typically weaker than those seen in other regions.¹

Tornado Alley is the name given to an area in the southern plains of the central United States that experiences a high frequency of tornadoes every year. In this area, tornadoes typically occur in late spring and occasionally in early fall. This area is not be confused with “Dixie Alley,” in the Gulf Coast which has a relatively high frequency of tornadoes occurring in the late fall.²

It is possible that a large number of significant tornadoes have occurred and failed to make it into the history books because Tornado Alley was sparsely populated during the 20th century.³ Increased occurrences, and more inhabitants in the region, it is critical that we consider rethinking construction methods.

An average of 1253 tornadoes per year occurred in the United States between 1991 and 2010, with Texas averaging 155 tornadoes per year.⁴

---
¹ (NOAA n.d.)
² Ibid NOAA
³ Ibid NOAA
⁴ Ibid NOAA
**The Science of the Storm**

Most tornadoes are directly related to the strength of a thunderstorm. Thunderstorms typically gain the majority of their energy via solar heating and latent heat released by the condensation of water vapor. This is why most tornadoes occur in the afternoon and evening hours. However, tornadoes can occur through all hours of the day. Especially daunting are nighttime occurrences that may give sleeping residents of a threatened community little or no warning.⁵

If the conditions are just right, a tornado can occur anywhere. According to the National Oceanic and Atmospheric Administration, every region, and every continent has reported a tornado aside from Antarctica, where it is scientifically possible. No area is immune to tornadoes then, but certain regions, such as the loosely defined boundaries of Tornado Alley experience more of these phenomena.

An elementary response of how tornadoes form in Tornado Alley is that warm moist air from the Gulf meets cold Polar air and dry air from the Rockies. Most of the thunderstorms that form from those conditions never actually make tornadoes. Even when the conditions seem just right and appear to be extremely favorable for tornadic thunderstorms not every thunderstorm generates a tornado. The formation is actually not fully understood. The deadliest and most destructive tornadoes occur from supercells. Supercells are rotating thunderstorms with a clear definition of an upwardly rotating circulation called a mesocyclone. It is said that “recent theories and results from the VORTEX programs suggest that once a mesocyclone is underway, tornado development is related to temperature changes

⁵ (NOAA 2011)
across the edge of downdraft air wrapping around the mesocyclone. Mathematical modeling studies of tornado formation also indicate that it can happen without such temperature patterns; and in fact, very little temperature variation was observed near some of the most destructive tornadoes in history on 3 May 1999.\(^6\)

Tornadoes usually travel from the southwest to the northeast (Because of the shear size of the tornado, the forces exerted on a static object at a given moment can be thought of a one directional force.) Though they don’t always follow this, rather they are cyclical in nature; this directional prevalence should be noted when concerned with the position of the home.

Figure 2 Tornado Tracks

\(^{6}\) (NOAA 2011)
Figure 3 A Tornado Path
Granbury, Texas

Granbury is a small town in Hood County located in Texas. Located outside of Fort Worth, Texas, the population in Granbury in 2012 was 8,356. Summer months range from March through August, while winter months span September and February. The summers have an average high of 83°F with temperatures up to 107°F. The winters average low are 41.5°F with temperatures sometimes getting as low as 19°F. Granbury gets about 33 inches of precipitation every year and has an average wind speed of 17 mph. Historically, tornado activity in Granbury is above Texas
state average. It is 227% greater than the overall U.S. average.\textsuperscript{7} The number of natural disasters in Hood County is 12, which is the US average.

**May 2013**

In May 2013, an EF4 tornado (166-200mph) hit the small town of Granbury, Texas, damaging and destroying over 100 homes and killing 6 people. Many of the homes destroyed were Habitat for Humanity homes. Many of the residents of these homes were given the keys to their new homes the day before the tornado hit.\textsuperscript{8}

The summer of 2013 showed to be one of the worst years in recorded history for tornadoes. The tornado in Granbury is part of what is now referred to as the “May 15-17 2013 Tornado Outbreak.” Overall, 4 states, 26 tornadoes, an estimated 272 million dollars in damage, 63 injuries, and 6 deaths were reported.\textsuperscript{9} It is for these reasons I chose Granbury, Texas, as the site for my thesis.

**Homes Continually Destroyed**

As mentioned, many homes destroyed were Habitat for Humanity homes. All of the work the residents had put into their homes was destroyed in minutes.

Why do we keep building the same homes using the same methods of construction in disaster-prone areas? These homes do not respond to these disasters and yet we rebuild the same home in the same place.

Contrary to myth, tornadoes do hit the same place more than once. Here is a list of places that have experienced tornadoes more than once:

\textsuperscript{7} City-Data 2013)
\textsuperscript{8} (Garza 2013)
\textsuperscript{9} (contributors, May 15-17, 2013 Tornado Outbreak 2014)
Harvest, AL: Two tornadoes within 10 months

Cordell, KS: Three consecutive tornadoes on May 20th, 1916, 1917, and 1918

Guy, AK: A church was hit three times on the same day from 3 separate tornadoes


Albertville: April 24, 1908 and April 24, 2010

Anderson Hills: May 18, 1995 and April 27, 2011

Figure 5 Neighborhood Devastation
The Program of Home

A home should aspire to offer permanence through sound construction. To design this home one should look not only of the environmental conditions of today, but look to the entire life cycle of the structure. To build a thoughtful, well-built home that offers years of occupancy we have to look into how the home will be perceived from potential future perspectives. A 21st Century family conducts itself differently than a family of the early 20th Century. This is in part because of change in technology, but it is mainly due to change in life style. Building on the work of Christopher Alexander, I have investigated the inherent qualities that positively influence family life. Accordingly, certain floor plans and strict attention to adjacencies and interactions between shared and private spaces can aid in family
interaction. These inherent qualities of the space of home should strive to be timeless and continue to be relevant to families and lifestyles of the future.

In my thesis I aim to select construction methods that will withstand inclement weather, and will be less dependent on high-energy comfort technologies. By building a home with less need for air conditioning and heating, the home’s structure will have a higher potential of being timeless. It will hopefully be linked to smart design; an idea that smart design is greater than fuel-dependent technologies.

I will explore construction systems that could be quickly delivered to a site recently exposed to disaster and have untrained contractors; members of the community assemble the system. The system would yield a structure that would be built more quickly than traditional construction methods. This would allow the community to be less dependent on contractors, who tend to be in high demand after such disaster. They themselves would assemble new homes that would respond to destructive natural phenomena. I believe investigating robust construction methods would be a good initial staring point for dealing with the tornadoes and hurricanes of Granbury Texas.
CHAPTER 2

CONSIDERATION OF PROGRAM AND APPLICATION

Figure 9 Diagram of Direction created by author
Life Styles of yesterday, today, and tomorrow

We can only hypothesize what shape and form a home might take, to be considered ideal for future generations and for future usage. A look into the past at how homes have evolved over time and what elements have remained is a good place to begin. Along with cultural shifts, technology in its many facets has drastically changed the size, shape, and layout of the home.

Looking back, the family home in America has drastically changed from what was first built by the colonists having just arrived in America. Many architectural styles seen in American homes were brought over from Europe. Although, many styles, especially in the west, were generated from what the Native Americans had been doing for centuries. As years went on the people of the new America developed their own styles as well. Taking advantage of all of the resources this country had to offer immediately influenced our homes. America is seen as the land of homes of timber, especially when compared to European homes.¹⁰

There has been a lot of debate around architectural styles regarding what should be the purpose of architecture and what should be the role of the architect in generating these styles. My first thought would be that in order to build a home for today and for tomorrow, it would ideally be a home that would not be visibly beholden to any period or style. This, however, reminded me of the tendencies of the post modernists, the deconstructivists, and today's style, or lack there of. We do not want to wipe the design slate clean do we “as once said...” We rely on learning

¹⁰ (McAlester 1984)
and discussing history so that we do not repeat our mistakes. One of the well-known critiques of the deconstructivists was that they tried to rewrite everything, to change the way a building is perceived, and in essence do away with any style that ever existed before. Arguably, what was left was a style of their own, and a style that seemed to lack any real usable purpose.

Rather than write a stylistic history of the family home, I want to take what has worked in the past, and combine it with a concern for technology, and environment, and program.

Early American homes were comprised of square units, and massed floor plans, as they were called, and was the primary shape. More rectangular linear plans followed with demonstrable advantages and disadvantages.

At this time that thatch was used for the roofing material. The nature of thatch requires that a thatched roof must be at a very steep angle in order for the thatch to properly shed water. As homes grew in size, and the “massing” floor grew in size, the roofs became nearly impossible to construct because in order to maintain the proper angle of the thatch roofs, the roofs became too high. The introduction of wood shingles and sheathing, A-Frame, and hip frame construction completely changed what was possible for the layout and size of the home. These technological changes in construction as well as advancements that improve daily life resulted in changes to the homes of this time.

---

11 (McAlester 1984)
12 (Alexander 1977)
13 (McAlester 1984)
In the 1830’s the cast iron stove came into production. This stove was smaller, more efficient than a traditional masonry fireplace, and much easier to install. Doing away with the large, and cumbersome fireplace yielded more space and more irregular floor plans were seen in homes. The invention of the furnace completely changed this once again. Placing a furnace typically in the basement or attic space freed up even more room. The heated air was piped to each room and space as needed. The floor plan had essentially become independent from a heating source. While heat and proper warmth may be one of the most primitive elements of survival, it is quite amazing how its means of delivery drastically changed the possible layouts for homes.\textsuperscript{14}

With the invention of balloon framing construction the house could take on even more irregular shapes. Before balloon framing, the joining of corners was expensive and somewhat inefficient, so homes were built with as few corners as possible, typically only four. Corners were now easy to construct with balloon framing and relatively inexpensive. Balloon framing completely changed timber frame built homes.\textsuperscript{15}

Once Henry Ford’s wish came true and every American had a car, Americans wanted to keep them out of the elements and in a garage. In 1930, the one car garage took up roughly 15% of the overall square footage of the family home. In 1960, when many families now had two cars, 45% of the overall square footage was allotted to the two-car garage. Presently, in 2013, where many families have more

\textsuperscript{14} (McAlester 1984)
\textsuperscript{15} Ibid
than two cars and many homes have 3 car garages, how much space is now allotted to the garage? Some parts of the house have shrunk - we do not need big boiler rooms as much any more, or even big pantries anymore because the proximity and number of grocery stores has increased.\cite{McAlester1984}

Why have we seen the size of family homes grow so much in size then? The average family size appears to be smaller than the average size in the early 20\textsuperscript{th} century. We are now in a time with McMansions present in every new subdivision. Families now seem to need their own space. In addition to individual bedrooms, members of the family feel the need for their own space aside from their own bedroom. The men need a man cave, and the kids need a game room for their big screen television and numerous game consoles. Master bedrooms appear to have grown in size as well. Why do we need such large Master bedrooms? Are parents using the extra space for a second living area without kids? This leads to my beliefs on what the family and communal space of the home should be like.

Just as the technological advancements of roofing materials and types of construction changed the home, technological advancements in the home changed the usage and size of the home. Today, most family and/or living rooms are designed to be positioned solely around the television. Before the television there was the radio, which was positioned within arms reach and at a reasonable volume proximity to a chair or two. Before the radio what were these spaces primarily used for? Likely for guests. Now when guests arrive at the home, there is nowhere to go in a home other than the living room or the family room. One has to turn down or turn

\cite{McAlester1984}
off the television in order to have a conversation, and the position of the furniture typically is not situated to foster the most intimate conversation.

I can only hypothesis on what elements of design exist in homes of the past and what elements will remain. It is clear that the design of the home must in the future be built in a manner though that will have a better chance at accommodating unforeseeable and inevitable changes.

There are many factors present in family homes, present in ourselves, and present in nature that should not change. Human beings will always gravitate towards the sun, and should typically try to maximize day lighting within our home and yard as much as possible. However, author Christopher Alexander, points out this often not the case.

Alexander pointed out that even the most thoughtful of designs are wasted if they are not south facing. People that had north facing back yards ultimately used their front yards. His rule is simple. We should design our yards and placement of windows with concern for the South. He points out while it may be simple; it is not always easily achieved based on many layouts of residential design. He argues that we must make a change in land use, and building lots should be linear from the north and south with homes placed on the north end.\(^\text{17}\)

If we want to take advantage of natural light, why do we tend to build such wide and massive structures? Without the implementation of systems such as lighting shelves, light will only penetrate a building 20-25 feet, and useful light is

\(^{17}\text{(Alexander 1977)}\)
only present 12-15 feet from the windows.\(^{18}\) Daylight plays an important role in the circadian rhythms of humans as well. Alexander argues that every room should have two outdoor walls. However, having two exterior walls in every room can be difficult to achieve especially in larger structures. Costs associated with heating and cooling, as well as constructing a room with two outside walls are higher. In impact resistant homes, placing more glass exposed to potential threats only increases the likelihood of severe damage.

Though these reasons for not having two window walls in every room may be true, we should only consider them and work around and work them into our design and not let it discourage our final product. Nonetheless, Alexander says it is a false belief that daylight must be sacrificed in order to reach high densities. We do need natural light to improve our living conditions, to reduce our dependence on artificial lightings, but also to conduct daily tasks. Reading requires more than 20 lumens per square foot.

Alexander also raises the point that many outdoor spaces are essentially space left over from the buildings footprint on the site. In mathematics, a convex space is where if a line is drawn from any two points and that line is in the boundaries of the space. If a yard is non-convex, it is just the opposite, and studies show that these spaces that by mathematical definition are negative, are negative on the inhabitants as well. I believe this to apply to indoor space as well. Alexander discusses how our most primitive selves reside in similar spaces in nature. I think of how an animal rests in its den. Animals surround themselves, whatever the material

\(^{18}\) (Alexander 1977)
may be, with one open ended side. The animal can look out and get out quickly as need be but is sheltered from all other directions.¹⁹

¹⁹ (Alexander 1977)
CHAPTER 3
UNDERSTANDING WHAT HAPPENS
A Matter of Seconds

When a home is subjected to a tornado's wrath, and is ultimately destroyed, it happens within four seconds. Looking closer into how a traditional American wood-framed home is destroyed will help clarify weak points and help address where attention should be given in order to mitigate damage.

Second 01-
Flying debris shatters windows and hits hard against the exterior walls. The high-speed wind creates lift, the same aerodynamic force that allows airplanes to fly. Building materials such as roof shingles, and roof decking tear away, becoming part of the twister's funnel of destruction.  

Second 02-
Air rushes into the home through the broken windows, causing a pressure change inside the structure like a balloon. Internal pressure then pushes up against the ceiling, joining the uplift on the roof from the outside winds flowing over the roof. Typical building construction methods between the roof and the walls give way and the roof blows off.  

Second 03-
With the roof now gone, the walls are left to topple over. Tornadoes typically spin counter-clockwise from the southwest. Because an average tornado's footprint is

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20 (Hadhazy 2011)
21 Ibid
500’ wide, the winds acting on the home are technically straight-line winds. The exterior walls parallel to the winds typically fail first because these walls experience the most suction. The opposing wall goes next taking out the back wall all within a second.22

00:04 and after-

The interior walls go next from the outside into the buildings core. This is one reason why bathroom, closets, and or basements offer the most protection. It is thought that in some instances where a tornado is moving fast an occupant has a good chance of survival by taking cover under a robust object like stairwells or even tables because the tornado may pass before the protecting object experiences lift.23

The Next Day-

Do we re-build using the same methods of construction?

**Method and Material**

There are potentials through various building materials and methods of construction for greatly reducing the destruction or mitigating the damage entirely. Currently, there are “solutions” for residents of Tornado Alley. Many homes in these areas have basements, offering protection with the likelihood of preserving life. Various companies make above ground safe cells that can hold around 10 adults. The downside to these options is they require the occupant to have adequate warning time. These options also completely disregard protecting your home. Why

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22 (Hadhazy 2011)
23 Ibid
not think of the home as an entire safe-cell? Some materials and precedents are as follows:

Figure 10 Wall Construction of Rammed Earth

Rammed earth shown in Figure 9, offers a way of thinking about construction, feasibility, and a potentially highly robust structure. It would be interesting to think of rammed earth paired with other methods. Rammed earth by itself may be a cost efficient, energy efficient and durable design build. An unsolved problem is how to adequately structurally tie in roof to the wall.

Figure 11 Rafter Clips
Insulated Concrete Forms (I.C.F.), in my opinion, offers greater structural integrity and building opportunities more completely than rammed earth. The lightweight foam blocks with an integrated structure can be easily delivered to the site and are snapped together making the assembly process relatively easy. Concrete is then poured, usually pumped, into the forms. Unlike rammed earth forms, the ICF blocks remain and provide an insulating layer to create a high R-Value system. The block-integrated structure also provides mounting strips for virtually any type of skin to finish a building. ICF is not new, and while it has caught on in certain areas, its unfamiliarity for buyers and builders keep it somewhat unconventional. ICF homes have been proven to withstand tornadoes and hurricanes. The configurations the blocks can take are somewhat limiting, and unless a concrete roof is cast to the walls, the roof blowing off remains to be an issue.

![Figure 12 Typical ICF Block Construction](image)

*Figure 12 Typical ICF Block Construction*
The traditional methods of toenailing rafters into wood-framed walls, is insufficient. Rafter Clips seen in Figure 11 give additional connection strength between the roof and the walls. Perhaps similar clips applied to a robust wall structure such as an ICF system, could help keep roofs in place mitigating catastrophe. It may be useful to implement this strategy in my design.

It is my intention to design the safest home and minimize as many possible breaks in the home’s structure as possible. There are ways in which engineers and designers have helped reduce the severity of damage in a variety of disasters. In earthquake prone-areas, methods of blocking and sheathing to increase resistance to a variety of different forces. These forces may be different from those experienced during a hurricane and a tornado, but similar methods could potentially help walls maintain their integrity when subjected to high winds.
Engineered lumber such as the Laminated Veneer Lumber (LVL) shown in Figure 13, and others like parallel strand lumber (PSL), are much stronger than traditional beams and studs, and are much more immune to wrapping and twisting. Using LVL in a balloon framing assembly would be expensive and likely not yield any better results because of the way a home comes apart during a tornado. However, LVL could be used in critical areas in conjunction with other methods previously discussed.
Thinking of Form that Responds

Figure 15 Geodesic Home

Aside from underground dwellings, geodesic domes can provide protection. The basic mathematical principles of the geodesic domes offer a potential form solution that can withstand tornado and hurricane winds. Flying debris, which will later be discussed, can still pose problems for this geometry.

Figure 16 Cave
Author Christopher Alexander, explained how human beings revert back to our most primitive selves by appreciating the clear protection offered from a cave-like dwelling. He noted that we appreciate the ability to hunker down into a protected area while still being able to look out and scan our surroundings.

The integrity of Native American housing suggests forms that might work in tornado and hurricane situations. The ingenuity and simplicity is very interesting.

Plank housing seen in Figures 17-19, built buy Yurok Indians out of local cedar timber in Northern California are particularly interesting. These structures are often submerged into the ground. Nonetheless, they maintain a consideration for light, and outdoor adjacencies. I have been inside one of these and they are very comfortable. I could imagine how they would give a sense of security in tornado-prone areas.

24 (Alexander 1977)
Figure 18 Northwestern Native American Housing

Figure 19 Partly Submerged Native American Housing

Figure 20 Native American Plank House
Icelandic Turf housing appears to merge some traditional characteristics of modern tract housing with early principles of protection. It is easy to see the evolution of the design from caves in the above image.

These homes implemented over a thousand years ago do have a wooden structure to support the overlaying turf.²⁵

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²⁵ [contributors, Icelandic Turf House 2013]
A challenge in the aforementioned resilient home is one of inhabitation. The home needs remain a delightful place for living while offering protection reflecting structural characteristics found in a concrete bunker. Joseph Eichler homes were built all over California and in my opinion, mastered the idea of indoor/outdoor living. The way he and his design team brought together privacy and openness is quite amazing. Eichler’s designs, ethics, and business model have had a substantial influence on my direction and solution.

Eichler gleaned delightful aspects of an unaffordable modern design and made it practical and affordable via tract housing. He made it accessible and commonplace in California to live in an Eichler designed home.
It is critical that my solution is accessible to all income levels. A robust, concrete structure runs the risk of being expensive. I do not think it is impossible to design a relatively inexpensive structure. Joseph Eichler was successful with taking modern homes that were at the time only available to the wealthy, and refocusing them to be accessible to an array of income levels.

**Matrix of Responses**

- **High Risk Area of Homes being Destroyed**
  - Granbury Texas
  - Tornado

- **Winds 75+ MPH**
  - Counter-Clockwise in the Northern Hemisphere
  - Usually coming from the South, tornado alley
  - 10-15 Times Per Year
  - Heavy Winds, Flooding, Storm Surge, a lot of Rain
  - Usually Warm Climates
  - Life Span: Numerous Days
  - Warning: Days to Weeks
  - Shape: Symmetrical with Defined Center
  - Diameter: Hundreds of Miles

- **Winds 40-60 MPH**
  - Counter-Clockwise in the Northern Hemisphere
  - Usually spawning from the North Atlantic
  - Fujita Scale: 4-5
  - USA Avg. 1,200 Tornadoes Per Year
  - Very strong cyclonic wind; very heavy rain; large hail; strong cloud to ground lightning
  - Places where cold and warm fronts converge
  - Life Span: Minutes
  - Warning: Minutes to Hours, Sometimes none
  - Shape: Cone-Shaped

**Initial Thoughts on Building Characteristics that Might Mitigate the Disaster**

- **Low-Slung Form to reduce lift**
  - As many as anchor points to foundation as possible, as well as roof connection to walls
  - Avoid Big Windows susceptible to debris
  - Irregular Shaped Building Envelope to minimize Wind Loads
  - Attention to slope of Roof
  - Vegetation, and or swamped earth to reduce wind loads on structure

- **Low-Slung Form to minimize impact**
  - As many as anchor points to foundation as possible, as well as roof connection to walls
  - Avoid Big Windows susceptible to debris
  - Irregular Shaped Building Envelope to minimize Wind Loads
  - Attention to slope of Roof

**Figure 23 Matrix of Responses created by author**
Having looked into methods, materials, and form, we can begin to create a checklist of initial building traits for the home. Having an understanding of how and what happens during a tornado is paramount in designing a structure that resists these disasters. Before we can go further, we should examine how high the velocities reach in various tornado sizes.

![Figure 24 Fujita Scale and Enhanced Fujita Scale Modified by author](image)

The Fujita scale (F-Scale) is a scale for rating the tornado intensity, based on associated speeds, and the severity of damage inflicted on structures and vegetation. The official Fujita scale rating is given once a ground and or an aerial damage survey is completed, and determined by meteorologists and engineers. In 2007, the Enhanced Fujita Scale (EF-Scale) replaced the F-Scale.²⁶

²⁶ [Contributors, Fujita Scale 2014]
CHAPTER 4

A NEW UNDERSTANDING

Aerodynamics

Knowing how exactly a home comes apart under tornado situations from the information previously mentioned in this paper is critical to understanding how to stop the damage. Additionally, I believe having a thorough understanding of aerodynamics will help counter the strong forces applied.

The way aircraft can pierce through the air at such high speeds and the frame of the aircraft can withstand those forces, via flexing, and being aerodynamic is quite amazing. Airplanes are able to counter their mass and take flight because specially designed wings, or airfoils, create lift. A home constructed with typical methods subjected to a hurricane and tornadoes will naturally create lift from the roofs typical profile. This is drastically magnified once the windows blow out due to pressure changes within the home. Therefore, to counter the lift, the downforce applied to the home should be maximized, and simultaneously, the structures profile shall mimic that of an upside down wing. This admiration led me to think not only the home should be aerodynamic but also the frame of the home could be mimicked from an airplane wing. But first, lets look at the principles of aerodynamics first.
Air:

Air can be thought of as a fluid and has the ability to change its shape when it experiences even the smallest changes in pressure. This is because air lacks a strong molecular cohesion.\(^{27}\) We know this to be true when we think of any type of gas filling any sized or shaped container. The gas changes its shape and quickly occupies the entire container.

Air has a mass and weight to it, and is viewed as a body. For the reason air is a body, air reacts to the scientific laws of bodies in the same way as other gaseous bodies. Upon the Earth’s surface the body of air has a weight and at sea level creates an average pressure of 14.7 pounds per square inch of surface. Air’s thickness reduces with gaining altitude, and therefore, there is less air the higher the altitude. At 18,000 feet the weight of the atmosphere is only one-half of what it is at sea level.\(^{28}\)

It is critical that we understand air. Air has substance. Air has its highest density near the Earth’s surface, and loses density as it moves away from the Earth’s surface.\(^ {29}\)

Pressure:

There are various types of pressure, but I am most concerned with atmospheric pressure. Atmospheric pressure is a large contributor to changes in weather. It is the pressure difference between the top and bottom side of an airplane wing, or airfoil, that causes lift.

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\(^{27}\) (U.S. Government Materials 2006)  
\(^{28}\) Ibid  
\(^{29}\) (How Airplanes Fly 1965)
Though air is very light, as previously mentioned, it does have mass and is most certainly affected by gravity. Therefore, like any other substance, we know it has weight. Because of this, we then know air has force. Certainly, we can view how much force air is cable of applying. Because it is a fluid substance, this force is exerted equally in all directions, and its effect on bodies within the air is called pressure.\textsuperscript{30} I mentioned the weight of air at sea level, but now in terms of pressure it is easier to see and understand that at standard conditions at sea level, the average pressure exerted on the human body by the weight of the atmosphere over its surface area is approximately 14.7 psi.

### Density of Air:

The density of air has significant effects on the airplane’s capability. Looking further into an airfoil in flight, as air becomes less dense, it reduces power because the engine takes in less air affecting air and fuel mixture. It affects thrust because the propeller is less efficient in thin air, and because of thinner air, lift is reduced because of less force on the airfoils. With concern for safe home design, air density is the thickest at the Earth’s surface.

### Effects of Pressure on Density:

Recapping, it is understood that air can be compressed or expanded. When air is compressed, a greater amount of air can occupy a given volume. Alternatively, when the pressure changes for a given volume of air, and is decreased, the air expands and occupies a greater space. In other words, the density is decreased. Density is directly proportional to pressure. Assuming a constant temperature, if the

\textsuperscript{30} (U.S. Government Materials 2006)
pressure is doubled, the density is doubled, and if the pressure is lowered, so is the density.\textsuperscript{31}

\textbf{Bernoulli:}

18\textsuperscript{th} Century mathematician, and physicist Daniel Bernoulli, found that the pressure of a moving liquid or gas varies with its speed of motion. Specifically, he stated that an increase in the speed of movement or flow would cause a decrease in the fluid’s pressure.\textsuperscript{32} An airfoil, or an airplane wing, proves this to be true. The curvature of the topside of the wing has a decreased pressure than the flat side of the bottom of the wing ultimately creating lift.

A practical application of Bernoulli’s theorem is the Venturi Tube. The Venturi tube, or Venturi effect is thought of as a jet effect, and is named after Giovanni Battista Venturi, an Italian physicist who was born during Bernoulli’s life.\textsuperscript{33}

The Venturi tube has an air inlet, which narrows to a throat, or a constricted point, and an outlet, which increases in diameter toward the rear to match the size of the inlet. It is shown that at the throat, the airflow speeds up and the pressure decreases; at the outlet, the airflow reduces to the speed at the inlet and the pressure increases to where it was at the inlet. I have created a diagram showing the Venturi Tube. (See Figure 25.)

It is the laws of fluid dynamics that show why the fluid increases at the throat of the tube. The governing laws dictate that the fluid’s velocity must increase as it passes through a constriction to satisfy the principle of continuity, while its pressure

\textsuperscript{31} (U.S. Government Materials 2006)
\textsuperscript{32} Ibid
\textsuperscript{33} (contributors, Daniel Bernoulli 2014)
must decrease to satisfy the principle of conservation of mechanical energy. Consequently, an increased velocity will increase the fluid’s kinetic energy as it enters and travels through a constriction, or throat, but is negated because of a drop in pressure. The Venturi meter uses the direct relationship between pressure difference and fluid speeds to determine the volumetric flow rate.  

$$\begin{align*}
\text{Entrance Area} &= A^2 \\
\text{Entrance Speed} &= 100 \\
\text{Mid Section Area} &= 0.5A^2 \\
\text{Mid Section Speed} &= 100 \text{ mph}+ \\
\text{Exit Area} &= A^2 \\
\text{Exit Speed} &= 100 \\
\end{align*}$$

**Figure 25 Venturi Tube created by author**

**Airflow:**

Air has viscosity, which means it will have resistance with movement over a surface. “The viscous nature of airflow reduces the local velocities on a surface and is responsible for skin friction drag.” As air flows over the wing’s surface, the air particles closest to the surface come to rest. The next layer of particles is slowed

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34 (contributors 2014)  
35 (U.S. Government Materials 2006)
down but does not come to rest. A slight distance from the surface, the air particles are moving at free stream velocity. The layer of air over the wing's surface, which is slowed down or stopped due to the viscosity, is called the “boundary layer.”

Typical boundary layer thicknesses on an airplane vary from fractions of an inch near the leading edge of a wing up to 12 inches at the rear end of a large commercial airplane.

There are two different types of boundary layers known as laminar, and turbulent. The laminar boundary layer is a very even smooth flow that shapes to the airfoil, where as the turbulent boundary layer contains swirls or “eddies.” The laminar flow creates less skin friction drag than the turbulent flow, but is less stable. It is less stable because it can abruptly break apart. At the front of the airfoil, referred to as the leading edge, the boundary layer flow begins as a smooth laminar flow. As the flow continues back from the leading edge, the laminar boundary layer increases in thickness and pulls apart. Depending on the airfoil design and the angle of attack as well as other factors, a varying distance back from the leading edge, the smooth laminar flow breaks down and transitions to a turbulent flow. With concern for drag, it is ideal to have the transition from laminar to turbulent flow as far back on the wing as possible, or to have a large amount of the wing surface within the laminar portion of the boundary layer. As mentioned, the low energy laminar flow tends to break down more suddenly than the turbulent layer.

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36 (U.S. Government Materials 2006)  
37 Ibid  
38 Ibid
Following the turbulent layer, another fact of viscous flow, is separation. It occurs when the airflow breaks away from the airfoil. The natural progression of viscous flow is from laminar boundary layer to turbulent boundary layer and finally to airflow separation. Airflow separation produces high drag and ultimately destroys lift. The boundary layer separation point moves forward on the wing as the angle of attack is increased.\textsuperscript{39}

An increased Alpha results in an increase in the pressure difference creating more lift, shown at the bottom of Figure 26.

Lift is essentially when air accelerates over the airfoil causing a reduction in pressure thus overcomes the weight of the plane and airfoil; see Figure 26. In flight, equilibrium occurs when thrust equals drag, and lift equals weight as shown in Figure 27. Therefore, increased thrust will increase drag. Increased thrust will increase lift as well because more air is flowing over the airfoil.

We know that the angle between or relative wind and the chord line of the airfoil are alpha. This angle is known as the angle of attack. Typically, once this angle reaches 15° stall begins of the airfoil. Stall seen in a wind tunnel shows that eddies occur off of the wing. Between 15° and 90° the stall becomes more severe as it approaches 90°. Lift reaches its maximum and quickly falls off the closer alpha gets to 90°.\textsuperscript{40}

\textsuperscript{39} (U.S. Government Materials 2006)
\textsuperscript{40} (How Airplanes Fly 1965)
Bernoulli’s principle of pressure, and what is shown in Figure 26, does not explain the distribution of pressure over the upper surface of the airfoil entirely.\textsuperscript{41} Since air is a body, when the leading edge of the airfoil pushes against air in a circular path, it offers resistance in the direction away from the center of the curved path. This is known as centrifugal force.\textsuperscript{42} As air particles move in the curved path over the leading edge of the airfoil, centrifugal force tends to apply more air pressure at the leading edge. As air begins to move over the airfoil and reaches the point of reversal of the curvature of the path, the centrifugal force pushes the air away from the topside of the airfoil, reducing pressure. Nearing the tailing edge of the airfoil, the second point of reversal of the curvature of the airflow, air pushes against the tailing edge.

\textsuperscript{41} Ibid
\textsuperscript{42} (U.S. Government Materials 2006)
Figure 26 Air Density over Airfoil created by author
Figure 27 Lift Diagram created by author
Figure 28  Airfoil created by author
Lift (L) and Drag (D) are proportional to area of wing. If Area (A) is doubled, Lift and Drag are doubled. If the Relative Wind is doubled, Lift and Drag are doubled by a factor of four. The reason is because lift and drag are proportional to Relative Wind Velocity Squared.\textsuperscript{43}

\textsuperscript{43} (Official Training Film - Aerodynamics 1941)
Lift and Drag are proportional to Area of Wing

![Diagram](image)

Where Area = \(A^2\)

Therefore: Lift and Drag are doubled

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**Figure 30 Wing Area created by author**

It was once discovered that the most efficient airfoil for producing the greatest lift was one that had a concave bottom surface. Consequently, a concave underside of the airfoil as a fixed airfoil, sacrificed too much speed while producing lift and, therefore, was not suitable for high-speed flight. In concern for tornado and hurricane proof homes, we of course, want to mitigate lift. These laws of aerodynamics previously discussed prove that perhaps by reversing these theories of airfoils, having a concave roof line would yield high pressure and actually create the opposite of lift; downforce.

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44 (U.S. Government Materials 2006)
Drag

There are two different types of drag: parasite drag and induced drag. The first is called parasite because it in no way functions to aid flight, while the second is induced or created as a result of the wing developing lift.\textsuperscript{45}

Parasite drag is comprised of form drag, which is resulting from the disruption of the streamline flow, and the resistance of skin friction. Form drag is the easier of the two to reduce when designing an airplane, or in this case, a home. Essentially, the more streamlined an object is the better it is at reducing the parasite drag.\textsuperscript{46}

Skin friction on the other hand is much harder to reduce. Every surface has a certain roughness to it, even if it appears to be smooth. Even machined surfaces appearing to be perfectly smooth have a rough appearance to them when viewed under magnification. A rough surface will aid in deflecting the streamlined air on the surface, causing resistance, or turbulence. Covering the surface with a glossy clear coat or something similar to cover imperfections will help reduce this unwanted skin friction. \textsuperscript{47}

Another type of drag is created from the summation of form drag and skin friction, which is called interference drag. If two objects are adjacent to one another, the turbulence generated may be 50 to 200 percent greater than the objects tested separately.\textsuperscript{48}

\textsuperscript{45} (Administration 2008)
\textsuperscript{46} Ibid
\textsuperscript{47} Ibid
\textsuperscript{48} (Administration 2008)
All three, form drag, skin friction, and interference drag, are all calculated to determine parasite drag on an airplane. I do not assume the home needs to have a parasite drag total as low as found on an airplane wing, after all, our home will be stationery. However, allowing it to be smooth as possible is still important.

It is no surprise that the shape of an object is a big factor in parasite drag. Please see Figure 31, Figure 32, and Figure 33 for a visual explanation. Airspeed is an equally important factor when concerned with parasite drag. The profile drag of a streamlined object held in a stationery position relative to the airflow, such as a home, increases roughly of the square of the velocity. For instance, doubling the airspeed increases the drag four times, and tripling the airspeed increases the drag nine times. This remains true for subsonic speeds, which is applicable here, as noted herein calculated speeds less than 300 mph are in my realm of concern.49

Moving forward, the other type of drag is called induced drag. We know that no mechanical system is 100 percent efficient. Meaning that whatever the system may be, the required work is obtained through the additional work that reduced or lost all together in the system. Therefore, the more efficient the system is, the smaller this loss will be.50

In flight where a specific body in motion is parallel to the ground plane, the aerodynamic properties of the wing produce the required lift. This can only happen with the expense of induced drag. Induced drag is inherent whenever a wing is

49 Ibid
50 Ibid
producing lift and it could really be called “Inevitable Drag.” Whenever lift is present, there is induced drag acting on the body in motion.\(^{51}\)

Taking what was learned earlier about lift, the wing produces the lift force by making use of the energy of the available air, known as the “free airstream.” Again, whenever the wing is producing lift, the pressure on the lower surface of the wing is greater than that on the upper surface. Consequently, the air tends to flow from the high-pressure area underneath the wingtip upward to the low-pressure area above the wing. Around the area of the wingtips, it is common for these pressures to equalize, causing a lateral flow outward from the belly to the upper surface of the wing. This lateral flow adds a rotational velocity to the air at the wingtips and trails off behind the wing. The air at the wingtips therefore, will have two vortices trailing behind the wings.\(^{52}\) I believe this to be important when concern for our home placed adjacent to other structures and homes of the same type. If I design a structure to be as aerodynamic as possible but it is throwing off turbulent air into the neighbor’s vicinity, what could happen?

**Downforce**

We want to create as much downforce as possible. In flight, separation of air reduces lift, and increases drag. We want to improve downforce, so the same applies here. We want to reduce the amount of separation we have. Therefore the viscous flow shall be laminar and not turbulent.\(^{53}\)

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\(^{51}\) (Administration 2008)  
\(^{52}\) Ibid  
\(^{53}\) (John D. Anderson 2001)
Figure 31 Different Shapes Respond Differently

**Sphere**
Round objects such as baseballs experience a medium amount of drag.

**Aerofoil**
The shape of an aircraft wing minimizes drag.

**Square**
Flat, edged objects such as boxes experience a high amount of drag.
Figure 32 Drag Coefficient Measured
Figure 33 Various Drag Coefficients
Looking at Figure 32, it is easy to begin to start hypothesizing coefficients of drag to a traditional elevation of the home. The bottom depiction of Figure 32 shows a form generating a 0.15 coefficient of drag. If we look to the top we see how much lower our drag can be reduced by a having a symmetrical form. The bottom image is that of form resembling an automobile. Notice how its’ profile is an upside down airplane wing.

**Inverted Wing Design (Downforce)**

It is clear then the more aerodynamic our home is the better off we are for having less drag. The less drag we have, a higher potential of the reducing the unwanted force applied to our walls goes down. Consequently, the more reduction of drag we reduce, the more separation of air we are decreasing. Of course in this case, we don’t want lift. The home needs just the opposite; anti-lift, or more commonly known as, downforce.

I mentioned earlier how I believe that not only the profile of the airfoil could be beneficial to generating the form, but also the structure of the airfoil and how it deals with wind forces acting on it. I began to look at and study the structure more closely as shown in Figure 34, and Figure 35. Perhaps I can look at the ribs within the wing’s structure and apply it to a primary frame design for a house, and the rib as the secondary structure to assist with other loads.
Figure 34 Wing Design

Figure 35 Wing Structure
I mentioned earlier how most people typically think of tornado winds acting upon a home as one directional because of the size of the home in relation to the tornado, and the common direction of tornadoes. Looking at Figure 36, we can agree with it but what if the winds shift? Do we really want a one-directional airfoil form such as a wing? Well, tornadoes typically spin counter-clockwise from the southwest. Designing the sides of structure to withstand the impact of debris and the force of the winds should be considered. The northeast façade could be less robust or at least offer more apertures, and considering the climate in Texas, reducing southern exposure and increasing northern exposure will enable the home to be more energy efficient.
The Monocoque

Monocoque in Greek means, “single-shell.” Monocoques are used in both airplanes and high-end automobiles. The shell gives the occupant(s) a high level of security. In the event of an impact, the outer body can absorb a majority of the shock and stresses leaving the occupant(s) safer. In auto design, the skin absorbs most of the impact as it breaks off and away, and the monocoque is typically integrated into the chassis. Similarly in use, but different in design, we can think of a safe room, or a basement within a home. I wish to design the whole home under this principle that the entire structure is the monocoque. Therefore, the entire home will be safe, and will not be completely destroyed in a tornado or hurricane. If the skin blows off
somewhat, it shouldn’t affect the integrity of the home because as the pressure changes, as it surely will with a breach in the buildings envelope, the roof is the walls, as it is the foundation as well.
CHAPTER 5
APPLIED FUNDAMENTALS - TAKE OFF OF DESIGN

360° Ringed Frame

Before I thought to look into monocoque design, I thought of a 360° continuous ring or frame structure like the one shown in Figure 38. The frame would be arrayed in one direction creating the entire structure of the home. This framing system would provide the foundation, the walls, and the roof without the need for any connections. The frame could be skinned much like an airplane wing. This concept remained through all iterations of design and is evident in my final solution.
Figure 39 Trench House Concept Created by author

Figure 40 Airfoil Home Concept Created by author
Figure 40 and 41 are the next iterations were I brought in aerodynamics. Notice how they both have a different shape from the initial ring but the design principles are the same. Both of the homes sit above grade and allow air to move underneath the home so that suction is created from the convex underside. Formula 1 racecars, utilize the same technique to create more downforce.

Formula 1 racecars enable air to cut through their wings in order to even get more downforce and not sacrifice speed. We know the old adage of opening your windows during a tornado is now proven false, for it enables the home to fill up like a balloon, ultimately adding more pressure on the roof blowing off. If we can allow some of the air passing over to actually go through the home, perhaps the pressure changes upon windows breaking out will not be as significant. Wanted to bringing light into the home, and have a protected outdoor space, I thought an atrium would be a good solution. Since the home is elevated somewhat off the ground, I thought of putting holes in the floor of the atrium. During warm months, cool air from below
can come up and flush the hot air up and out, pulling unwanted hot air in the home. During a tornado, or hurricane, the direction metal flaps close automatically. Any wind that comes through could actually go straight through to the belly of the home, creating more downforce. See Figure 42 for a visual explanation.

![Diagram of airflow through a atrium concept](image)

**Figure 42 Airflow through Atrium Concept created by author**

Figures 43 through 46 show different iterations of the design principles I chose to adhere to. They all strive to be aerodynamic, and offer protection from all angles. They also are all below 2,000 ft2.
Figure 43 Concept A created by author

Figure 44 Concept B created by author
Figure 45 Concept C created by author

Figure 46 Concept D created by author
With the next iteration shown in Figure 47, my design concept emerged: the “Fox and the Bird.”

There are two ways to deal with wind forces. One is to submerge the structure into the ground and allow winds to move over the object. The second is through aerodynamics. (See Figure 48) Having a home that offers both creates a nice balance within the home. I then had two integral, yet distinctly different forms that together create one final structure: the monocoque. The fox section is hunkered halfway into the ground to the southwest and begins to open up to the northeast to the bird section. The bird sits facing to the northeast perched above the site, dealing with wind loads head on through fundamental aerodynamic principles.
After many iterations, I felt I had begin to really discover what the final product should look like. Through all the study and research, it was clear where to go next.

Figure 48 Fox & Bird Concept Section created by author
The program is divided so that the bedrooms are located in the fox section. This section has relatively small windows parallel to the dominant winds. The feeling created here is somewhat solid and grounded, safe, and a comfortable space to retreat. Shown in Figure 49, is a section of a children's bedroom, and the entrance to the second children's bedroom. The Master, not shown, along with the 2
bedrooms are all on different levels. This gives each room a feeling of being on its own, yet the proximity to one another ties them together.

The bird portion of the home (see Figure 50) has a very light and airy feeling to the space. The program in the bird features a galley kitchen and two separate living spaces that flow comfortably into one another. The space opens to the main entrance with storage space, a place to hang jackets, and a half bath. The half bath in the bird keeps the fox private, and allows people to have immediate access to a bathroom. The framing is spaced further apart than the frame seen in the fox allowing ample light to enter the space, while the aerodynamics and robust frame protect the space.
CHAPTER 6

FINAL PROJECT

Figure 51 Final Home Situated on Site created by author

Living in a tornado-prone area, one must consider the possibility of a tornado hitting their home. The home must provide them with a sense of security and protection.

We could design a home underground and almost completely mitigate the chances of a tornado destroying a home, however, the 360 some-odd days in the year without a tornado, a bunker might not be the most desirable place of inhabitance.

As stated, the home's structure was derived from aerodynamic research and thus reduces potential winds loads upon the home, creates downforce instead of lift, and feature apertures parallel to the dominant winds to reduce the chances of debris breaking through.

The home is broken into two distinct forms that respond to aerodynamics in two separate ways. The front southwestern portion is made from concrete and
imbedded into the site. Much like a foxhole. Here, the living environment is cool, calm, and safe. The other frame is the lighter element of the home that mimics a bird. It deals with wind forces head on, exploiting the findings in aerodynamic research. The frames are more spaced apart with more apertures. The living in this space has a much lighter feeling, with the feeling of being perched over the site.

Both frames known as the fox and the bird, are based on the principles the monocoque. The frame is 360° of continuity with the absence of any joint. The benefit is the walls are the structure, foundation, and roof, with concrete flooring poured over the top. The structure is then secured into the Earth, making the chances of a tornado pulling the home apart nearly impossible.

![Figure 52 Perspective Render created by author](image)

You can see how the southwest façade is mostly protected from the earth pushed up to the home. You can see how the windows are parallel to the windows more clearly here in Figure 51 Final Home Situated on Site created by author
Figure 53 South West Elevation created by author

South West Elevation- Indicates how protected the home is from the southwestern winds.

Figure 54 North East Elevation created by author

North East Elevation – The lighter portion of the home can be seen here with its windows to the northeast sitting atop the 2-car capacity carport. The site landscape is meant to taper down as shown to assist with airflow and downforce.
South East Elevation - shows the aerodynamic profile of the home. As air flows of the home it sticks to the profile and creates downforce over the bird through its concave roof and flows underneath its convex belly through the carport keeping it adhered to the foundation. You can see how the form tackles winds from the sides indicated from the material in brown color. You can see the fox portion has a cutout area underneath the concrete structure. This allows side winds to carry through and create downforce. It also allows for rainwater to be funneled into the rainwater collection tanks.

North West Elevation – Notice how the site is pushed up to the southwest and tapers downward to assist with airflow over and under the aerodynamic bird
portion of the home. The Bird’s frame structure, along with the side panels, can be seen in Figure 56 helps direct the air underneath the home and is sped up and directed straight out the rear of the home, thus offering more downforce. The top frame elements over the courtyard and over the interior perpendicular roof sections offer a line of travel for the air. As mentioned earlier, air is technically a fluid, and by allowing for a controlled path of the fluid, the better off we are for aerodynamics.

Figure 57 Site Plan created by author

Site Plan – Here you can see how the site plays an integral role in the maximizing the aerodynamic structure.
Figure 58 Protected Courtyard created by author

Shown is a depiction of the entrance and the protected courtyard with the ability to add automatic closing louvers. This will allow for light to enter the courtyard while offering additional protection. In the warmer months the louvers (not shown) will provide shading keeping the space cooler.

Figure 59 North West Section created by author
Figure 60 North West Section Perspective created by author

Figure 61 South East Section Perspective

Figure 62 South West Section created by author
Figure 63 North East Section

Figure 64 Entrance and Bird Section created by author
The Home

Figure 65 Floor Plan created by author
As you can see Figures 65 depicts the final floor plan. In keeping in with the concept of the fox and the bird, the bedrooms to the southwest are somewhat set into the site. The master bedroom, is set at 3’-6” higher than other 2 bedrooms which sit 6” higher than the protected courtyard. (See Figures 59-64)

Upon walking up the main entrance (see Figure 66) one would enter and find themselves in a nice, naturally lit entrance area featuring an area to hang your coat and belongings and immediate access to a half bath. One can continue forward into the home’s office which features pocket doors that either open up to be used for more entertaining space or can be closed off to give a nice study and work space for family members.
Rounding the corner one enters into the main living, or gathering areas, which again have a lot of natural light, and offers a very comfortable feeling via being perched above the site. Adjacent to the living spaces and office, is the galley kitchen, which can be entered from both off the entrance or off the main gathering space. The kitchen has fixed counter space with seating and optional tabletop to accommodate more seating.
Figure 68 Living Area looking into Kitchen created by author

Figure 69 Kitchen created by author
Entering into the atrium bridge the exterior wall to the courtyard is full glass with a glass door. This is possible because it is protected within the courtyard. This area also has a fixed table and seating overlooking the courtyard.

Walking into the private area, the master is flush with the bridge atrium and 1’ below the living area in the bird. Both my initials ideas and findings in Christopher Alexander’s “A Pattern Language,” for the plans stressed that the layout should encourage positive family interaction. The children would have to walk through the entire living area and past the parent’s bedroom before they could enter their own bedroom. The different heights and location of bedrooms allows for each
occupant of each bedroom to feel as though it is their own space. It is equally important to have ones own defined space.

Figure 71 Hallway/Patio Space created by author

Overall, there is a nice gradient between public and private space, and the connecter element, the atrium bridge, allows that to be quite comfortable. The atrium bridge allows for one to enter into the courtyard space. This way the courtyard is accessible from the more public area, and would-be guests would not have to enter in through the private bedroom areas. This also enables the protected outdoor space to be more integrated with the interior space.
The final home has 2,049 ft\(^2\), 3 bedrooms, office, and 2.5 baths. Protected carport sit below the bird portion. The home utilizes natural ventilation to cool the home off in the warm Texas months and a rainwater collection system.
Natural ventilation (See Figure 73) within the bird is functional because of the aerodynamic profile of the bird. There are vents at the top of the bird that allow air to enter into the vents placed in between the frame. This helps distribute even amounts of airflow. The air then continues through the backside out the windows and or vents pushing the hot air out in the hotter months. These vents are designed to close automatically during a tornado.

![Figure 74 Rainwater Collection System created by author](image)

The home has a rainwater collection tank buried beneath the fox portion of the home. The hallway/patio space has perforations to enable cool air to enter up into the space from the cool air in the tank below. Additionally, the perforations in the floor allow for unwanted water that may enter into the patio space when the windows and door are open. The water would then percolate down below.
The roof portion shown in blue, seen in Figure 74, was designed to mitigate winds coming from the side. The slope of the roof creates downforce by having a smooth fluid surface for the winds to carry over. It remains recessed below the frame of the fox so dominant winds from the southwest remain fluid over the exterior profile. Additionally, this area of the roof enables a solution for rainwater, and can be easily directed into the tank as shown. When at full capacity, the tank is large enough to supply enough water for 1 month based on the average American family usage of 400 gallons of water per day.\textsuperscript{54}

\textsuperscript{54} (Water Sense 2014)
**Construction Process**

Keeping inline with my original idea, I want this home to be relatively easy to build. Thinking of it as a building system, or kit-of-parts, that can be delivered to the site. The thought is that the community could do most of the work, which would be beneficial in post-disaster situations where contractors are in high demand. This is an initial idea for a prototype for construction, and I will take you through the steps.

![Concrete Forms Delivered](image)

**Figure 75 Concrete Forms Delivered created by author**

**Step 01:**

The foam forms, modeled after ICF blocks, would have required integral rebar. The forms could easily be delivered to the site on a flat bed truck. The forms were designed to be manageable in size for this reason. The forms could be laid out in a methodical manner, much like tilt-up construction.
Step 02:
A concrete truck can hook up to a pump and a work can quickly fill the forms with a lightweight, fast-setting, high psi concrete mix.
Step 03:
Once the concrete has cured, the rods pierced through the blocks would be twisted off to enable a flush surface. These allow for the forms to remain parallel, and true. This is a common practice in concrete forming. The foam would be stripped of clean and could either be used for insulation between the forms or sent back to the company who supplies the forms for future reuse.
Step 04:
Once the forms have been stripped, the forms can be set in place with a small crane much like tilt-up construction.

Remaining Steps:
Once all the frame elements are installed, able-bodied community members can come in and finish the build with a relatively basic knowledge of construction.

A Thought on Cost
It is my opinion that this solution must be similarly priced to current housing in Tornado Alley. I believe that my solution is a start for thinking of how to reduce construction costs. Once the concrete frame is in place the majority of the remaining work would be completed by able-bodied community members. This would allow for construction costs to be reduced and help reduce the added price of the concrete. Perhaps, insurance companies would lower their costs by recognizing this home as a viable solution for offering protection and stopping homes from being destroyed.
CHAPTER 7

CONCLUSION

Looking Forward

This thesis was really about how to successfully build housing that can survive and offer substantial protection to the occupants in these disaster situations. I believe that by researching how homes are built and how they are destroyed in tornado and hurricane situations I was able to clearly pinpoint weak points in the homes structure and design. The current conditions and principles of the home were reflected via aerodynamics. Using my findings in both aerodynamics and robust technologies I was able to generate a form that would counter most of the heavy wind loads while still being a pleasant and desirable place of inhabitance.

Once I had a form that successfully worked, it was equally important to create a floor plan that supported positive philosophies of the family home. It became more about “re-programming the family home.” It was critical that I looked into precedents and historical ideals and views of housing. It enabled me to have a critical understanding of what is truly necessary within the family home and glorify these programmatic essentials.
Final Thoughts

Looking into the future, I would love for an actual program and plan to spawn out of this thesis and be put into action. It would be very interesting to work with Habitat for Humanity or a similar organization in building these homes. I believe that it is plausible to design a kit of parts, such as the one shown in this thesis. It should be a home that offers a sense of permanence and security for families in tornado alley and along hurricane-prone coastlines. It may not be common practice to design for these disasters in such a thorough manner, but it should.
APPENDIX

PHYSICAL STUDY MODELS
BIBLIOGRAPHY


How Airplanes Fly. Produced by Department of Transportation - USA. 1965.


Official Training Film - Aerodynamics. Produced by The Cheif of Air Corps. 1941.


