Kirra McCollum

Lessons from the Solar Decathlon

Marshall Plan Final Report

January 2018

Table of Contents

1 Summary

This research paper was written under the Austrian Marshall Plan Foundation scholarship at Fachhochschule Salzburg University of Applied Sciences. I traveled from Oregon State University in Corvallis, Oregon, USA to Kuchl, Austria where I spent three months researching the winning designs from past Solar Decathlon competitions; particularly Austria's winning design of 2013. The goal of this research was to determine key attributes of designs and technologies each winning team used to win. I choose to complete my research at the Fachhochschule Salzburg University of Applied Science because of its winning Solar Decathlon design of the LISI house in 2013. The Fachhochschule Salzburg University of Applied Science professors and students worked closely with the Vienna University of Technology during this completion which allowed me to work among the creative minds who designed this outstanding achievement. The Fachhochschule Salzburg has a lot of experience and research in the wood technology field which also gave me the opportunity to conduct my stay in an in environment that would increase my knowledge of these concepts. By working in an atmosphere unlike my current education at Oregon State University I was able to apply a different perspective to my research.

1.1 Introduction

Efficient is a term that has been around for thousands of years, but only in the last 50 years the term has been paired with the concept of housing. Similar to sustainability, in the context of buildings, "efficient" means creating a space where environmental, social and economic benefits are seen while simultaneously protecting public health and the environment from the use of harmful materials. Simply stated, we don't have enough resources to sustain a growing population on our earth the way we currently live. Buildings are unnecessarily using large amounts of energy. With careful planning, we could eliminate energy waste globally. The U.S department of Energy created the Solar Decathlon as a competition that gave incentive to collegiate teams to make buildings more efficient. Solar Decathlon has also impacted the public's perception of innovative technologies and designs. It is beneficial for both future competitors and the public to take note of the prevailing designs that show reasonable potential to penetrate the building consumer market.

Some of the most resourceful and innovative concepts are generated from this competition. Researching winners of the Solar Decathlon allows us to harness the technology used in this competition and benefit homes all over the world. Collegiate teams focus their attention on homes that will benefit the community and environment. Although there are other platforms that encouraged sustainable home design such as LEED or Passive House, they don't advocate new technologies the way the Solar Decathlon does. The encouragement of solar homes pushes the boundaries to form new standards for energy production. Currently there are no legal requirements that force people to design or construct buildings to sustainable standards, as it is all optional. People who feel that reducing their ecological footprint is important are the primary market for organizations like LEED and Passive House. The Solar Decathlon provides a platform to inspire sustainable home design. By studying the similarities and differences of teams designs for the Solar Decathlon and those standards of LEED and

Passive House, more insight of sustainable concepts and technologies will be generated.

1.2 Overview

My main goal during my research in Austria was to determine similar designs and technology attributes of winning team designs. During this process, I was careful to manage my research based on the time constraint of my three month stay in Austria. I made sure my goals were met by conducting loosely structured interviews with several of the project managers of the winning teams. This allowed me to isolate unique design and technology features the winners of the Solar Decathlon used. By carefully analyzing the winners of the past five competitions of the Solar Decathlon, comparisons can be made among the common themes to find the "winning" takeaway concepts. I focused on the categories that are common to each year of the solar decathlon completion including; architecture, market potential/appeal, engineering, communications, health and comfort, appliances, home life and balanced energy. I took these eight criteria common to each contest, and examined how each winning design performed in each category; and if teams applied innovative designs or technologies to any of the areas mentioned.

Another goal of mine was to identify the level of compliance the winning designs had with sustainable building standards including Passive House and LEED. Both organization are well known for promoting efficient design and sustainable building regulations. After analyzing the standards outlined by organizations such as Passive House and LEED I understood the viability of design and technologies created in the Solar Decathlon and their potential to reach the market. It is important to consider all of these factors when moving forward in today's society, as our world is running out of resources.

Innovative products may be appealing in a prototype platform, but if the designs and technologies cannot translate into public use, the attractiveness is low. It was crucial to my research to account for those technologies that could not be used in future consumer homes and

disregard these designs. By conducting my study, I was able to grasp a better understanding of the future technology possibilities that can improve buildings and reduce energy.

2 Solar Decathlon – A Global Completion

The Solar decathlon was created by the United States Department of Energy as a student based completion that inspired sustainable design. Since 2002, the Solar Decathlon has provided a platform for collegiate competition in 10 contests where student teams build and design livable solar powered homes. The Solar decathlon has grown to be an international competition as it spreads awareness on alternative energy sources as well as technologies and solutions which teams have created to advance the residential building industry globally. Unified by a single idea – designing energy efficient homes for a cleaner, healthier, and safer living – participants of the Solar Decathlon apply innovative concepts to build low-energy houses. Occurring biennially, the winners of the competition are selected based on a point system made up of ten different categories, eight of which are seen in every competition: architecture, market potential, engineering, communications, health and comfort, appliances, home life, and balanced energy. To receive points in each of these categories, teams must follow guidelines set by the competition organizers while simultaneously being creative [7]. One of the most important purposes of the completion is to demonstrate to the public the potential benefits and savings of homes that combine energy-efficient design, construction, and appliances with onsite renewable energy production. It shows the general public, peers, industry, and governmental leadership the opportunities for energy efficiency, renewable energy, and innovative technology that will transform housing years into the future. Because the completion has spread to an international level, the flow of innovative concepts are at an all-time high. Although it is a collegiate competition, the unifying goal of creating solutions for future efficient homes have allowed technologies to reach the market, letting general consumers acquire the benefits from the Solar Decathlon.

This paper explores the key technologies and designs used in competition that lead to prevail a winning team each year. By breaking down the past winners of the Solar Decathlon and concluding common themes, a clear diagnosis of these technologies will be identified. This paper will describe the root contributors to an efficient home based of the Solar Decathlon 10 contests. At the end, this paper suggests ideas for the implementation of these technologies and designs into consumer housing on an international level.

3 Key Attributes of Winners

The key attributes of those who won the Solar Decathlon over various years can be broken down into six areas.

1. Detailed building façade
2. Modular construction
3. 100% Sustainable Materials
4. Built to Passive House Standards
5. Pure Solar Power

In the following section, these factors are described and highlighted by each winning team from the past five competitions.

	NeighborHub	SURE	LISI	WaterShed	surPLUShome
Detailed Building Façade	✓	✓	✓		✓
Modular Construction	✓	✓	✓		
100% Sustainable Materials	✓	✓	✓	✓	✓
Build to Passive House Standards	✓	✓	✓	✓	✓
Pure Solar Power	✓	✓	✓	✓	✓

Chart 1: Visual explanation of teams who incorporated key attributes into their designs and those who did not.

3.1 Detailed Building Façade

The attractiveness of using façades in private homes is becoming more and more popular. Using façades with the intention of ventilation creates a way to reduce heating and cooling energy needs within a home. When combining these ventilated façades with solar panels, a home can reduce its overall energy use. Façades can be used to provide with other beneficial features such as privacy, energy or protection. By combining aesthetic appeal and functionality, these homes possess a unique strategy. By adding a detailed façade to team's designs, teams were able to score notably higher scores under the contests of "engineering" and "architecture". It directly added to the subcategory of Functionality under the engineering category to answer the question "Did the house systems enhance occupant comfort and house performance?". The detailed facades that teams incorporated into their designs helped the architectural integration with house's overall performance and efficiency. Under the Innovation subcategory of the engineering contest, the detailed façade was an answer to the question "Were unique approaches used to solve design challenges?". The design solution also helped to gain points under the Architecture category and design approach subcategory as well by answering the question "Was there coherence among architectural, structural, mechanical, electrical, plumbing, and landscaping elements?". By combining a detailed façade into their designs, teams scored higher on their engineering and Architectural contests, which substantially contributed to their wins.

The winning home of the 2017 Solar Decathlon was the NeighborHub, or Swiss Team, which used a façade as an "extended skin" to their core building. This particular detailed façade supports the solar panels that gives this house a technological advancement. The extended skin allows the design to be flexible in its use as the two areas complement each other by creating different comfort conditions for the various activities taking place. Depending on the time of year and weather, the folding doors system offered an extra openness to the surroundings. It allows its users to monitor, control, and adjust mechanically without disrupting the visual connection between the outside and the inside. The Swiss Team uses an integration of solar panels on the façade which was innovative approach to solar technologies that are commonly concealed on the roof. The extended skin works passively to maximize heat through the arrangement of transparent and translucent panels on the facades [12]. The folding doors open, and skylights allow for natural ventilation so conditions are better inside the home. The modular adjustable façade creates a semi-outdoor space that can offer shade, wind protection, natural lighting and ventilation during any season.

Figure 1: NeighborHub 'Exterior Skin' façade. Source: http://www.swiss-living-challenge.ch/en/swiss-living-challenge/

In 2015 the SURE house winner, the Stevens Institute of Technology team, used a wooden façade as a part of its winning design. Rather than using the façade as a vertical energy system like the Swiss Team, the SURE house reaps the benefits of the façade in other ways. The SURE house incorporated a wooden façade into its design as an added storm protection to the core building. The building façade is known as a "storm shutter", with doors that act as protection against storms, a shading system, and solar collectors. The façade also allows ventilation to the building through openings that let wind and cross ventilation through. The façades in the East, West, and North are constructed from durable cedar-shake wood to create a rain screen façade over horizontal wood batten. This method of installation creates and air space between the siding and the building. The SURE house was designed to be resilient to any disasters, particularly hurricanes that may hit coastal regions [9]. The wooden façade can act as a weather barrier and allow for better evaporation and drainage increasing the durability of the house. The façade can be completely closed and sealed to strengthen the home from extreme weather conditions that may otherwise cause damage.

Figure 2: SURE house storm protecting façade. Source: https://www.solardecathlon.gov/2015/assets/pdfs/sd2015_narrative_sit.pdf

Team Germany won in 2009 with their surPLUShome design. The incorporation of a façade on this house was also an important attribute for team Germany's win. Unlike entries from other years, this particular façade does not provide the house with a second layer to the core of the home, but rather acts as a vital energy producing exterior. SurPLUShome's façade integrates a shingle-like ventilated skin that incorporates photovoltaic modular design for added efficiency. The façade is able to produce energy through indirect sunlight, therefore the photovoltaic shingles are placed on all sides of the building. A copper indium gallium selenide solar cell, or CIGS cell, technology was used to create the modular shingles that allowed the façade to beneficial as well as aesthetically pleasing. The innovative modules were able to respond better to an increase of temperature [2]. Because of the thin-film solar cell, the shingles were able to handle diffuse radiation more efficient than common photovoltaics. Team Germany also wanted the façade to hold many architectural functions such as weather protection and shading.

Figure 3: surPLUShome's innovative solar panel façade. Source: https://www.solardecathlon.gov/past/2009/team_germany.html

3.2 Modular Construction

Modular construction is a method of building that breaks the house into several sections, or modules, and are usually constructed off-site. Since teams come from all over the country and internationally to compete in the Solar Decathlon, this method of construction is quite appealing to most teams. Because teams could partially assemble their houses at their home bases before shipping to the competition site, modular construction was a notable advantage for those teams who took advantage of this form of construction. The use of modular construction in the Solar Decathlon helped teams score higher in the Architecture and engineering contests. The modular construction fulfilled the question "How effectively did the team create a holistic and integrated design, inclusive of space, structure, and building envelope?", under the Architectural implementation and innovation sub category. Modular designs are a holistic approach to construction, and use interconnected concepts to create a whole house. Under the Engineering contest, the use of modular construction helped teams gain points under the sub-category of Performance, answering "How effectively does the prototype's envelope design and material specification manage potential issues from moisture, condensation, and mold?". By using modular construction, teams avoided potential moisture issues that could occur in the construction process.

The 2017 Solar Decathlon winner, NeighborHub, incorporated modular construction into their designs. The NeighborHub team focused a large portion of their concept on mobility which was achieved through the design of several modular sections that made up the core home. The short on-site construction time means teams need to design with little need for heavy equipment in order to be successful. Similar to other winning designs, the NeighborHub used prefabricated wooden building blocks as the house components. During the prefabrication stage all of the

technical elements are installed. This includes insulation, ventilation, and a plug-and-play electrical system are that in place when they arrive on the construction site. A combination of Tenon joints and structural glue is used to connect the modules together. The assembling system consists of bearing-type connections and threaded inserts, leaving minimal impact to the wood and allows for easy assembly. The modules are separated into bedroom, bathroom, kitchen, and storage. As stressed before, NeighborHub focused on mobility of function. The prefabricated modules work so well because they are coupled with a technical "donut". This donut allows and an empty space over the modules that distributes utilities to each module as needed. These modules make up the living area for the NeighborHub where users can cook, work or sleep. The technical donut allows for the necessary utilities to be provided to each area no matter the specific function that has been assigned to the module. The Swiss team intended the use of the house to be multifunctional and act as a house, community meeting space, bike repair area, or as a garden workshop. The prefabricated modular design allows for flexibility in public and private uses.

The SURE house of the 2015 Steven Institute of Technology winner also adopts the use of modular construction. The SURE house has broken its house into three closed zones; kitchen space, bedrooms, and wet systems (also known as shared, private, and service). The modules within the home surround a large open living space which looks out to the south-facing deck. The SURE house concept stresses the need of being both sustainable and resilient to natural disasters, such as hurricanes or flooding. By incorporating modular construction into their design, the SURE house found a way to construct meeting both of these needs. Insulating and preparing the house with its technical and service needs installed before assembling on site

allows the construction to be better controlled for air quality, as any transported moisture within its roof, walls and floor assemblies is diminished [8].

3.3 100% Sustainable Material

Wood is a great sustainable material source as it's found renewable and is found in abundant areas of the Earth. As a structural element, wood is one of the best materials for a prefabricated and flexible designs which is why so many teams in the Solar Decathlon have found success through the use of this material. Wood makes for light travel and eliminated the need for heavy machinery. One of the concepts of the Solar Decathlon is to have a minimal ecological footprint, which means disassembly is just as important as the assembly of buildings. Because of this factor, wood became the frontrunner when looking at materials, because it can be easily taken apart and repurposed, or saved for the reconstruction of the winning teams back at their home bases. By using wood as a sustainable material, teams gained points under the contests of Innovation and Engineering. Teams gained notable points when incorporating wood into their designs as it fulfilled the question under Sustainability subcategory "How well does the team integrate sustainable design, detail, product, and performance decisions into the competition prototype house?". Teams also got points since the use of wood helped to answer the question "To what extent does the team holistically integrate passive strategies, materials selection, life cycle, and local strategies to maximize sustainability?". Under the engineering contest, teams gained points for using wood under the design subcategory. Wood helped to response the question "How well will the home's envelope and active comfort systems maintain occupant comfort in the permanent site location year-round, including but not limited to: air temperature, humidity, surface temperatures, temperature asymmetries and stratifications?".

Wood is a raw material that can be used to improve indoor air quality. Many teams incorporated wood into their designs for this reason and others.

NeighborHub is a great example of how a team incorporated the use of wood into its winning design. Since the prefabricated building was constructed in Switzerland, it is made entirely from wood, a raw sustainable material that serves multiple purposes. Not only does the wood material add a pleasing aesthetic appeal to the interior, but it acts as a lightweight structural material for the shell of the building. The prefabricated modules are made of cross-laminated timber panels (laminated veneer lumber). The laminated panels provide vapor permeability to prevent mold and moisture problems without the need for additional sealing [11]. There is also minimal wood variation that could cause humidity variation and deterioration.

The SURE house also used wood as the main material for construction, but for different reasons. Wood, when properly treated, can be resilient to water, wind, and extreme temperatures. Because of this, it makes the perfect material for a house that is facing natural disasters. The SURE house uses Baltic Birch wood on its exterior paneling, as well as cedar shingles and façade. Inside, wood finishes are used to help maintain and control the climate and air quality of the interior [8].

The 2011 Watershed winner by the University of Maryland showed a strong presence of the use of wood in their design. Unlike the usual structural framing used in American homes, the Watershed home uses triple 2”x6” stud packs that are placed 4’ on center. 1-1/2” thick tongue-and-groove decking is used as sheathing for the Watershed house. This dramatically reduces the thermal bridging insulation of the house exterior [1]. This creates a hybrid of conventional framing and heavy timber framing. The heavy timber framing allowing the various joints to remain exposed for aesthetic appeal. The new structural innovation technology can resist large

wind forces and lateral movement by using a combination of southern yellow pine and engineered laminated veneer lumber (LVLs) wood material [1]. Wood is also seen on the exterior of the home in the form of thermos-treated poplar wood. The thermos-treated wood has properties similar to pressure-treated lumber, but without chemicals. The wood used is cooked at a high temperature over a period of time. As a result, the wood is resistant to rot or insects making it a perfect material to use on the exterior.

Figure 4: Watershed's use of sustainable material throughout the home. Source: http://2011.solarteam.org/

The German team's surPLUShome also showed the use of wood as one of its winning attributes. SurPLUShome used wood to solve its international material transportation problem. Wood is a material that is easy to handle and allows lightweight construction, therefore providing a viable option when shipping across the Atlantic to the United States for construction in the Solar Decathlon. The surPLUShome used local woods throughout the house, such as white fir, spruce, and oak to create a low ecological footprint. The home was constructed through timber frame construction which allowed the reinforcement of the wood frame to be guaranteed by OSB-plates (oriented strand board). Elements of a block construction was used to create minimal structure of the basement and ceiling letting a box-section ceiling stretch over 10 meters without additional columns.

3.4 Built to Passive House Standards

Passive House is a German energy reducing building standard that encourages a low building ecological footprint. This unique building standard is increasing the standard for buildings in Europe, specifically Germany and Austria. In Germany and Austria, it is used as a standard when constructing buildings such as schools, supermarkets, office buildings, other commercial spaces, and residential homes. The German standards have been shown to reduce home energy use by up to 90% compared to homes constructed without these standards [3]. The standard has three main requirements to maintain simplicity:

1. Specific Heating Demand: < 15 kWh/m²a or 4.75 kBtu/ft²-yr
Specific Cooling Demand: < 15 kWh/m²a or 4.75 kBtu/ft²-yr

2. Primary Energy Use: < 120 kWh/m²a

3. Air Tightness: 0.6 Air Changes per Hour at pressure (50 pascals) [10]

Although this standard is not mandated by the Solar Decathlon, several teams have noted the energy efficiency model and how their homes can adapt these attributes for a winning design. Using Passive House standards allowed teams to score higher in the energy and engineering contests. Under the engineering sub-category of performance, the use of Passive House standards helped to solve the question "How well does the design address maintenance, longevity, lifecycle costs, and owner operation?". Passive House standards, as mentioned above, substantially lower utility and maintenance costs. These standards also resolve the sustainability subcategory under the innovation contest by answering the question "To what extent does the team holistically integrate passive strategies, materials selection, life cycle, and local strategies to maximize

sustainability?". Sustainability is maximized through passive strategies such as solar heat gain and vacuum sealed insulation.

In order to maximize energy efficiency for the multipurpose NeighborHub home, the Swiss team incorporated Passive House building standards into their designs. The house features many passive solar concepts through its "extended skin". The solar envelope acts as a semi-exterior space that is passive controlled. The passive strategy is designed to provide its users with a comfortable environment while being energy efficient. The NeighborHub completes this goal by using the closing and opening façade to maximize solar energy. During the winter time, the façade closes trapping heat to the interior while letting sunlight generate energy through the photovoltaic panels on the exterior. In the summer, the doors fold up which provides shade to the building while letting the warm air and breezes keep the house at a constant comfortable temperature. The Passive technologies used on NeighborHub helps maintain appropriate climates year round and collects energy that sustains the home, while reducing energy costs by the carefully engineered design.

The SURE house also uses Passive House standards to help their design win, but for a different concept. As mentioned before, SURE house strives to be sustainable while resilient to storms. By adopting the German standards, SURE allowed their house to simultaneously be energy efficient and more resistant to potential damage caused by excessive water and winds. To achieve an efficient envelope, SURE house used four main strategies: super-insulation, intelligent detail design, control of solar gains, and an energy recovery ventilation. Thicker walls, floors, and roofs were used to reduce heat flow in or out of the house and create a super-insulation effect. To achieve super insulation of the walls, floors, and roof SURE house is constructed with 2x6 structural walls filled with mineral wool batt. Mineral wool batt is an

innovative material as it is durable and water resistant, which are two important factors in the SURE house [9]. The 1-1/4" continuous mineral wool boards are installed over the exterior sheathing as well as an additional 2-1/2" of mineral wool batt added to the interior of walls. The roof and floor cavities consist of 9-1/2" inch deep mineral wool batts. An additional polyiscoyanurate insulation is applied to the roof to create a unique 'triple-layer' insulation strategy to the framing. This creates a flexible framing that allows for modification during construction if needed. The added insulation to the SURE home was used to reach Passive House standards by increasing their insulation R-values. R-values are based on the insulation effectiveness, the higher the number the more effective and resistant to heat flow. The windows on the SURE house are high performance, airtight, and oriented to maximize solar gains during the winter months. To decrease the risk of air transported moisture, vapor air-tight construction was used to meet Passive House standards.

A tightly sealed and well insulated building envelope gave the Watershed House a winning design for the Solar Decathlon in 2011. The energy efficient home uses passive house standards as well to achieve their success. A combination of soy-based spray foam insulation, extruded polystyrene ridged insulation, and thermos-treated wood clad walls to create an efficient home. The soy-based spray foam insulation was used in the walls as open-cell and in the roofs and floors as closed cell insulation. The 5- 1/2" open cell in the wall insulation combines with the two layer 2" rigid insulation that wraps the outside of the house to reduce thermal bridging as open cell has a lower R-value. Closed cell, which has a higher R-value, is used in the roof and floors to provider better heat flow. The thermo-treated wood clad walls used ventilated cavities to allow water to drain and shield rain from the house. High performance windows and doors are used, as they are double glazed with argon fill gas to reduce heat flow. The windows

are translucent, insulated panels, providing light and are also more insulated than average windows.

SurPLUShome continues the pattern of using Passive standards to advance their design to be a winner. With their German background, surPLUShome had the advantage of understanding the building standards needed to be energy efficient. The building concept for this home was to have one single room. The single room concept increases the capacity of thermal mass while reducing the need for lighting and mechanical ventilation. The parameter of the building includes the thermal mass system which is increased by latent storage in plasterboards. The one room concept also allows for a natural ventilation system of cross ventilation during operation for users to manually circulate air flow. To reduce heat loss, the surPLUShome used thin, 5cm vacuum insulation panels, which also reduce thermal bridging. These panels are mounted throughout the building envelope along with the airtight shell. Combined with triple glazing windows, the home is a fully energy efficient passive house.

3.5 Solar Powered

The Solar Decathlon's main goal is to encourage competitors to come up with innovate designs that allow homes to be solar powered. It only makes sense that the winning homes took this factor to the next level and created buildings that are completely solar powered. Although the use of solar power is requirement in the competition, the winning teams used advanced technologies to make their designs completely solar powered. Teams are required to incorporate the use of solar power into all home designs, however, some teams' use of solar power was greater than others - which lead them to scoring higher points under the Energy contest. According to guidelines under the Energy contest, teams will receive full points if enough energy is produced to power the house as needed. All winning teams discussed in this paper received full points under this category. Many of the teams managed to have surplus of energy at the end of the competitions, which could be used for other purposes, such as charging electric cars.

The NeighborHub home takes an innovative approach to creating a solar powered home by using a vertical energy production system. This system is composed of several dye-sensitized solar cell panels that produce electricity by simulating photosynthesis while being transparent and colored for better integration. These 29 panels are spread out among the east, south, and west sides of the building for maximum energy gain throughout the day. Each of these panels serve various purposes of an intergraded energy production. The photovoltaic panels on top of the façade are used for electricity production, while the solar thermal panels are used for domestic water heating. The combination of polycarbonate and acrylic glass panels allow for solar heat and light to enter into NeighborHub. There are also several red dye-sensitized solar cell panels that have been position in front of the vertical greenhouses inside for optimal vegetation growth.

The integrated innovative solar technologies have pushed the boundaries of solar technology and allowed NeighborHub to benefit from a vertical energy production system.

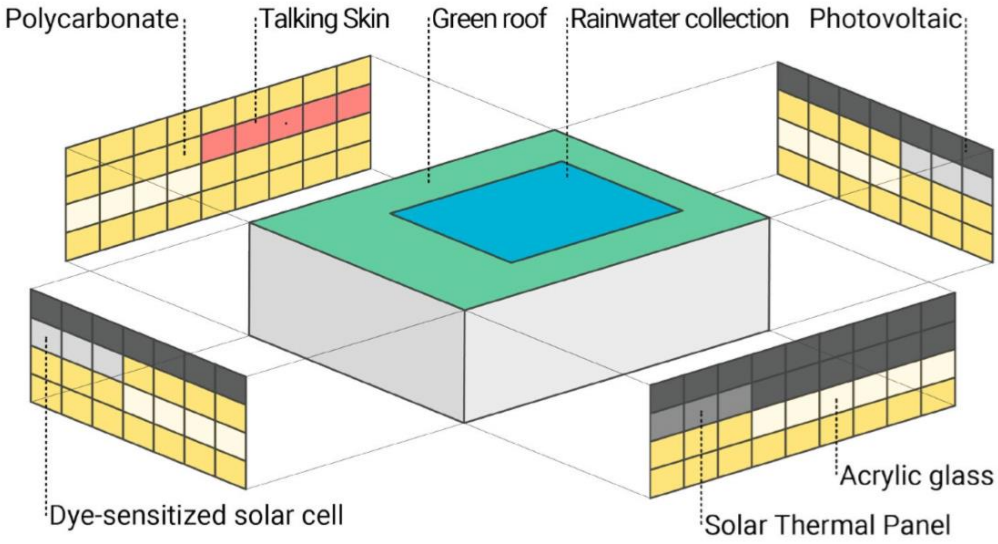

Figure 5: Detail of NeighborHub house's translucent solar 'Extended Skin'. Source: http://www.swiss-living-challenge.ch/en/swiss-living-challenge/

SURE house has uses the rooftop solar array technology that provide enough power to supply all of the house's energy needs over the course of a year. The storm shutters on the SURE house are marine grade solar panels that can withstand ocean climate and forces while producing energy [8]. The thin and flexible photovoltaic panels are placed on the shutters to generate the home's energy when raised. The building-integrated photovoltaics (BIPV) are used on the storm shutters so that they are storm resistant and in the case of natural disasters, the technology can be turned into "resilient mode" and continue to produce energy. The flexible thin-film cells are placed on slim layers of a special plastic polymer, so the modules are lightweight and easy to use. The plastic material is also more durable during storms, which allows constant energy production.

The WaterShed home has also been designed to gain 100% of its electrical needs through solar energy [1]. By using photovoltaic arrays on the roof of the building, enough energy is produced to run the home. There are 42 panels that are mounted to the roof, which can generate up to 9.2 kW of DC power [1]. WaterShed also has an adapted heat exchanger technology to optimize excess solar thermal. The technology consists of a hot water coil and a fan built into the liquid desiccant waterfall system cabinet. This system allows excess solar thermal array to be used for additional space heating and cooling, increasing the homes overall efficiency.

Germany's surPLUShome has a unique approach to the solar energy used to power the home. The homes special façade features photovoltaic panels on the side and roof of the building. Thin-film photovoltaics with CIGS technology make up these modules to respond better to increases of temperature and for architecture integration [2]. The photovoltaics on the roof of surPLUShome are high efficient mono crystalline photovoltaic. The combination of photovoltaic arrays on both roof of the building and the façade allow surPLUShome to reach the energy efficiency needed to power and heat the house.

4 Case Study- LISI House

After narrowing down the key attributes of those who won the Solar Decathlon over various years into the following five areas, I was able to directly understand how a building benefits through visiting the LISI house.

The LISI house, or Living Inspired by Sustainable Innovation, was a house created by Team Austria in 2013. The design won the collegiate competition for 2013 and was awarded a 951.922 out of 1000 points; one of the highest scores of the Solar Decathlon [7]. The LISI house is currently located as part of the Blaue Lagune, or "Blue Lagoon" in Vienna, Austria. The Blaue Lagune is a comprehensive exhibition of prefabricated houses. The LISI house sits on the pond located on site, which gave me the opportunity to walk around and though the house. I was able to visit the LISI house several times throughout my three month stay in Austria. I applied the data I had collected on previous Solar Decathlon winners to the LISI house. The house was built with the help of 46 students form several universities around Austria including the Fachhochschule Salzburg: University of Applied Science. During my research project, I was able to work directly with Professors Herman Huber and Michael Ebner, both of whom worked on designing and constructing the LISI house. This particular building used a unique combination of the concepts mentioned above to prevail as a winning design in 2013. The case study I performed on the LISI house allowed me to gain a better understanding of the innovative concepts and technologies a team must develop in order to win the competition.

Austria is rich in history and culture, which inspired the LISI house's unique design. Being only one of the four international teams that competed in the 2013 competition, team Austria wanted to show a connection between Austria and the United States in living and

design. Majority of houses built in Austria between 1452 and 1934 used wood structures [5]. Team Austria used its long tradition of building with wood to influence their design. The use of the wood products in this particular house makes it stands out as the front runner of successful sustainable design. For a country that has specialized in wood for centuries, it is important to use as many parts of the tree as possible; therefore, all materials used in the LISI house are from locally sourced wood. Resources from trees such as pine needles are seen in lamp shades to create interesting detail. Other parts, such as tree bark, is used for furniture design or an aesthetically appealing wall texture. After looking at the five attributes a Solar Decathlon winning design and comparing those to the LISI house, it is clear why this home scored so high.

The detailed façade the LISI house features offers privacy to the outdoor areas as well as providing users with an element of shade. Made from leaves of a fir tree, the façade has an appearance of a plastic-like texture that allows breathability while being semitransparent to yield privacy. Residents can take advantage of the climate control the façade offers by allowing cross ventilation and sunlight through the façade. The North and South sides of the façade are completely glazed, allowing complete privacy for its residents who can also manually open and close the façade for sun protection.

Figure 6: Detail of LISI house's façade. Source: Photo by Kirra McCollum

Lightweight construction was needed to reduce transportation costs, as the home was built several times for a prototype with adjustments before being shipped to the U.S for final construction. The modular concept was to design a floorplan that could fit into the shipping containers for international travel. There are four core floor modules that are positioned horizontally, while two ridged modules which contain the buildings services and utilities are places on top. These prefabricated modules were constructed on the site of Fachhochschule Salzburg: University of Applied Sciences, where students and professors could make the necessary adjustments and changes.

As mentioned before, the LISI house was one of a kind when it comes to its amazing use of wood. Inside and out the LISI house was constructed using several types of local woods including spruce, larch, and fir. The prefabricated modules that make up the core of the house feature CLT panels tested and composed at the University. Bark of the trees was also made into a composite and placed on panels as an aesthetic yet functional wall covering in both the bedroom and bathroom. The bark acts as an insulation to the home, much like the way bark acts

as the skin and natural insulator of the tree. Team Austria recognized the potential wood has to adapt to cold or hot temperature to create a comfortable indoor climate.

Figure 7: Interior view of the LISI house with detail of wood usage. Source: http://www.solardecathlon.at/house/

Built to Passive House standards, the LISI house if a fully energy efficient home. The LISI house features a combination of cellulose and bark insulation among its prefabricated walls to ensure adequate insulation. The modules are also airtight and sealed together to prevent air transported moisture or thermal bridging. The passive solar gains through the large windows allow the natural light to heat the space during winter months. The roof overhang provides shading so that solar gains are maximized in the winter and kept to a minimum during summer months. The passive solar design includes and automates screen and awning system which provides shade for comfortability.

The LISI house has incorporated many solar features into its winning design to be sure the home is fully solar powered. A roof mounted photovoltaic array provides the home with the

adequate amount of energy needed. The LISI house also features an innovative shower system that can recover up to one third of the solar energy by utilizing the shower tray as a heat exchanger. The used water begins to flow along the tray and heat up the cold feed water in a counter flow arrangement creating energy. The rooftop photovoltaic modules can provide an annual surplus of energy which can then be used to power electric cars or bikes on site.

The LISI house features several innovative concepts unique to Austria. My case study proved that with the proper execution and materials, you can save energy without compromising the quality of life. Team Austria chose to make all the materials found in the LISI house solve solutions of sustainability. The LISI house found a brilliant way of meeting all the attributes in a unique and sustainable manner, setting their winning achievements apart from other entries.

Figure 7: Exterior view of LISI house at its current location at Blaue Lagune. Source: Photo by Kirra McCollum

5.1 Conclusion - Results

The results I found from studying the past five Solar Decathlon winners was quite clear. A combination of the following attributes lead teams into the winning position.

1. Detailed building façade
2. Modular construction
3. 100% Sustainable Materials
4. Built to Passive House Standards
5. Pure solar power

As discussed above, most of these attributes gained points under the Engineering contests, which proved to one of the most important contests of all. Most of the attributes also gained points under the contests of Architecture and Energy, which also show where the importance design solutions should be emphasized.

I was also able to identify a clear advantage towards teams that were based in Europe over those teams based in the United States. Because of the transportation issue these teams faced, they were forced to design their houses in a modular manner, each in its own innovative manner. Additionally, the advantage of coming from areas that are more familiar with Passive House technologies and standards was apparent in their winning designs - as they used the technologies available to them to make their homes more efficient. The United States based winning teams scored lower scores when it came to Engineering and Energy Balance compared to their European counterpart teams. There was also notable technological advancements that were featured as part of the European team's winning designs, such as vertical energy production systems, 100% use of wood materials throughout the home, or thin-film photovoltaics used as a façade.

5.2 Recommendations

There are clear features that stand out as "winning designs" that can be used in residential homes to make them more sustainable. The Solar Decathlon has repeatedly featured teams who have utilized these concepts in innovative ways, and it is time we use these concepts to better home architecture, engineering, and energy. The teams that placed an emphasis on the specific combination of architecture, engineering, energy, and innovation, had stronger designs. I would recommend that homes for future development also place an emphasis on this combination for better design.

Today, the average home size has increased by 62% since 1973 [6]. The increase in house size has led to an increase in construction costs from 2005 to 2015 by 8.5% [6]. With larger homes also comes greater expenses, in utilities such as electricity. Although homes are more energy efficient than previous years, they don't necessarily incorporate sustainable concepts. One of the fundamental issues that residents face today is affordability of sustainable products. As seen by the SURE house, achieving a low energy usage home does not have to be difficult. The SURE house adopted the detailed Passive House Building envelope that allowed them to build an energy efficient home with larger start-up costs but lover average energy bills. The Passive House Planning Package (PHPP) included data for building envelope geometry and orientation, shading, window placement, and thermal bridging to create a final energy balance. By using technology such as this an energy efficient home becomes quite attainable.

Between 2002 and 2015, 124 houses have been constructed through the Solar Decathlon competition [7]. Building science, advanced technology, and renewable energy have all been demonstrated through these homes and can offer future solutions for U.S housing and renewable energy industries. Technologies such as modular housing construction approaches has been

developed, demonstrated and perfected throughout the competition. Previously, there has been a stigmatism towards people having manufactured homes. With the help of innovative high-quality modular houses designed in the Solar Decathlon, there has been a growing trend in demand for modular construction of residential homes. In June of 2017, Google announced to the public that the company would be using modular housing to solve their housing shortage crisis in Silicon Valley [4]. Demonstrations of quality modular construction where shown throughout the Solar Decathlon competitions such as the 2013 LISI house. The market-innovative idea of expandable core modules that can fit in shipping containers for rapid construction is a concept that thousands of residents can use for efficient, and affordable construction.

The Solar Decathlon does include the 'solar' in the title, so we can't forget the importance of using solar energy as an efficient energy source. One of the strongest arguments in favor of using solar energy is the fact that many areas don't have the climates that would deliver enough sun to produce enough energy for a home. The Solar Decathlon competitions are held in various locations across the United States, and receive entries from teams all across the globe. Many collegiate teams have found solutions to gaining energy through indirect sunlight such as the 2009 surPLUShome winner. Through the use of CIGS cells in modular panels placed on all sides of the building, the photovoltaic panels can harness the sun's energy, no matter what side of the building they are on. Taking note of the 2017 NeighborHub's innovative use of a vertical energy production, that used dye-synthesized solar cells as part of a façade, shows consumers a photovoltaic array does not need to be a bulky rooftop issue. These are just a few of the unique and innovative solution that teams of the Solar Decathlon have creatively composed. Incorporating these solutions into the market for residential use would allow Americans and Europeans the benefit of better integrated and energy efficient homes.

An area that could be improved in future designs within the Solar Decathlon is the concept of reuse or repurposing materials. As of the 2017 competition, the Solar Decathlon has now incorporated 'Innovation' as one of its new contests. The concept of reuse or repurposing materials in teams' designs could be a design solution to the following two questions, "To what extent does the team holistically integrate passive strategies, materials selection, life cycle, and local strategies to maximize sustainability?" and "To what extent does the design solution utilize new, unique, or atypical technologies that improve upon the status quo?". This could be a way for future designs to stand out to the judges and gain extra points in each Contest.

Some of the most resourceful and innovative concepts are generated from this competition, which is why studying the winner's designs of the solar decathlon can bring valuable information to the public. Through my research, I was able to carefully analyze the winners of the past five competitions and come up with five key attributes that led each team to prevail to the winning position. Harnessing the innovative technologies this competition generates each year can help create attainable and affordable solutions to sustainable living. If we turn to organizations such as Passive House or LEED alone address these issues, we are eliminating a resource that could potentially solve many issues such as renewable materials or efficient energy use. With our growing population, a need for housing, and limited resources, we need to take advantage of all sustainable ideas generated. As the Solar Decathlon stresses: practices of using clean energy are important to adopt to preserve a healthy living environment.

6 Acknowledgement

I am very grateful and honored to have received this award. I would like to take a moment to thank the Austrian Marshall Plan Scholarship and Oregon State University for the opportunity to complete this research program. Without the generosity of the Marshall Plan scholarship, I would not have been able to participate in research at this advanced international level. This program gave me the opportunity to travel to an unknown area and further my education.

Secondly, I would like to thank my mentors Prof. Hermann Huber and Mag. Michael Ebner at the Fachhochschule Salzburg University of Applied Science for enabling my research project. Without their assistance and knowledge, I would not have been able to learn about the LISI house in the manner I did. I would like to thank you for your support and friendship throughout my stay in Austria. I had the pleasure of knowing both of you, while you helped me gain knowledge of wood products and materials. Having the experience to travel to Wittenberg for the deconstruction of Reformation project was insightful, especially seeing the wood construction and true possibilities through using wood products. The creative uses of wood I saw will influence my future as an Interior Designer and advocate for Sustainability.

Next, I would like to thank Dr. Alexander Petutschnigg, Dr. Marius Barbu, and Mag. Ulrike Szigeti for not only hosting, but also for the unwavering support of my endeavors. Their support throughout the application process and upon arrival to the University was more than generous. They not only supported me in the educational environment but also in my acclimation to Austria. I felt welcomed, supported, and safe at the Fachhochschule Salzburg and in the town of Kuchl.

Similarly, I would like to thank Kerry Menn, Michele Justice, and Lindsay Andrews for their helpful administrative support coinciding with the time sensitive tasks of coming to Austria. They supported me in my academic difficulties between Oregon State University and the Fachhochschule Salzburg University of Applied Science.

Without the wonderful support from professors, advisors, and mentors I received throughout my stay in Austria through the Fachhochschule Salzburg University of Applied Science and Oregon State University, I would not have been able to complete my research. Once again, I would like to deeply thank each person who helped and supported me with my research. The opportunities that were given to me through the Austrian Marshall Plan scholarship provided a life changing experience that will forever affect college education and future career.

7 References

[1] "Design." *WaterShed at the University of Maryland US Department of Energy Solar Decathlon 2011 RSS*, University of Maryland, 2011.solarteam.org/design/architecture/structure.

[2] "Engineering." *SurPLUShome Solar Decathlon 2009*, Technische Universität Darmstadt, www.solardecathlon.tu-darmstadt.de/solar_decathlon_2009/surhome/engeneering/landingpageengeneering.en.jsp.

[3] "Highly Efficient Envelope." *SURE HOUSE*, Stevens Institute of Technology, 2014, surehouse.org/innovation/highly-efficient-envelope/.

[4] Kusisto, Laura. "Google bets on modular homes to fill housing demand." *Fox Business*, Fox Business, 14 June 2017, www.foxbusiness.com/features/2017/06/14/google-bets-on-modular-homes-to-fill-housing-demand.html.

[5] Michael Grabner, Günther Buchinger, Markus Jeitler. (2017) Stories about building history told by wooden elements – case studies from Eastern Austria. *International Journal of Architectural Heritage* 0:0, pages 1-17.

[6] Perry, Mark J. "New US homes today are 1,000 square feet larger than in 1973 and living space per person has nearly doubled." *AEI*, 5 June 2016, www.aei.org/publication/new-us-homes-today-are-1000-square-feet-larger-than-in-1973-and-living-space-per-person-has-nearly-doubled/.

[7] Simson, Joseph, et al. *Insights on Technology Innovation – A Review of the U.S. Department of Energy Solar Decathlon Competition Entries 2002–2015*. National Renewable Energy Laboratory , 2017, *Insights on Technology Innovation – A Review of the U.S. Department*

of Energy Solar Decathlon Competition Entries 2002–2015, www.nrel.gov/docs/fy18osti/70179.pdf.

[8] Stevens Institute of Technology. "Jury Narratives." *SURE House*, The Solar Decathlon, Oct. 2015, www.solardecathlon.gov/2015/assets/pdfs/sd2015_narrative_sit.pdf.

[9] "SURE HOUSE." *Storm Resistant Construction*, Stevens Institute of Technology, 2014, surehouse.org/innovation/storm-resistant-construction/.

[10] "The Passive House – sustainable, affordable, comfortable, versatile." *Advantages*, International Passive House Association, www.passivehouse-international.org/index.php?page_id=79.

[11] The Swiss Team. "Architecture." *Swiss Living Challenge,* Solar Decathlon, Oct. 2017, www.solardecathlon.gov/2017/assets/pdfs/sd2017_swissteam_narrative_architecture.pdf.

[12] The Swiss Team. "Engineering." *Swiss Living Challenge,* Solar Decathlon, Oct. 2017, www.solardecathlon.gov/2017/assets/pdfs/sd2017_swissteam_narrative_engineering.pdf.