## BUILDING WITH THE DESERT: PLACE CONSCIOUS ARCHITECTURE AT BURNING MAN

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#### Abstract

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This thesis project examines sustainable designs at the 2006 Burning Man Arts Festival, a weeklong event in the northern Nevada desert. In 2006, the 40,000 festival attendants created a temporary community to celebrate art in a natural environment. This thesis investigates what the temporary structures of Burning Man can teach us about the principles of sustainable design. Given the challenge presented to Burning Man attendants to design their 'camps' to conserve the limited resources they bring into the desert, Burning Man is an excellent test site for the field of sustainable design.

Although the Burning Man event itself does not display sustainability, the camp designs test and sometimes innovate sustainable design. By exploring these designs, this thesis will explore the successes and failures of field tested sustainable designs. This thesis explores the designs of an non-traditional group that has not yet been examined by the sustainable design community, the experimental Burning Man designers.

This study explores the lightweight structures and cooling strategies found in this

temporary community in order to examine strategies for of ventilation, insulation, earth coupling, and shading, as well as the obstacles that need to be surpassed in passive cooling design. This study also explores aesthetics and the blending of form and function. Through combining form and function, buildings are able to reduce redundant material use. Finally, structural design theory is tested through tent design and vaulted dome designs. The examination of tents provides guidelines for future tent designs, while the examination of vaulted domes presents a new understanding of hybrid tensegrity structural design.

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This thesis is dedicated to a future of living with nature

## Introduction

#### Why Burning Man, why now?

The world is coming to an end! Or so the pessimistic breed of ecological activists tells us (Gauzin-Müler, 2002). Taking a more balanced approach, we may say that the world as we know it will change fundamentally if we are not proactive about reducing over-consumption and begin living in accordance with the land. Today, seventy-six percent of the energy produced in this country is used to heat, cool, and light our buildings (Mazria, 2006). Our buildings are therefore an obvious place to start our examination of how we can approach sustainability.

This is not a new idea; people have been building in accordance with the land for much of history. Frank Lloyd Wright, who made the first attempt at revitalizing this architectural approach, dated its demise to the first US World's Fair in 1893 (Wright, 1939). Roughly one hundred years ago, Western architecture became disassociated with the location of each building. Architecture became a de-contextualized object in an architecture book. In this context, de-contextualized means that the realms of society, nature, and science (architecture) have been separated, so that architectural theory has no connection or is separated from the context of its location (Bauman and Briggs, 2003). Some architects date the de-contextualization of architecture to the invention of the mechanical air conditioner, which allowed people to build without paying attention to the local environment (Cook, 1989). Frank Lloyd Wright disapproved of this transition, stating that "architecture which was really architecture proceeded from the ground and that the terrain... the nature of the materials, and the purpose of the building, must

inevitably determine the form and character of any good building" (Wright, 1939; 1).

Wright's view is the basis for the sustainable school of architecture and design that seeks to reclaim the knowledge of the past by building and learning from the land. Designers from this school focus on reducing a building's environmental impact through passive solar cooling and heating, among other techniques. Over the last fifty years, sustainable architects such as Sim Van Der Ryn, William McDonough, John Todd, Amory Lovins, Christopher Alexander, and Ed Mazria have been furthering the science of passive design and regionally appropriate design. Although the work sustainable designers have done is vast and important, there is still much work to be done in the field of sustainable design, given that we are still using seventy-six percent of fossil fuels to heat/cool our buildings. Since this way of living cannot continue, both because fossil fuels will one day run out and because their use has impacted the land so gravely, there is a great deal of work to do in sustainable design. However, I believe the outlook is optimistic. Because we began de-contextualizing our buildings only one hundred years ago, and we began using fossil fuels to heat and cool our houses only seventy years ago, we can easily look to our past – as well as other communities – for other ideas to undo the problems of the past one-hundred-year trend to build un-sustainably.

In this thesis I would like to introduce an experimental group of designers to the field of sustainable design. These are the experimental designers of the annual Burning Man Arts Festival. I attended this festival in 2006 to document and learn about the architecture used by the participants. These designers have proclaimed themselves native to the harsh northern Nevada desert for one week every year. Each year they have the opportunity to create a new design or modify an old design to make their shelter

comfortable and livable in a desert that has no plumbing, gas lines, or electricity. In other words, they situate their design to the desert in which they are building. The question I address here is, how do the temporary structures of Burning Man demonstrate the principles of sustainable design?

# How do some structures at Burning Man demonstrate sustainable design?

There are numerous challenges when designing appropriate housing for Northern Nevada's Black Rock Desert. The remote location of Burning Man necessitates that all consumable resources used throughout the event are brought in with each participant at the beginning of the event (except for ice and coffee, which can be purchased at the event's official café). Due to limited cargo room in participants' cars and trailers, the desert's extreme heat, and participants' financial restrictions, resource conservation at Burning Man is crucial. People are required to conserve resources both in their shade/housing structures, as well as in their consumable resources, such as electricity, food, and water.

During the day, temperatures can reach 120-Fahrenheit degrees while at night they can drop to forty degrees. Because the only infrastructures provided by the festival are roads and porta-potties, reliance on public utilities for air conditioning or heating at night is not possible. In this environment, designers are required to create appropriate designs that can mediate the extreme temperatures festival attendants experience every day. Instead of using mechanical air conditioning, Burning Man designers have to work

with the local environment to create comfortable microclimates within each building.

Some designers have been more successful than others. This study will explore the successes and challenges of these designs to answer the question how do the temporary structures of Burning Man demonstrate the principles of sustainable design? To answer this question, this study will examine the two key aspects of sustainable design, lightweight building design and passive cooling. The study will also examine strategies for indoor temperature regulation. These strategies reflect the experimentation at Burning Man, and reflect the current work in the field of sustainable design. Thus, this study will present building strategies as well as temperature regulation strategies that can be applied to future construction projects.

#### Is Burning Man sustainable?

The sustainability of Burning Man is a complicated issue. If our question is "can the festival as it existed in 2006 be replicated year after year without damage to the environment?" the answer is definitely not. There are many reasons for this: The first is that people drive from across the country to get to Burning Man. Although some people carpool, they often drive U-haul trucks, tractor-trailers, and RVs, all of which require enormous amounts of gasoline. The moving trucks and trailers are used to bring water, food, clothing, mopeds, art cars, buildings, and massive art projects that may require multiple tractor-trailers to transport. Calculations estimating the gasoline used to get every attendee and their belongings to Burning Man in 2006 show that it took roughly two million gallons of gasoline. I produced this Figure by assuming that the 40,000 participants drove an average of 600 miles to get to the site, at an average of 12

miles per gallon (MPG). 12 MPG was used as an average between the MPG of cars, SUV's, RVs, Buses, and Trucks. Cars comprise 45% of the vehicles, SUV's comprise 40%, and Rvs, Buses, and Trucks comprise 15% of the vehicles traveling to the festival (Cooling Man, 2007). Likewise, it would take another 2 million gallons of gasoline to get them and all of their belongings back from the festival. This is a total of 4 million gallons of gasoline just to get everybody to and from the festival! The 'Cooling Man' group has calculated that the 2006 festival produced a total of 27,000 tons of carbon, 25,000 of which were generated through participant travel.



Figure 1: Burning the Man (Yoga Chicago, 2007)

Fire is one of the most common art forms to be found at Burning Man. From firedancers to post apocalyptic art cars outfitted with flamethrowers, there is no conservation of petroleum products once people have reached the Burning Man festival. There is no way to accurately calculate the volume of petroleum being burned at the festival, but we do know that it is an enormous amount.

With the shortage of petrol fuels, and their effects on the atmosphere, Burning Man as it occurred in 2006 was far from sustainable. However, there is much to learn from Burning Man, and there are many festival attendees who would like to do right by the earth. The first of these groups is the Alternative Energy Zone, a theme camp "Free of Stinky, Noisy, Polluting Generators" (Alternative Energy Zone, 2007). The second group worth mentioning is called Cooling Man, an organization that seeks to offset the carbon dioxide of all the fuels and wood burned both at the festival and for transportation to and from the festival. In 2006, Cooling Man received enough donations to purchase 200 tons of carbon offsets; carbon offsets are attempts to neutralize carbon creation through strategies such as promoting renewable energy and planting trees. Their goal for 2006 was to offset the 110 tons created by the burning of the festival effigy, The Man. For 2007 Cooling Man is attempting to offset all the emissions of the festival, including travel. As the Cooling Man website states:

"You might be thinking, 'Trying to make a huge, temporary city in the desert sustainable is ridiculous; its very nature is unsustainable'. Well, you'd be right. We can never erase the entire environmental impact of an event as large and resource-intensive as Burning Man. But we can effectively reduce our climate impacts, and in so doing show ourselves and others that it's possible to take action on this issue" (Cooling Man, 2007).

Cooling Man's carbon offsets are achieved through donations to foundations for renewable energy as well as foundations that plant trees to sequester carbon. Planting trees goes a long way toward reducing environmentalist guilt, but the fact is that even if our entire planet were to be planted with carbon sequestering trees, we would still only be sequestering one tenth of the carbon we are putting into the air every day (Catton, 1982). Problematic to the young carbon offset industry is the lack of regulations standards and institutional oversight. The offset industry would like to pump liquefied carbon into drained oil reservoirs for storage (to prevent it from contributing to global warming), but liquefying and transporting that much carbon is an insurmountable task. The offset movement is being critiqued as being analogous to the sale of indulgences by the Catholic Church, in the Middle Ages, where people purchased God's forgiveness to ease their guilt (Thompson & Moles, 2007). To make the Burning Man festival sustainable, huge changes would have to be made.

Burning Man may be far from sustainable as it is, but that does not mean it cannot further the goals of sustainability. Through the community and through the design process of each camp, festival attendees are learning to reconnect with the land they are living on. They call this place home, albeit for only one week. This is exactly what William McDonough believes is necessary if we are going to create a sustainable world. To make McDonough's idea work, we need to 'declare ourselves native to a place', to commit to and learn from the land (McDonough, 2001). Although the festival is not sustainable, it is an excellent tool to re-introduce native living in the form of a festival. As Frank Lloyd Wright argued, it is when we separated buildings from their local surroundings that our problems with un-sustainability began (Wright, 1939). Since Burning Man is local and native to a place, it is an ideal site to test and learn about sustainable design.

#### An introduction to Burning Man

Burning Man is an "annual experiment in temporary community dedicated to radical self-expression and self-reliance" created by artists, designers, and the contributions of the forty thousand people who attend this weeklong event (Burning Man Organization, 2007). This event was created as an exploratory space for a community of artists.

The location for the event is a dried up Pleistocene lake bed set in a valley between a few barren mountains. This lake bed has been nicknamed the 'Playa', which is Spanish for beach. Unlike a beach, this is not sandy but is composed of highly acidic sediment that quickly turns into a thick mud when it rains.



Figure 2: the author caught in a dust storm

When this sediment is dry, it forms the famous cracked mud patterns of the world's deserts. The surface of the lake bed is quickly beaten into dust when people

walk, bike, and drive over it. When the wind picks up, the dust envelopes the whole landscape, creating a total whiteout, making a difficult landscape in which to live and build houses.

Each year, Burning Man organizers arrive months before the event begins, to erect artistic structures, public spaces, and roads throughout what becomes 'Black Rock City'. Next the theme camps come to build their housing and artistic spaces that offer drinks, fun activities, educational opportunities, and other services for the greater Burning Man community.

The participants arrive in the first few days of the event, near the end of the summer, to set up their housing and shade structures. Following Burning Man's official slogan "leave no trace," all structures are removed along with all trash and camping materials at the end of the week long festival. When participants leave, the Burning Man event site is left in pristine condition with no evidence of the experimental temporary community. The festival site is leased from the Bureau of Land Management (BLM), and the phrase "leave no trace" is actually taken from the legal agreement with the BLM. Organizers often stay for months after the festival, scouring the desert inch by inch to ensure a complete restoration. If any trace is left, the lease of BLM land will be terminated, and no future festival will be possible.

By analyzing the built environment of such a community, this thesis intends to examine the successes and failures of the experimental lightweight architecture and passive cooling designs of the Burning Man Festival. The housing challenges presented at this festival offer a unique and expansive test site for these aspects of sustainable design.

#### **Participants in the study**

Participants were selected based on the demonstration of principles of sustainability in the design of their temporary living spaces at the Burning Man Arts Festival. The investigator surveyed campsites and temporary living spaces at the Burning Man event. If any architecture or design looked innovative or ecologically sustainable (for example if there was evidence of solar panels, innovative building materials or design), the investigator approached the camping group and asked if anyone involved in the camp design would be willing to participate in an interview to explain the design and/or would allow photographs to be taken of the structure.

#### **Data collection**

Data for this project were collected using ethnographic methods throughout the 2006 Burning Man Festival, which was held during the last week in July and the first week in August. Participant observation was employed to learn about the place-based conditions that participants' structures were responding to, as well as the effectiveness of participants' designs in their response to these local conditions.

Data consisted of 10 hours of audio-recorded interviews and 700 photographs of buildings and structures that exhibit sustainable or innovative designs. Interviews were audio recorded on an Archos Jukebox Mp3 recorder with an Audio-Technica stereo condenser microphone. Interviews included the following questions: "What building materials did you use for this structure?" "How have you prepared this building/structure

for the hot and cold weather of the desert?" "Are you using any electrical appliances, and if so how are you powering them?"

When permission was given, the principal investigator took photographs of the structures to record the design, the use of materials, and the use of space, along with other circumstantial documentation. The photographs and information provided in the interviews was analyzed for sustainability and compared to designs currently being used in the field of sustainable architecture and design. Subjects for photographic documentation included camps, shade structures, and living spaces/structures.

### **Chapter 1: About Sustainability**

Sustainable architecture is a field composed of a combination of general sustainability theory and general architecture theory. Understanding the relevant pieces of both these fields will be essential to my analysis of what the fields of sustainable architecture and sustainable design can learn from Burning Man. I will first explore current theories of sustainability to situate my later discussion of architecture in terms of sustainability.

#### Why sustainability is important

There are many reasons why the term sustainability is on everyone's lips these days. The reason most often discussed is climate change and global warming. NASA's head scientist, James Hansen, is one of the many scientists to warn the American public about the climate change that has already begun. Hansen (2007) tells us that our climate has already risen one degree as a result of human activity. The gases that we have already released into the atmosphere will raise the Earth's temperature by another degree. Hansen goes on to say that if we make all the changes officials deem necessary to "address the issue," the gases that we will release given our industrial infrastructure will raise the temperature yet another degree. Hansen warns that if we do not change our behavior, we risk increased coastal tragedies like the tsunami and hurricane Katrina, and will experience a rising sea level, fresh water shortage, shifting climatic zones, and desertification.

Hansen has laid out 5 steps to curb global warming. The first is to ban the

building of new coal power plants. Ed Mazria, one of the founding fathers of green building, has also called for a ban on all new coal plant construction. The second step is to put a price on emissions that gradually rises (in order to give consumers time to adapt). Such financial pressure will theoretically push people towards responsible consumerism and responsible lifestyles. The third step is to enact energy efficiency standards. Green architects have for years stated that it would be simple to make our buildings at least 50%more efficient, and that an 80% reduction in buildings' energy use is not unreasonable and is in fact easy to accomplish (Mazria, 2007). The fourth step Hansen gives us is to create awareness about the rapidity with which the west Antarctic ice sheet can melt. New scientific data shows that the whole ice sheet could collapse in as little at one hundred years. This collapse would cause a 16 to 19 foot rise in sea level, which would inundate coastal cities, and displace hundreds of millions of people. Hansen's (2007) final step is to reform our communication practices, making scientific knowledge available to the public without censorship by the White House administration, as happened to Hansen himself.

Recent critiques of our economic systems and power structures are also crucial to understanding the importance of sustainability movements. David Korten states that most of the problems we face today, including climate change and issues of social justice, stem from modernity's basic assumption of the necessity for hierarchical power structures (2006). Korten calls this hierarchical power system 'Empire', and he tells us that we need to remove this power structure and embrace a vision of earth-centric communities. Under a hierarchical structure, change can only occur from the top down. Recently we have seen that Americans would like things to change, while the U.S.

government has consistently stalled because of political hesitations and corporate incentives (Norberg-Hodge, 1996).

Helena Norberg-Hodge gives a similar critique of our current situation, citing globalization rather than 'Empire' as the root cause of most of the world's problems, including global warming, species extinction, job insecurity, poverty, crime, and the erosion of democracy. When this argument is made it is not uncommon for people to defend globalization and the pleasures they derive from it by saying that globalization is inevitable (Norberg-Hodge, 1996). Norberg-Hodge responds:

Globalization is neither an inevitable nor an evolutionary process: it is occurring because governments actively promote it and continually subsidize the framework necessary to support it. The current dominance of the western industrial model could never have arisen without the prolonged access to the South's (southern hemisphere) raw materials, labor, and markets. (Norberg-Hodge, 1996; 2)

Needless to say, Norberg-Hodge supports a movement away from the single centralized economy that produces vast homogenized markets and "transforms unique individuals into mass consumers" (Norberg-Hodge, 1996; 2). To move away from global models, she advocates a movement toward local models, much as David Korten does. Norberg-Hodge (1996) tells us that such a move would lead to economic and environmental health as well as support cultural diversity, thus lessening ethnic conflicts and violence. Other authors such as Angela Dean, the author of *Green by Design* (2003), supports these claims, saying that sustainable design calls for living with natural systems rather than relying purely on technical support for our survival.

The shift towards local models and 'Earth Communities' has already begun. Norberg-Hodge points to the WTO protests as an example of American citizens standing up against globalization, in the name of the environment and in the name of human rights. This protest shows a mass awareness and willingness to act. Norberg-Hodge also points to the many grass roots activities that are empowering the local, such as community banks, Community Supported Agriculture (CSA) Farmers' Markets, and the Eco Village movement, as examples of the shift in action. Angela Dean supports Norberg-Hodges belief that this shift has begun:

I believe the revolution has begun. The beginnings are rooted in the empowerment of each of us making decisions for our own living. Starting within ourselves, our actions affect the place where we take root, our families, friends, community and so on. There is a collective conscience about the need to live more sustainably- it's not just a few people on the fringe... [Green] owners, builders, and designers... are meeting the challenges of today's cultural, social, economic, and market influences that had been seen as barriers to building green. They are dissolving those barriers with powerful success stories. (Dean, 2003; 43)

The Harris Interactive poll recently reported that 90% of Americans believe that corporations have too much political power, and that 92% of Americans believe small local businesses should have more power (Harris Interactive, 2007). David Korten in his book *The Great Turning* (2006) points out that 83% of Americans agree that our government has the wrong priorities. Korten tells us that what Americans care about is people (education, family, and communities) rather than profits, spiritual rather than financial values, and international cooperation rather than domination. The people of the United States are starting to mandate a change from our global economic model.

#### Sustainability theory

All types of sustainability root their definitions in the ability to maintain a

practice, whether financial or ecological. The World Commission on Environment and Development (1987) defines an environmentally sustainable economy as "An economic system that meets the needs of its current members without compromising the prospects of future generations." Included in this definition is the pillar of sustainable design, embodied by the statement: "whatever we do, we should do it in a way that does not compromise the prospects of future generations" (McDonough, 2001).

There are two forms of environmental sustainability (Van Der Ryn & Cowan, 1996). According to David Orr (1992), these are sustainable development (technological sustainability) and ecological sustainability. Technological sustainability maintains that "every problem has either a technological answer or a market solution" (Orr, 1992; 24). Sustainable development is achieved by "more rapid economic growth…greater technology transfer, and significantly larger capital flows" (World Commission on Environment and Development [WCED], 1987; 89). Ecological sustainability, on the other hand, "is the task of finding alternatives to the practices that got us into trouble in the first place…" (Orr, 1992; 24).

Because sustainable development is dependent on better management and technological solutions, Van Der Ryn and Cowan (1996) tell us sustainable development will not achieve sustainability by itself. They contend that what was outlined in *Our Common Future* (WCED, 1987) is a "thinly veiled, business-as-usual optimism" (Van Der Ryn and Cowan, 1996; 7). Even the authors of *Towards Sustainable Building*, who believe in sustainable development, agree that the results achieved by the international recognition of these goals are "modest" at best (Maiellaro, 2001; 12).

Ecological sustainability calls for an ideological shift (Van Der Ryn & Cowan,

1996). David Orr (1992) laid out the principles of such an ideological shift that are needed for Ecological Design. The most important of these for the purposes of this thesis is a shift towards traditional or place-based knowledge, which is essential for learning to live in ecologically sound ways (Orr, 1992).

Sim Van Der Ryn has been one of the most influential leaders in this ideological shift. He tells us that the solution to the ecological problems we have created lies in our ability to interweave our lives more closely with nature (Van Der Ryn & Cowan, 1996). Western countries have become disassociated from nature, as a product of the modernist project, and as Locke and Bacon would have hoped, we have become de-contextualized from everything except 'pure knowledge' or its manifestation, technology (Bauman & Briggs, 2003; 45). De-contextualized, in this context, means that the realms of society, nature, and science (architecture) have been separated so that architectural theory is separated from the context of its location. This is the basis for what has come to be known as the international architectural style – or the one size fits all approach to building and design (Dean, 2003).

The ideological movement towards a place-conscious existence began with Frank Lloyd Wright (1939), when he introduced the concept of Organic Architecture. Many current authors and activists including William McDonough (2001) agree with the necessity of this ideological shift. By asking questions such as "What is here? What will nature permit us to do here? What will nature help us to do here?" we can begin tailoring our buildings to site-specific designs that truly approach ecological sustainability (Van Der Ryn & Cowan, 1996; 51).

#### **Sustainable Architecture**

Sustainable architecture has a long history. As Frank Lloyd Wright pointed out, up until the late 1800's, vernacular architecture was the norm (Zeiher, 1996). In the last two hundred years we have abandoned site-based architecture in favor of an architecture born out of dry books, as Wright (1939) put it. In the 1970's, the oil shortages frightened a few architects began trying to relearn how the sun could be used to heat and cool our buildings (Zeiher, 1996). This is approach to architecture has aptly been named solar architecture. Solar architecture is based on passively heating and cooling buildings by orienting the building south for maximum solar heat gain in the winter and minimal solar heat gain in the summer (Lechner, 1991).

From the work of the early solar architects come four ways to approach sustainable architecture. The first is through conservation and efficiency (Livingston, 2007). These are termed the 'first step towards sustainability.' Conservation is about curbing our electrical use by turning lights out when you leave the room and the like01.0000000 Efficiency is achieved through energy efficient light bulbs and intelligent appliance designs where appliances like refrigerators and washing machines can operate optimally with the least use of electricity or gas (Livingston, 2007).

The second approach to sustainability is through heating and cooling (Stitt, 1999). Heating and cooling require 49% of an average household energy input (Livingston, 2007). Heating and cooling are about house efficiency: How well are the windows sealed? Was the insulation installed correctly? Are the ducts designed to provide an even air pressure in all rooms? These are all problems that limit the average house's

ability to heat or cool (Cook, 1989). Through proper insulation and draft proofing, a house gains great efficiency (Dean, 2003).

The third approach to sustainable architecture is to design a building to be passively heated and cooled with the aid of the sun, the wind, and the heat of the earth (Livingson, 2007). Through proper solar orientation, a building can be heated by the low winter sun entering the south windows, and protected from the high summer sun through awnings or recessed windows (Stitt, 1999). The wind can be employed to remove excess heat from a building through cross ventilation and roof ventilation. The earth can be used as a heat-sink, absorbing heat during the day to keep the building from overheating, and radiating that heat back into the building at night, to keep it warm (Olgyay, 1963).

The fourth approach to sustainable architecture is through the use of renewable energy (Zeiher, 1996)). Renewable energy is energy that can be produced with resources that can regenerate, unlike fossil fuels (Mazria, 2007). Renewable energy mostly comes in the forms of Photo Voltaic or solar electric (PV) panels, Photo Thermal (PT) panels, wind turbines, geothermal, tidal pumps, and hydropower (Stitt, 1999). Although hydropower is renewable, large hydroelectric plants are rarely seen as sustainable by anyone other than the big businesses that enjoy the cheap subsidized electricity produced by dams (Russell, 1999). This is because dams disrupt the ecology of the river and cause mass aquatic extinction (Shiva, 2002). Paul Stamets, the eminent mycologist, tells us that the earth's ecosystem is dependent upon biodiversity to survive and recover from natural disasters. By damming rivers, we reduce the dynamism of the Earth's waters and dramatically reduce the biodiversity of our rivers (Stamets, 2005). Dams contribute greatly to the de-evolution of the Earth's gene pool, which results in reduced ability to

handle the diverse challenges that climate change will bring.

The drive for renewable energy was born out of the oil scare in the 1970s. The search for renewable energy found its primary energy source as the sun, which allowed a shift away from dependence on natural gas and coal powered power plants (Mazria, 2007). PV panels made of sliced silicon wafers became a popular way to gain freedom from petroleum fuels. Initially PV panels could capture 11% of the sun's energy, which could then be used in the home. The technology developed quickly until the early 1980s when President Reagan cut all funding to this research and removed the solar panels that had been installed on the White House by the previous administration (Brown, 2006). Research started picking up again in the mid 1990s (Mancini, 2006). Current PV panels have reached 30-40% of the sun's energy. Capturing the energy of the sun thermally proves to be far more efficient. PT panels capture the suns energy thermally to heat water. PT panels get between 60 and 95% of the incoming solar radiation (Mancini, 2006).

Sustainable architecture is also achieved through the thoughtful use of materials. Green builders favor materials that have been used before or have been recycled (Stitt, 1999). By reusing materials, we spend less energy extracting materials from the earth. To truly be sustainable, building materials should come from as close to the building site as possible, in order to reduce the amount of energy spent transporting materials (Van Der Ryn & Cowan, 1996).

Green builders are finding rainwater collection and reused grey water collection systems important for the protection of our water supplies even in areas that have an abundance of water (Stang and Hawthorne, 2005). Our fresh water is often highly

contaminated both by industrial scale agriculture, which dumps petrochemical fertilizers into our rivers, and by manufacturing plants which contaminate our rivers with industrial byproducts (Shiva, 2002).

Many buildings are built in the desert, where the water level can be hundreds of feet below the surface. In these climates it is necessary for buildings to not only conserve their water through efficient plumbing fixtures, but also to collect as much rainwater as possible. Rainwater is typically collected off of a building's roof and stored in large tanks and cisterns (Lancaster, 2006).

Our expansive suburban sprawl has also contributed to our water problems by both using more water than ever in history and by draining all the water that falls on suburban neighborhoods into storm drains. Through the use of storm drains, we have removed the ability of the land to absorb water, which allows plants to grow and recharges the aquifers (Lancaster, 2006). To counter this trend of water rejection, many designers are calling upon the work of permicultureist Brad Lancaster to design permeable landscapes that are designed for water uptake rather than water ejection. However it is achieved, water consciousness and conservation are becoming increasingly crucial to the success of sustainable architectural planning.

#### Sustainable Architecture and Burning Man

One of the most important lessons to remember about sustainable architecture is that sustainability is created through location-responsive designs. The Burning Man Arts Festival is located in a desert with temperature swings from 30 Fahrenheit degrees to 125 Fahrenheit degrees within 24 hours. There is no water source near the festival, and all evidence of the temporary city must be removed at the end of the festival. These are challenges that make Burning Man a unique test site for some aspects of sustainability. Although most of the living structures employed in this temporary city of 40,000 are not able to heat and cool themselves, there are a number of buildings and living structures found at the 2006 Burning Man that used sustainable architecture principles to prevent overheating during the day and excessive heat loss at night. Despite the lack of water, there are a few evaporative cooling strategies that were employed in conservative and responsible manners. Also of interest to this study are the many lightweight structures employed to shelter 'Black Rock' city's residents from the elements.

The selections of building examples from Burning Man presented in this thesis were based on a set of criteria related to material usage, evidence of passive cooling, and construction technique. Criteria of material usage include: material conservation, use of recycled materials, and reuse of building materials from the previous year's festival. Criteria for passive cooling include: evidence of ventilation strategies, shading, evaporative cooling, and earth coupling. Criteria for construction techniques are based in individual solutions rather than mass-produced or prefabricated structures such as Costco carports.

The structures we will be examining are the homemade structures people bring with them or build when they arrive. These structures are almost entirely comprised of tented and domed structures. Before we examine what people are doing with these structures at Burning Man, it is important to understand the history and development of the sustainable structures found at Burning Man

## **Chapter 2: Lightweight Buildings**

Central to understanding and learning from the buildings at the Burning Man Arts Festival is the understanding that each participant brings their own housing and removes their housing when they leave. This requires a nomadic approach to architecture. Because each structure must be transported, often year after year, each structure must be light enough to be easily transported and must be simple to erect and disassemble. This chapter will analyze three aspects of Burning Man's lightweight architecture, including tent design, dome aesthetics, and small scale tensegrity structures.

#### **History and Theory of Lightweight Domed Structures**

Domes are one of the oldest architectural forms, dating back to 705 B.C.E. (Makowski, 1984). They have captivated the interest of modern architects because they can enclose the largest amount of space with the least building materials (Howell, 1974). The geometry of a dome allows for stress loads to be distributed to the edges of a structure whereas flat or trussed roofs require columns to support the center of the roof (Robbin, 1996). There are two types of domes, vaulted domes and spherical domes. A vaulted dome is a dome that bends in one direction as an arch does. A spherical dome bends in two directions, thus resembling a sphere (Khalili, 1996). Both of these dome types have been used throughout history (Guidoni, 1939). The strength of a domed building is based predominantly on its shape rather than the strength of individual components (Robbin, 1996)

The rounded shape of a vault naturally supports its own weight, because as the

weight is transferred downward weight is transferred outward to the edges that support the whole ceiling. One of the common problems with vaulted ceilings is that the transference of weight outward has the potential to buckle the walls (Khalili, 1996). Spherical domes do not exert outward pressure and are often self balanced. This is because curvature of any point on the dome is the same in all directions. Such geometry cannot be flattened without significantly stretching or compressing the entire structure (Pugh, 1976). All other geometric forms that are used to contain space can be flattened through the failure of singular structural components (Makowski, 1984).

Domes can be built either by compiling massive amounts of material into a domed structure, or built with structural bracing to support roof and wall coverings (Robbin, 1996). The amount of materials used to make massed domes is not practical for Burning Man, given that all materials have to be transported to and from the festival.

There are two main types of braced spherical domes - those that use structural ribs and those that use structural polyhedron to approximate the shape of a sphere (Robbin, 1996). These two construction methods are of particular interest in the study of Burning Man's architecture for three reasons. First, they require relatively little building materials, making them easy to transport to and from the event (Makowski, 1984). Secondly, they are comparatively economical and easy to construct (Hopster, 1981). Thirdly, such domed structures are one of the most common building types found at the Burning Man festival (Alternative Energy Zone, 2006).

Polyhedral domes are a type of ribbed domes that employ Euclidean geometry to connect planar ribs to approximate the form of a sphere. Polyhedra are compilations of planer surfaces that are circumscribed by a sphere. The strength of these forms lies in

their geometry (Pugh, 1976). In polyhedric geometry, so long as structural beams are engineered properly, the connections between structural members are the weak points. So if we assume that the connections are flexible and examine these planar geometric forms, we find geometry that relies on the strength of the structural members rather than the connections (Howell, 1974). This is the basis for Buckminster Fuller's Geodesic domes (Makowski, 1984).



Figure 3: Geometric stability (Pugh 1976)

Buckminster Fuller was the first dome pioneer to recognize and develop the triangular planed dome. His versions are called geodesic domes (Marks & Fuller, 1973). Fuller claimed that his geodesic domes were modeled after the mathematical principles embodying force distributions similar to those found in atoms, molecules and crystals (Edmondson, 1987). He believed, as many people now do, that nature always builds the most economical structures and that the crystalline and molecular structures could be reproduced architecturally to create the lightest, strongest, and cheapest constructions (Marks & Fuller, 1973).

There are many types of geodesic domes; all of them begin conceptually with a

polyhedron (Pugh, 1976). The icosahedron was a logical choice for Buckminster Fuller because it is the most spherical of the platonic polyhedra that are composed of triangular forms (Pugh, 1976). Fuller knew that should people desire large domes with long spans, the addition of further structural braces would be necessary (Pugh, 1976). According to Fuller, the best way to accomplish this is by bisecting each equilateral triangle of the icosahedron into six triangles (Makowski, 1984). Although the geodesic dome is archetypal, there is nothing that significantly differentiates geodesic domes from other triangulated domes (Makowski, 1984).

Some of the domes I will be discussing in later chapters have a striking resemblance in their material use to the great vaulted domes of the Middle-Eastern marshlands. The only building materials available within the marshes are reeds (Thesiger, 1964). The reeds are bundled together to create structural members. Large bundles of reeds are sunken into the earth, leaning away from the center of the building. These large bundles are then bent over the center of the building and lashed to the bundle that has been bent over from the opposite end of the building (Schoenauer, 2007). Smaller bundles are then lashed to the larger bundles to create a latticework that will support the roof and wall coverings (Thesiger, 1964). The reed vaults are covered in mats that are also woven out of reeds. The woven reeds protect against sun and rain while allowing air to flow slowly through these buildings (Thesiger, 1964). These building materials come from the land and quickly return to the land as nutrients when the buildings are not maintained for long periods of time. This method of building fits nicely into William McDonough's (2001) assertion that "waste equals food."



Figure 4: Vaulted Reed Domes (Thesiger, 1964)

#### **Criteria for the Inclusion of Domes**

The domes pictured in this chapter were chosen based on material usage and construction techniques. All of the domes that were selected for analysis in this chapter are made of recycled materials or have been used at previous festivals. By the nature of domed construction, the materials used in these structures have been minimized. The ways in which materials were employed was also a significant part of the decision to include or exclude examples of domes found at the 2006 Burning Man Arts Festival. Domes built with materials that were of structural or aesthetic interest were considered to be particularly relevant to this thesis. Finally construction techniques also played a role in the decision to include or exclude examples of domes. Through an examination of how these domes were erected, domes that are classified here as small tensegrity domes, a strategy of dome building that relies on the tensile strengths of building materials, were found to be of particular interest due to their uncommon material use and construction techniques.

#### **Small Tensegrity Domes**

The simplest structures found at Burning Man were vaulted tensegrity domes.

In these vaults, PVC pipes are bent forming ribs that hold the roof aloft. Bolts of cloth or vinyl are stretched across the structure.



Figure 5: Vaulted PVC Dome

Figure 5 shows a basic version of the vaulted PVC dome. Stakes (usually rebar) are driven into the ground along both edges of the structure. Equal length PVC pipes fit onto the stakes and are bent over to the opposite site where they are fitted over opposing stakes.



#### Figure 6: Bending PVC Ribs

Some vaulted domes such as the dome in Figure 7 use more advanced construction techniques. In this dome, the bent PVC are joined with T connectors on both ends to PVC cross bars that are held up by PVC poles. By having the roof bend start at chest height rather than floor level, the occupants do not feel as though the walls are caving in on them. In this type of design, the benefits reach beyond the walls; with a vaulted roof, even the smallest rooms feel open.



Figure 7: Stilted vaulted PVC dome

These structures bear a remarkable resemblance, in how materials age used, to the vaulted domes found in the marshes of the Middle East. Rather than using PVC, the buildings are constructed entirely out of reeds (Figures 4 and 8). Both of these vaulted domes can be recognized as tensegrity structures because the upper side of each rib is under tension and is opposed to the compression of the underside of each rib. The use of both the tensile and compressive properties of a material is a hybrid tensegrity approach to building vaulted domes that has not yet been recognized in sustainable design or
construction texts. Standard tensegrity theory utilizes materials that are placed under compression to oppose materials that are placed tension. In this hybrid approach, not only are the compression materials the same as the tension materials, but they are combined into one dynamically responsive structural member. This approach utilizes both tensile and compressing properties of the given construction material simultaneously.

One possible problem with this approach is durability. Although PVC is flexible when it is new, it becomes brittle over the years, as dioxin leaches out of the PVC, degrading the environment. This leads to a breakdown of both the tensile and compressive properties of PVC. The reeds, on the other hand, do not have this problem. So long as the reed structures are maintained, there is no breakdown of either their tensile or their compressive properties over time. Other materials such as bamboo or steamed wood could be used in these designs to make truly green buildings.



Figure 8: Inside a vaulted reed dome (Thesiger 1964)

### **Dome Aesthetics**

Despite the advantages, many people have found living in domes awkward and difficult (Oakes, 2007). Many people comment on the difficulty of living with sloping walls, but the majority of complaints are about poor aesthetics (Kahn, 2007). Geodesic domes are quite common at Burning Man. Most are built out of steel water pipe or galvanized steel conduit tubing. The domes pictured in Figure 9 were popular public spaces at the 2006 Burning Man festival that overcame the common aesthetic pitfalls of domed structures.



Figure 9: Multiple articulated domes

These domes are all at least 15 feet tall. The benefits of this height are twofold. First the dome walls do not begin to slope inwards until the wall has extended above head height. Second, the roof is not only high but it is rounded; both of these features give a feeling of roominess. Other design features include large shaded awnings and oversized open aired entrances.

Although all of these structures have been very successful at making the occupants comfortable, the most effective of these examples is Camp Citrus (Figure 10). The Camp Citrus dome is made to look like a giant lemon, through the yellow dome skin

and the yellow turbine vent placed on the roof. The entry way is fully articulated through a large orange doorframe that is topped with an oversized orange slice.



Figure 10: Articulated dome by Camp Citrus

These features provide a visual continuity that articulates the artistic concept of the camp while aesthetically appealing to pedestrians to draw them into the building. Natural ventilation and light filtering in through the intentional gaps between each section of the dome skin create a spacious and light indoor experience. Rather than dividing the space into indoor and outdoor spaces, this technique fuses the indoors with the outdoors (Robbin, 1996).

### History and Theory of Lightweight Tented Structures

Short of a cave, tents are the oldest shelter used by humans (Robbin, 1996). They are also the most common form of shelter used at Burning Man (Alternative Energy Zone, 2007). Tented structures range from a tarp covering a single pole, to membrane structures that require advanced experimental engineering to cover stadiums and auditoriums (Robbins, 1996).

The Bedouin tent is composed many of bolts of goat hair fabric that are sewn together, held aloft by wooden stakes, and anchored to the ground around the periphery as can be seen in Figure 11. The tents vary in size, and contain anywhere from one to four rooms. A one-room tent would have two sets of three wooden poles holding the fabric up. This pole arrangement is adapted to make smaller or larger tent, based on family size (Jabbur, 1995).

A cloth fence is erected coming directly out of the open side of the tent. This cloth fence provides an additional wind proofing mechanism, so winds that come around the side of the tent do not create turbulent air that would make fire lighting difficult (Dickson, 1959; 80). This strategy for wind protection has also been advocated for by the U.S. Army Corps of Engineers in an experimental study of dune building (Woodhouse, 1978).

In the summers, it is common for Bedouins to hang either another layer of goat hair canvas or a large rug directly underneath the roof of the tent. This second layer acts as a radiant heat barrier and creates a breezeway to dissipate the heat being radiated by the top layer as the summer sun heats it. This simple method is very effective at creating

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a microclimate in the tent that is 10-20 degrees cooler than the outdoor temperature (Dickson, 1959).



Figure 11: Bedouin tent diagram (Dickson, 1959)

These tents are designed for a nomadic lifestyle. They are easy to set up, take down, or move. They are also easily adapted for changes in family size. The basic principles behind the design of this type of tent can enable endless variations. This is however only one kind of tented structure, and in the last century many new tent and membrane structures have been designed.

#### Tensegrity and membrane structures

Tented buildings have been excluded from the category of buildings until recently. The recent re-categorization is due to Horst Berger's efforts to show that a membrane structure could be just as "strong, permanent, fireproof, and insulated" as any other building (Robbin, 1996; 8). Membrane structures are built out of fabrics or membranes that are either stretched over a space frame or are shaped by a set of cables that tension the membrane and poles that serve as raised anchors for the cables. Because of the economy of materials in tension, the overall cost of construction is reduced (Robbin, 1996). Examples of this building strategy include the Denver International Airport, the San Diego Convention Center, and the Cynthia Michael Woods center for the performing arts in Texas. The membrane performs all of the weather protecting functions of the roof while day lighting a building through engineered membrane transparency (Robbin, 1996). We can see that such structures are models of efficiency because the simple membrane creates the building's "form, structure, function, and the mechanical working of the building" all at once (Robbin, 1996; 9). Horst Berger tells us that this is the sort of building that we need to embrace to achieve sustainable design because our survival is dependant on our acceptance of "an aesthetics of economy" (Robbin, 1996; 9).

### **Criteria for the Inclusion of Tents**

Tent design and construction were central to the inclusion-exclusion decision for tent examples pictured in this chapter. The tents in this chapter were chosen based on factors of material usage and construction techniques. All of the tents that were selected for analysis in this chapter used recycled materials or have been used at previous Burning Man festivals. With tent construction, material usage is reduced dramatically compared to traditional buildings used to enclose the same amount of space. Designs were chosen that best illustrated the varied approaches to tent design found in Burning Man's 'Black Rock' city, to illustrate the possibilities and principles of tented construction.

### **Approaches to Tent Design**

The basic idea of a tent begins with a pole and a covering anchored to the ground, with the pole raising the covering above the ground to provide a small shelter. This idea has been adapted to include multiple supports and elaborate coverings. There are countless adaptations to this design at Burning Man.



Figure 12: Single poled parachute tent

The first example uses a single pole (Figure 12). The covering is a recycled parachute held open by a PVC pipe that has been bent into a circle. This circular support for the covering is the only adaptation made to the basic tent form. Through this adaptation, the structure uses fewer guy wires to tension the covering.

Figure 13 shows a three-poled tent, which is an adapted two-poled tent. In the two-poled tent, increasing the portion of the cover that is raised high above the ground increases the amount of usable covered space. The further apart the two poles are placed the more space can be opened between them. Increasing the number of supporting poles can expand usable enclosed space. This open design is prone to the wind and requires extra guy wires to hold the tent down during windstorms.



Figure 13: Three-poled tent

As the number of poles increases, some techniques work better than others. Figure 14 shows a twelve-poled tent. Due to the shallow angle between the roof angle and the guy wires, many of the perimeter poles were shaken loose in the wind. Campers needed to re-tension the guy wires and stabilize the poles during the storm.



Figure 14: Continuous angle between the roof and guy wires

To prevent future problems, camp Temple Whore might learn from the tent in Figure 15, which depicts a large fifteen-poled tent. To overcome the high roof angle, this tent uses a second set of guy wires that extend from two-thirds the way up the center poles to the top of the perimeter poles. These guy wires are tensioned against the perimeter poles much more effectively than the guy wires that extend from the top of the center poles. This arrangement strengthens the structure by tensioning the perimeter poles against the ground and preventing them from being shaken loose.



Figure 15: Alternative guy-wire arrangement



Figure 16: Poles arranged perpendicularly to tensioning membrane

The last of the tent variations utilized five poles, one in the center and four on the perimeter (Figure 16). The four perimeter poles angle outward, so that the forces applied by the tensioned covering are perpendicular to each pole. This minimizes the possibility that the poles will loosen in the wind. This is likely the most stable pole arrangement to be found at Burning Man.

An alternative to the basic pole designs commonly found at the 2006 Burning man is achieved by replacing poles with scaffolding as can be seen in Figure 17. Through this construction technique, individual supports are strengthened, thus reducing the number of roof supports that are required.



Figure 17: Scaffolding tent

### How do these Domes and Tents Illustrate Sustainable Theory?

#### A New Model for Hybrid Tensegrity

In the book *Engineering a New Architecture*, Tony Robbins pushed for further research in hybrid tensegrity structures. He called on Horst Berger's mandate for an aesthetic of economy through membrane structures. The structures Robbins outlined as

examples leading the way in tensegrity and hybrid tensegrity oppose materials used for compressive strength with those used for tensile strength. These are remarkable structures that have inspired hundreds of architects.

This thesis re-introduces an ancient model of hybrid tensegrity, informed by the vaulted PVC domes of Burning Man and the reed domes of the marsh Arabs. Rather than opposing compression materials with materials placed under tension, we can design tents so that the compression and tension are combined in one structural member. By relying on both the tensile and the compressive strength of a material, a structure can be built with fewer materials, while the structure itself will respond more dynamically to the loads placed on these buildings. Through such hybrid approaches we can achieve the "aesthetics of economy" that Horst Berger advocated (Robbin, 1996; 9).

#### **Dome Aesthetics**

Domes have long been regarded as shapes that achieve Berger's aesthetics of economy. Unfortunately this aesthetic by itself has often driven people away from the concept of dome houses. Although many domes found at Burning Man were left unadorned, the domes that people were attracted to went beyond the basic dome image. To create spaces people are drawn to, there needs to be something of interest to look at.

This concept is similar to one of the central premises of the many recent city revitalization attempts happening throughout the US. To achieve this concept, city planners focus their attention on what they call "façade articulation", wherein city planners attempt to change the image of central corridors. This change is a shift away from flat cinder block storefronts to storefronts that are interesting to look at.

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The same idea is relevant to the design of domes. The domes that drew people in had articulated entrances and design features that captivated the eye of the passer-by. The point was not to hide the fact that the structure was a dome but rather to make the dome interesting and attractive. Unarticulated buildings quickly tire the eye, so it is important to give the observer something more to concentrate on.

In addition domes can quickly become stuffy and cave-like if not properly designed. To overcome this obstacle it is important to ventilate and daylight each dome. This connects the occupant with the outside world and minimizes the cave-like feeling of a dome. By ventilating and daylighting domes, occupants are given the feeling of being protected while still feeling the openness of the outdoors as light filters into the space (Robbin, 1996).

#### Tent design

The challenges faced by Burning Man's tented structures have given us an opportunity to create a few guidelines for future tent designs. The guidelines that stem from the examples in this thesis pertain to membrane tension distribution and pole/truss usage in large tented spaces. As the Bedouins of the Middle East have known for centuries, it is important to distribute the tension applied by the membrane equally among the poles or beams that support the membrane structure. This can be achieved through roof angles, secondary guy wires, and articulated pole angles.

The use of scaffolding in Burning Man's tent structures provides an interesting alterative to the basic pole design. The use of scaffolding for support alludes to the possibilities of membrane structures that are supported by trusses rather than poles, as found in tented structures such as the Cynthia Woods Mitchell Center for the performing arts in Texas. The possibilities for such structures are endless and deserve further work, including the inquiry into applications of this construction technique for individual homes.

# **Chapter 3: Passive Cooling**

There are many passive cooling strategies in use throughout the world. To ensure the success of these strategies, it is essential to employ them in a locally appropriate and site-specific manner. Cooling strategies that work in dry climates may not be effective in humid climates, and vice versa. This chapter will examine the passive cooling strategies in use at the Burning Man Arts Festival such as shading, ventilation, earth coupling, and evaporative cooling. The cooling strategies presented in this chapter test the applicability and feasibility of passive cooling theory through site-specific designs that are relevant to building in hot climates around the world.

### **History and Theory of Passive Cooling**

Assuring livable temperatures in our homes through design is not just possible, but been the only way to keep buildings comfortable until quite recently (Maiellaro, 2001). Use of mechanical air conditioning was unheard of until the 1920's, when evaporative swamp coolers were first mass marketed (Cook, 1989). After WWII, compression coolers replaced these machines because more precise thermostatic control could be achieved (Cook, 1989). The introduction of a mechanical unit to produce evaporative or compression cooling differs from historic evaporative and other historic passive cooling techniques in that the mechanical units separated the climate control of the building from the building design (Cook, 1989).

The first step any designer must take in designing the thermo-comfort of a

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building is to become knowledgeable about the local climate (Gauzin-Müler, 2002). Information such as the sun angle and wind directions can inform the building design, making it possible to keep a building at livable temperatures without the use of auxiliary mechanical systems (Cook, 1989).

Scientific studies of passive cooling systems started in the 1970's during the first energy crisis (Gauzin-Müler, 2002). Lechner identifies four main forms of passive cooling: ventilation, radiation, evaporative, and Earth coupling (Lechner, 1991). All of these passive cooling forms can be divided into two categories, direct and indirect (Cook, 1989). Comfort (direct) ventilation is daytime ventilation that helps the body cool by blowing air over the inhabitants' skin. Convective (indirect) ventilation is defined as nighttime ventilation and is used to pre-cool a building's mass in preparation for the next day (Lechner, 1991). Direct radiation is heat radiated from a building's roof into the night sky (Lechner, 1991). Indirect radiation requires heat to be radiated from a fluid that is pumped onto the roof at night (Cook, 1989).

With direct evaporative cooling, water vapor is introduced into the air entering the building; the process of evaporating water cools the incoming air (Cook, 1989). Indirect evaporation uses the principal of direct evaporation to pre-cool air before it enters a building (Cook, 1989). Direct Earth coupling requires the thermal mass of the earth to be in direct contact with a building, while indirect Earth coupling can use the Earth's thermal mass to pre-cool air before it enters a building (Lechner, 1991).

In the northwestern Nevada desert, the climate is very hot and dry during the summer, although there are occasional monsoons. In hot climates it is typical to use any combination of the cooling techniques described by Lechner. Unfortunately, water has to be hauled from far away because there is no local water source. The scarcity of water makes the use of evaporative cooling difficult in the northern Nevada desert. Vernacular architecture for similar hot and dry climates around the globe usually calls upon use of massive thick walls of adobe, brick, or stone (Lechner, 1991). Because there are no mass buildings at the festival, the primary methods used for passive cooling of buildings at Burning Man are shading, comfort ventilation, and direct Earth coupling.

By shading a building, the building no longer needs to overcome the direct heat of the desert sun, and needs only to be protected against the ambient air temperature (Lechner, 1991). Through shading, designers can lower the average temperature of the earth surrounding a building. Lower earth temperature maximizes the effectiveness of earth coupling (Cook, 1989). Because buildings cannot be dug into the ground, Earth coupling at the festival is limited by the ground's surface temperature.

Ventilation is crucial for most buildings in this climate. The days are hot and the nights are cold, so only comfort ventilation is used (Lechner, 1991). Apart from cooling the body, ventilation also has the beneficial effect of removing heat that has built up inside a building from solar radiation. Vents placed on both sides of the building funnel air past the occupants to create comfort cooling. This is particularly effective when vents are placed in line with the wind. Placing some vents low and others high, or simply utilizing tall vents allows fresh air to enter at the lower level while hot air is exhausted through the higher vents. The temperature differential creates a thermo siphon that is activated by heat build-up. This is called the 'stack effect' (Lechner, 1991).

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### **Criteria for the Inclusion of Passive Cooling Examples**

The examples of passively cooled buildings included in this chapter were based on the inclusion of passive cooling techniques in the basic building designs. The basic types of passive cooling that were selected are shading, evaporative cooling, Earth coupling, and ventilation. The criterion by which these particular examples were chosen was simple: The examples selected for inclusion did not utilize passive cooling techniques as an afterthought, but instead were designed based on passive cooling theories, and exemplify strengths and limitations of these theories.

### Shading

There are two main types of shading: building shading and open walled shade structures. Open walled shade structures are simple and effective for use as public gathering spaces. They are little more than a roof, but they are inviting because they are much cooler than their sunny surroundings. Figure 17 shows an extremely basic shade structure composed of little more than an awning. This is a simple and effective way to keep cool even in the 110-Fahrenheit desert heat.

Figure 18 shows a geodesic hemisphere that has been stilted progressively towards the pedestrian access way. Most of the benefits of this structure are simple: it provides shade for its occupants while allowing air to freely flow through the building.



Figure 18: Simple awning

The benefits of using a domed structure for this purpose are great. By doming the shade structure's roof, the roof does not need to be placed very high, which prevents the stronger winds (found higher above ground-level) from hitting the structure. The domed shape also prevents the shade roof from acting as a sail, because the wind will always provide a downward pressure on the dome. This dome is easily rotated to accommodate for shifting wind directions.



Figure 19: Stilted domed shade structure

Whole building shade structures are shading devices that are created on or around buildings to keep the inner structure shaded. Through the use of this strategy, buildings such as the Phoenix Central Library are able to dramatically reduce unwanted heat from entering the building (Ojeda, 1999). One of the simplest ways to achieve this is illustrated in Figure 19, which shows a tent erected underneath a tarp that is strung over two large tent poles. Although this strategy has largely been forgotten about in the Western World, it is highly effective and has been used around the world for centuries.



Figure 20: Shaded tent

One of the most common materials used at Burning Man to achieve whole-camp shading is agricultural shade cloth. A particular favorite of many attendees is a new type of shade cloth known as Aluminet, which is pictured in Figure 20. This product reflects 70% of incoming solar radiation, thus dramatically reducing the radiant heat in the camping area. The 30% of the sun's energy that comes through provides day lighting, thus preventing the unpleasant feeling of a cave.



Figure 21: Whole camp shading with Aluminet

Recently, the US Army has begun using this strategy for passive cooling in Iraq's and Afghanistan's deserts. The US Army uses sand-colored porous coverings to shade multiple tents in a comfortable and camouflaged manner. Figure 21 illustrates the Army's "small solar shade unit" technology in use at the Burning Man Arts Festival. This technique creates a microclimate under the shade cloth that is cooled both through a lack of solar exposure and by air that passes easily through this loose shade cloth.



Figure 22: Whole camp shading with military camouflage covering

Partial building shading is also employed at the Burning Man festival. Figure 22 shows a meditation structure that employs a decorative top to shade the roof. This decorative top is separated from the surface of the roof. This separation allows heat that builds between the shading device and the roof to be vented away. Temperatures inside this structure were approximately 5-10 degrees cooler than the outdoor temperature.



Figure 23: Partial shading

# **Evaporative Cooling**

There are two types of evaporative cooling, convective and mechanical.

Convective evaporative cooling is achieved by moving air over a moist object. Moisture can come from human perspiration, artificially introduced moisture, and from

ambient moisture in the air. Mechanical evaporative cooling is a form of convective evaporation that uses fans and water pumps to cool the air. Both of these cooling techniques are employed at Burning Man, although the scarcity of water makes their use uncommon.



Figure 24: Evaporative cooling porch swing

Figure 23 shows a man sitting in a porch swing. His swing has been attached to an insecticide sprayer filled with water. Every time he swings forward, the sprayer is primed. When he swings backward, the sprayer is pumped. The water is then sprayed onto the man in the swing. The moisture evaporates off of the skin to cool him off.

In Figure 24 two versions of evaporative mechanical air conditioning systems are exhibited. These closely resemble the design of swamp coolers. It is important to note the ease and affordability of these designs. Both of them have an evaporative membrane through which air is forced. These membranes are constructed whith open celled sponges and what appears to be a fiberglass mat. When the swamp cooler was first invented, this membrane was created out of straw, which was later replaced with slotted redwood. In these evaporative coolers, a recycled recirculation pump, as found in small garden fountains, is used to keep the evaporative membrane wet. Recycled 12-volt auto fans are used to move air through the membrane. Air that has been passed through these evaporative membranes is roughly fifteen degrees cooler than the ambient outdoor temperature. Power for one of these evaporative coolers was provided by solar panels while the other was powered by a combination of wind power and an electric drill that generates electricity when attached to an exercise bike. Water for one of these evaporative coolers was reclaimed from shower water; the particulate and shower grime was eliminated for sanitation purposes with the use of a small amount of Alum. This approach proved to be cheap, simple to construct, and effective for camp retrofits.



Figure 25: Mechanical evaporative coolers using recycled parts

# **Earth Coupling**

Earth coupling relies on the earth's thermal mass to neutralize the temperature differential between the day and the night. Because buildings cannot be built into the ground at the festival, earth coupling is limited to the floor of a building. This does not provide enough thermal mass to neutralize the extensive diurnal temperature shift in the northern Nevada desert. To reduce this temperature differential, these shelters combine earth-coupled floors with an insulative covering. These shelters are covered in an insulator commonly known as Reflectix®, that is composed of two layers of bubble wrap coated in aluminum foil. The bubble wrap acts as an R 15 rated insulator while the reflective coating reflects 98% of direct solar radiation.



Figure 26: Earth-coupled dome with insulative radiation barrier

Unlike other cooling strategies, this allows for the maintenance of warmth throughout the night. This is achieved through a heating phase shift in the earth. The earth acts as a heat sink during the day; at night this heat is radiated back into these structures, keeping the dome warm throughout the night.



Figure 27 Earth Coupled Hexayurt

Figure 27 shows an earth coupled hexagonal dome called the Hexayurt. This form of earth-coupled domes has been under development at Burning Man since 2003. It is made of reflectively laminated insulative foam that can be bought at stores like Home Depot. The designers of the Hexayurt have been working to make this design relevant to both festival goers and refugees given its affordable simplicity and comfort. For more information on Hexayurts visit http://hexayurt.com.

# Ventilation

Ventilation is not only the most common cooling strategy found at Burning Man, but it is also the easiest cooling strategy to implement successfully. There are two main types of ventilation in use at Burning Man, cross ventilation and stack effect ventilation. Both of these ventilation strategies have been very successful at the 2006 festival.



Figure 28: Ventilation between skin panels

### Cross Ventilation

In Camp Citrus, ventilation is achieved by loosely fitting each of the skin's panels together (Figure 26). Each panel is designed to have about an inch of space between itself and each of its neighboring panels. The gap between each panel allows air to flow around each panel and into the building. The panels are held onto the geodesic frame

with 'bungee balls,' an elastic device that allows each panel to move slightly in the wind (Figure 27).

On top of this dome is a turbine vent designed to release the hot air that rises to the top of the structure. Interestingly enough, the designer of this structure has run a few tests on the ventilation of his dome. The ventilation provided throughout the dome is sufficient to make the turbine vent redundant.



Figure 29: Bungee ball

The cross ventilation example shown in Figure 28 promotes a merging of indoor and outdoor space, while maintaining privacy. This is achieved by opening the walls on all sides of the building. Here, a dome is completely covered except for the bottom few feet. This ventilation strategy is beneficial, because it is easy to achieve ventilation during the day, and to either roll the covering down or wrap the bottom with a building apron to keep the building warm at night. The drawback to this strategy is that although there is a plethora of cross ventilation, there is no roof vent to allow the heated air to escape. Therefore, these structures are likely to get very hot starting a few feet above the highest vent level, unless additional vents are added.



Figure 30: Low cross ventilation

Figure 29 shows a complete sphere that has been given stabilizers so it does not roll away. The height of this dome increases the wind flow through the open windows or vents of this structure. This elevated vented structure provides an opportunity for occupants to cool down faster due to the increased airspeed that is accessed by raising the structure. The stack effect is also exemplified here by creating ventilation for the hot air at the top and by allowing fresh air to enter at the bottom.



Figure 31: Raised cross vented and stack vented dome

### Stack effect

Figure 30 illustrates the simplest construction of the stack effect vent, a thermosiphoning ventilation strategy that functions due to rising warm air. The raised portion of the tent has a vent along its upper wall. This version relies on the porosity of the tent's covering to allow air in, which allows the hot air to vent out at the top. The lack of a second vent source placed closer to ground level severely limits the effectiveness of this roof vent. This strategy, when used alone, can only normalize the temperature,

preventing the structure from acting as a solar oven.



Figure 32: Roof vent only for stack ventilation



Figure 33: Stack ventilation and cross ventilation

The photo in Figure 31 shows a tent that is ventilated both through cross ventilation and stack ventilation. This structure is open on opposing sides of the building to allow fresh air to flow over the occupants. The shaded roof vent allows the hot air that would otherwise be trapped in the upper portion of the building to be released. This combination of techniques allows for the maximum amount of daytime ventilation in a walled-in structure.



Figure 34: Stack ventilation through both form and function

By making a building both tall and narrow, the stack effect gains effectiveness, as shown in the examples in Figure 32 and 33. The first of these examples is practically a textbook example of the stack effect (Figure 32). The building is not only ventilated

using the stack effect, but the building itself is designed as a stack. Through this strategy, the inward flow of cool air washes directly over the occupants, as it replaces the hot air venting out of the upper portion of this structure.



Figure 35: Stack ventilation through both form and function with a radiant barrier

The second example of a building designed as a stack is very similar to the first example in that the occupants are placed at the bottom of the stack (Figure 33). This building cools itself through the stack effect, while cooling its occupants with the breeze created by the thermo-siphoning action of the stack. This building also reflects incoming solar radiation because it is built out of a reflective flexible hose similar to a dryer exhaust hose. Through the combination of the stack effect and the radiant barrier, this building is kept quite cool. Further cooling could easily be achieved by shading the entrance to the structure. Such shading would pre-cool the fresh air being pulled into the stack. Such a combination would prove to be as effective a cooling strategy as the radiant-barrier earth-coupled domes.

#### How do the passive cooling examples illustrate sustainability?

Shade

The use of shade in hot climates is perhaps the simplest technique available for the passive cooling of a building. Through the use of shade structures, festival attendees were able to create cool microclimates. There are many methods for shading; all shading methods proved helpful to the lowering of indoor temperatures through the reduction of incoming solar radiation. The options for how to shade a building are endless. The simplicity and success of shading are significant, and should not be overlooked in the design of any building.

### Ventilation

Ventilation is perhaps the simplest passive cooling technique to design into a building. There are many options for how to design ventilation and many good examples of well ventilated building designs presented in this thesis. The most important message to take from these ventilation designs is that the more ventilation, the better when trying

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to cool a building. At the Burning Man Arts Festival, a combination of two ventilation strategies proved to work most effectively. By combining cross-ventilation with stack effect ventilation, a building achieves near optimal cooling of its occupants. Through multiple sources of ventilation, both evaporative body cooling and hot air release can be achieved.

Two buildings at the 2006 Burning Man have illustrated how ventilation through the stack effect can be improved. By designing the building as a thermal stack, rather than utilizing the stack effect as an afterthought, stack effect ventilation can be optimized. This is truly a combination of form and function. Through this design technique, the occupants are cooled by air flowing over their skin as they would in a cross ventilated structure, while hot air is simultaneously being vented from the building. Because this ventilation strategy operates through a thermo-siphon, occupants' cooling demands are not dependant upon the wind, but achieved whenever the sun's rays come in contact with the building.

### Earth Coupling

Traditional Earth Coupled designs sink houses into the earth or build houses into hillsides. The increased thermal mass in these buildings in the form of earthen floors and walls allows these buildings to maintain a steady temperature for long periods of time. Conversely, the Earth coupled designs of Burning Man utilize only the surface of the earth, without any earthen walls or ceilings. This lower amount of thermal mass means there is less mass to absorb the heat of the day and radiate that heat at night. Thus the use of Earth coupling as a cooling strategy at Burning Man requires the use of an insulative

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thermal envelope. By reducing the heating loads placed on the building by the sun, and the cooling loads placed on the building by the cold desert night, the Earth coupled buildings of Burning Man are able to use this small amount of thermal mass to maintain a steady temperature through day and night.

### Evaporative Cooling

Ideally we would not need any mechanical evaporative coolers to cool our buildings; that is, we should be able to heat and cool our buildings passively. Unfortunately, passive cooling is far from a reality for many people as they are stuck with 20<sup>th</sup> century architecture that ignores the local environment and mandates the use of mechanical air conditioning systems. Because passive cooling is not possible in many existing buildings, the use of evaporative coolers is a very efficient way to cool structures that cannot cool themselves. The experimental evaporative cooler designs found at Burning Man provide models for efficient low cost air conditioners that could easily be built using entirely recycled materials.

# **Chapter 4: Conclusion**

Ecological design is necessary for the preservation of our planet. This thesis explores the built environment of the 2006 Burning Man Arts Festival as a test site for the principles of ecological design. Specifically, this thesis has examined strategies for material conservation through the examination of lightweight buildings found at the festival. This thesis also examined the passive cooling strategies utilized to keep the festival's built environment cool without the use of inefficient air conditioners. This thesis sought an answer to the question, "how do the temporary structures found at Burning Man demonstrate principles of sustainable design?"

The buildings and structures examined in this thesis were interesting because they exemplified lightweight architecture and passive cooling techniques. Given that the construction industry uses about half of the world's natural resources (Price Waterhouse Coopers, 2007), it is imperative to conserve construction resources through lightweight building practices to combat the resource scarcity problems we face today. In addition, our buildings currently consume 76% of the electrical consumption in the United States simply for heating, cooling, and lighting. Through passive heating and cooling strategies, we can reduce our electrical consumption, and prevent the building of 40,000 new coal-powered power plants that are scheduled to be built in the next 30 years (Mazria, 2006). Preventing new coal plants from being built will go a long way towards preventing
catastrophic climate change.

## Passive Cooling at Burning Man

The passive cooling strategies employed at Burning Man are strategies that have been employed around the world for millennia. Although recently forgotten in the western world, the cooling strategies found at Burning Man were inspired both by the cooling strategies of old, and the cooling strategies that have been reintroduced by the 'solar architects' of the 1970's. These strategies are applicable around the world and should be considered for *every* building design. The resources available at each building's construction site should be examined to best determine which passive strategies should be utilized. For example, if wind is a resource then tailoring a design to utilize this resource will prove to be highly beneficial.

Although less than 50% of the buildings found at Burning Man were passively cooled, a great majority of these buildings can be considered sustainable for their resource conservation. The principles of sustainable design were used by a few camping groups to create comfortable living spaces. I have used these camping groups to demonstrate the principles of sustainable design.

### Conservation through density

Burning Man's built environment is an exemplary illustration of the resource conservation made possible by compact and communal structures. Testament to the small size of buildings at this festival is the population density of the 2006 Burning Man Arts Festival. With an estimated 40,000 festival participants, and one square mile of

inhabited space, the density of the temporary Black Rock City was 40,000 people per square mile. In 1990, the density of New York City, the densest city in the US, was only 23,700 people per square mile (Gibson, 1998). Such density is lauded for the creation of walk-able cities - cities that do not require motorized transport. This density is also remarkable when considering that there are almost no two-story buildings in Black Rock City. These facts shows that people chose to live in spaces much smaller than the average American home, and chose a communal approach to living spaces that allowed for further conservation of construction resources.

## Aesthetics and sustainability

Some definitions of sustainability are purely mechanical in nature, focusing on efficiency of material use. Although efficiency and material conservation are important, as Sim Van Der Ryn (2005) points out, sustainability is about more than efficiency, it is a way of understanding the world. Sustainability is about interacting with nature and learning from natural systems. By Van Der Ryn's logic, interacting with and emulating patterns found in nature is as important if not more important than efficiency. According to this logic, building efficiency will achieved as a byproduct of emulating natural systems.

Learning from and emulating natural systems is highly intertwined with the discussion of sustainability and aesthetics. The look and feel of a place alters our experience; we can look to our biophilial responses to places in nature to guide the design of our built environment. Although described in different terms, this was fundamental to the design process of general builders up until the late 1800's (Munford, 1955). Through

the use of 'style books' that demonstrated how to reconstruct historic styles such as Greek and Roman architecture, as well as through the exposure to international styles through the 1893 World's Fair, designers who were familiar with the various international styles replaced the builders who used a local knowledge base. Munford pointed out that through this shift toward trained architects, we have lost the knowledge of site-specific design. The replication of styles produces buildings that are disconnected from the changes and transformations that situate architecture in space and time to create what Munford calls an "island with little appropriateness to the surrounding place or culture" (Munford, 1955; 19). Once such replication became standardized, we lost much of our connection with individual places, which is sculpted by our built environment. Thus place consciousness, a fundamental aspect of sustainable living, is dependent on the uniqueness of the built environment. As Timothy Beatley points out in his book *Native to Nowhere* (2005), we need genuine places rather than generic spaces in order to reconnect with the places we live in.

Ecologically minded architects have been re-learning how to build according to the resources of each site since the 1960's, but still another step needs to be taken to achieve sustainability, that is to achieve an aesthetic that reflects both the natural and cultural surroundings. By calling on nature to inspire our designs we can bring sustainability past efficiency and number crunching, and bring sustainability into our homes and our lives. The concept of emulating nature has been used by many luminaries of sustainable design such as Buckminster Fuller who called upon the crystalline structures found in nature to inspire the geodesic dome. We need to take the next step in designing with nature to not only utilize individual concepts found in nature, but to

situate these concepts organically so each building design fits the natural and cultural surroundings. Calling on the work of Christopher Alexander, we need to situate our built environment within the larger patterns found in nature, rather than reproducing individual forms.

#### *Future application for lightweight architecture*

The lightweight architecture of Burning Man is partly inspired by nomads and their architecture around the world. At the Burning Man Arts Festival, we see modern concepts and age-old nomadic approaches to architecture being combined to create comfortable and dynamic structures that respond to the local environment. With a nomadic approach we not only conserve resources, but we can reuse our buildings should we need to move. This mobility could increase the efficiency and reduce the long-term impact of our built environment in our increasingly mobile society. The nomadic approach to architecture shows us that foundations, a crucial concept of most modern buildings, can be left behind without compromising the quality or durability of one's dwelling. This is one of the most important lessons from the lightweight architecture of Burning Man.

Temporary structures could become increasingly important in the logistics of providing housing for displaced peoples around the world. As more and more people become displaced by the expansion of global markets, and people are increasingly being displaced by a rapidly rising rate of natural disasters such as hurricanes and tsunamis, the need for reusable temporary housing could prove essential for humanitarian aid efforts. The designers of the Earth-coupled Hexayurt are already working with the U.S.

Department of Defense and the Red Cross to explore these options. Another possibility for reusable temporary housing could come from the tensioned truss-membrane structures found at Burning man, which should be examined for their viability in small-scale building projects, such as emergency shelters for refugees and for disaster relief housing. Temporary structures could prove equally important for the housing of migrant workers who do not have the economic means to provide their own housing.

The lightweight structures found at Burning Man are both useful as demonstrations of the principles of sustainability and inspiring for future design work. There is, however, much room for improvement in the lightweight structures of the Burning Man Arts Festival. The most important change that would improve the sustainability of Burning Man's built environment would be to eliminate the use of RV's due to their inefficient nature, and to apply the principles of passive cooling to all the structures that have not yet utilized the techniques illustrated by the many buildings in this thesis. As we have seen with structures such as the dome of Camp Citrus, a combination of passive cooling strategies improves the success of indoor thermal regulation. By combining shading with ventilation, every building at Burning Man could be comfortable even in 120-degree heat. Another significant improvement would be to replace the plethora of PVC with renewable or recyclable materials such as sustainably harvested wood, steel, or bamboo, all of which possess both the tensile and compressive strengths that many structures found at Burning Man depend on.

# Concluding remarks

The designs and analysis presented in this thesis illustrate sustainable architectural

principles in action. The field of architecture could benefit from further design and analysis inspired by the designs found in this thesis. Specifically, the use of new hybrid tensegrity models should continue to be examined. Further testing of the experimental structures of Burning Man, using digital thermometers to monitor the indoor and outdoor temperature, would be useful to further our understanding of the success rate for these passive cooling techniques. Further examination and implementation of passive cooling strategies is imperative for the future of sustainable architecture.

Through the examination of Burning Man's built environment, this study has shown that ecological design is not only feasible, but that it can be achieved at a very low cost. Due to the conservation of building materials in lightweight buildings, such as those found at Burning Man, sustainable buildings can be built more cheaply than many 'traditional' American buildings of the same size. Through passive cooling, these buildings protect against future environmental damage, while reducing the cost of maintaining reasonable temperatures in our homes and public buildings. The tools for ecological design presented in this thesis are not high tech, and are easy to achieve on a building-by-building basis. These tools, along with others that continue to be presented in the field of sustainable design, show us that sustainability is possible for the masses, and that ecological design does not have to be luxury item.

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