THE MORPHOLOGY OF SPACE: A WIND TECHNOLOGY CENTER FOR MONTANA

by

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Jacob Kenneth Ostlind

December 2008
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ABSTRACT

There is often a logical relationship between what something does and how it is shaped. In biology this is known as morphology—the study of structure or form. The morphology of an organism is a product of environmental conditions and its interaction with that environment. The morphology of space, then, is the study of the relationship between the measurable forces acting on a space and its shape. It is an exploration of the poetic and pragmatic link between environment and design—a search for how a building can be cast by its shadow.

The research, observations and images contained in these pages form the foundation for the design of a Wind Technology Center for Montana. Inspired in part by the National Renewable Energy Laboratory’s Wind Technology Center near Boulder, Colorado, this facility will provide research services to private companies involved in Montana’s current wind energy boom. Additionally, it will conduct grant-funded research into alternative uses of energy generated by wind—an especially relevant topic in Montana, considering our significant wind resources and our limited transmission infrastructure. The site for this project is in the Yellowstone River Valley northeast of Livingston, Montana, one of the windiest places in the state and possibly the nation. The project’s program and design will express the forces present on the site (considered to include both the immediate site and Montana as a whole) through the development of system of analysis inspired by studies of morphology and facilitated by digital design techniques.

Importantly, the building will also be an icon for wind energy in Montana and a flagship building for sustainability as our culture transitions to a more carbon neutral fuel economy. Located on a highly visible site along Interstate 90, it is positioned to become an architectural icon as well, a facility for exporting both technology and awareness.
Architects have always been concerned with the movement of the world around them—the daily and seasonal rhythm of the sun, the push and pull of the wind, the invisible but constant pressure of the elements against our buildings. The fact that the sun rises, falls on surfaces, casts rich shadows, bounces into dark recesses, and does so according to a pattern is one of the few aspects of our existence that can be determined with some certainty. Wind, though less predictable, is just as powerful a presence in many places—the perpetual Pacific breezes of the Oregon coast, the warm Chinook winds whipping along the Rocky Mountain front, the prevailing northwesterlies of the high Wyoming plains. When Victor Olgyay describes sun and wind as the two most important factors in a building’s orientation he is echoing a similar conclusion reached by many centuries worth of builders. Environmental awareness is not a new concept. What has changed? Why do the sun and the wind matter in this age of alternating current and fossil fuel? Why is it so critical that we think about how buildings are shaped with the same clarity and logic with which we think about how organisms and landscapes are shaped?

The answers to these questions are a critical part of understanding the architect’s role as designer in our world and how humans as a species fit into this world. The most significant change in recent history is the increase in atmospheric carbon dioxide and other greenhouse gases and its affect on climate. According to Bill McKibben, “global warming presents the greatest test we humans have yet faced.” In the last generation, a societal consciousness of climate change has emerged, due in part to mass media, Al Gore, observable changes in weather and a general consensus within the scientific community. Understandably, society has also adopted a desire to do something about this disturbing change. Global warming has gone from being a controversial theory to an accepted but terrifying fact and will undoubtedly be a major cultural issue for our generation.

The concept and reality of climate change affects the profession of architecture in several ways. First, buildings produce 39% of carbon dioxide emissions in the United States and use 71% of its electricity. Small changes in the building industry can greatly affect societal carbon output.

Second, as the primary source of electricity for buildings in the United States and worldwide, coal-fired power plants produce a quarter of the carbon dioxide released into the atmosphere every year. Rethinking where our electricity comes from is an equally critical issue in this age of carbon awareness and one which architects can greatly influence.

Third, a value of sustainability has been adopted by popular culture. A company can no longer ignore sustainable practices and remain competitive because of the awareness society has of this issue. Wal-Mart. Starbucks. Microsoft.
General Motors. Major corporations are discovering that sustainability makes economic sense in the context of both profit margin and public relations. As a result, it has become a central issue for architects in this age and will be as much a presence in many projects as program and site has been throughout history.

Designers are trained to think about complex issues in abstract terms. Confronting climate change and embracing sustainability in our designs can transcend merely running energy use numbers and earning LEED points (although these are important strategies as well). It can become the design concept. Making our architecture more sustainable is not about compromising our creativity or sacrificing our freedom as designers. It can become a form of expression in architecture.
Montana, vast, isolated and sparsely populated by national standards has felt the effects of these changes as well and is in the midst of its own sort of revolution. When the Judith Gap (135 MW) and Cascade County (9 MW) wind farms went online in 2005 Montana jumped from being ranked 50th in the nation in wind energy output to 15th. Since then six more major wind developments have been planned statewide including a 500 Megawatt farm in Valley County. Presumably in response to both the tremendous success of these projects and the nation’s growing interest in renewable energy, Governor Brian Schweitzer has adopted a plan requiring 15% of Montana’s power to come from renewable sources by 2015. Before the major wind development of the last decade, approximately 60% of Montana’s energy came from coal-fired power plants and 40% from hydroelectric plants. Montanans will see significant changes in where their power comes from and in the physical landscape in the coming years as the state transitions into this new industry. As an anticipated leader in renewable energy Montana could export not only alternating current but knowledge and technology related to wind power as well.

While Montana’s wind resources are ranked number one nationwide there is a reason it has historically lagged behind other states in power generated from wind and is just beginning to develop this resource: transmission. As the wind power map shows, many of Montana’s greatest potential wind power areas are not serviced by high voltage lines. For better or worse, this is precisely what has limited wind development in high quality wind areas such as the hills east of Livingston. The area is crossed by only a 50 kilovolt line—not enough capacity for more than a few small 65kW turbines. The 170 kV line from Colstrip that would be needed to get a large wind farm online runs east-west on the north side of the Yellowstone River on its way to Bozeman and Butte, relatively inaccessible from the foothills of the Absarokas. Even if transmission infrastructure existed—a tremendous investment in itself—it would simply allow Montana to sell more power to its neighbors at wholesale rates—not a particularly profitable use of our surplus power. According to MSU philosophy professor and wind power proponent Gordon Brittan, Montana needs to find uses for our power in-state rather than simply building more transmission lines to sell it wholesale to neighboring states. This could be in the form of hydrogen or fertilizer production or other manufacturing. The Wind Technology Center proposed in this thesis would serve as a research center for these alternative uses of energy in the heart of wind country. It will serve as a source of valuable information as the world transitions to more carbon neutral fuels and processes. It is based on the premise of exporting knowledge and technology to accommodate the growing wind energy industry in Montana.
Some of Montana’s best wind resources are miles from high voltage lines. The east-west high voltage from Colstrip that supplies Livingston and Bozeman travels on the North Side of the Yellowstone River. www.windpoweringamerica.gov
Perhaps the most promising use for mechanical energy produced by wind is the production of hydrogen. As the world embraces carbon neutral fuel cycles, hydrogen may become the best option. According to NREL, 448 billion cubic meters of hydrogen are currently produced worldwide, mostly for use in industry. The primary method of production is currently Steam Methane Reformation (SMR) which provides hydrogen at $1.00-$5.00 per kg. While this is the most affordable way to produce hydrogen, it has several drawbacks that encourage exploration of other production methods: First, the fuel source for SMR is liquified natural gas which is largely imported to the United States. Also, a byproduct of this method is Carbon Dioxide, a concern in our carbon aware era. Considering this and the fact that it relies on a non-domestic resource, hydrogen for use in fuel cells or internal combustion engines is no better than gasoline and its reliance on foreign oil. Also, the hydrogen produced using this method often has impurities.

Electrolysis, on the other hand, produces 99.9995% pure hydrogen. It is currently limited by the fact that it is highly energy intensive method of production. According to NREL, “...utilities need to be involved if the future hydrogen economy involves electrolysis.” It takes approximately 39 kWh of electricity and 8.9 liters (8.9 kg) of water to produce one kg of hydrogen. For comparison, one kg of hydrogen contains 116,000 BTU of energy and one gallon of gasoline contains 108,000-123,500 BTU of energy. Critical issues in the successful development of an entirely domestic carbon neutral hydrogen economy are first, electricity costs, second, electrolysis efficiency and third, development of economical fuel cell and internal combustion hydrogen engines. In other words, the solution to this problem is technological—a system wide design challenge.
The recently completed windfarm at Judith Gap, MT was possible in part because of the high-voltage power line between Billings and Great Falls. Research into alternative uses of energy such as Hydrogen could allow greater flexibility in location of wind farms. November 2008.
theory and concept: morphology

morphology n (1830) 1 a : a branch of biology that deals with the form and structure of animals and plants b : the form and structure of an organism or any of its parts.

The conditions of this time and place—climate change, technology, renewable energy, a vast, empty landscape—are the foundation for the form and space of this thesis. This is not about a literal biomimicry of organisms but about allowing the characteristics of our cultural and natural landscape to inform the design in the same way environment determines the form of organisms.

The origins of this thesis grew equally from insights gained from reflection on past academic and professional work, an exploration of parametric design and a strong personal interest in sustainability. Thinking about architecture parametrically, lead to the exploration of work conducted by biologists. The pragmatic and methodical worldview held by biologists is a good example of how to think about the complex relationship between buildings and the environment. When D'Arcy Thompson describes the “mathematical beauty” of organisms¹ or when Victor Olgyay states that form in nature is a “diagram of forces”² they are both describing the rigorous and complex ordering system of natural world. When Jonathan Weiner marvels at how quickly the harsh climate of the Galapagos penalizes inadequate design in a population of finches³ it becomes evident how integral environment and the organisms that inhabit them really are. Following are more detailed descriptions of these three disparate perspectives on the origin of form and the architectural implications of these ideas. With these methods and ideas in mind, a synopsis of contemporary architectural techniques is presented. Architects such as Ali Rahim and design schools such as the Design Research Laboratory at the Architectural Association in London are using technology in unique ways to explore the affect of cultural, social and physical environments on architectural space making.
structure of a microscopic pollen revealed by a scanning electron microscope.
www.answers.com
During October 2006 I completed a vignette project as part of Mike Everts’ fourth year studio. The project was an exploration of the link between observed conditions and a space to accommodate those conditions. The understanding that all architecture is somehow a spatial manifestation of the context in which it is built was an important aspect of this study. Also important was the awareness that the project was the design of a system rather than the design of a space. The output was in no way preconceived.

As part of the site analysis for a project in Butte, MT, a list of 25 words was compiled. These words were drawn from observations of a small neighborhood in uptown Butte and were chosen for their perceived value to Butte residents. For the vignette project six of the most/least valued words were chosen. These six words represented the opposite ends of the emotional spectrum for Butte residents, according to observation. The words were:

New paint, Uptown, Continental Divide, Desert, Desolation, Desperation

The system of analysis was then developed. Four perceived qualities of each word were plotted on a simple 1-10 scale for the past present and future of Butte, MT. For example, one quality was “potential for creating happiness.” Again, these qualities were developed from “the data of perception.” These four sliding scales, then, defined the shape of a specific drawing for each word past, present and future. The six spaces created were representative of the perceived change in quality of each word over time. The system is abstract but consistent. This was not an irrational, ambiguous representation.

The result of this work was a repeatable system of analysis and a spatial diagram that was directly linked to that system. The designer does not “draw space.” Instead he designs the process for understanding the spatial implications of relevant data. The design process is still iterative and unpredictable.

This project resulted in an interesting generative process. While it served to restructure traditional methods of thinking about space and the spaces created were a direct response to observed (i.e. subjective) conditions, there was a sense that the experience and function of the spaces was as much a result of the arbitrary (though consistent) decisions about scaling and spatial orientation as it was an actual manifestation of these conditions. In other words, the final result asked the observer to take for granted such things as the linear relationship between various parameters and the direction of time (in this case it was equivalent to the Z-axis).
What if the parameters were, instead of ‘observed emotion,’ actual measurable characteristics of site and program? What if parameter one was, instead of ‘potential for creating happiness,’ the daily movement of the sun through the sky and the expression of this parameter was a device that created the ideal passive solar condition unique to that latitude and climate? The actual function of the space would be totally integrated with its environment. The architect’s role has shifted slightly from the ‘draftsman’ of space to a mediator between site and program. This process asks the architect to be as much an observer as designer. As always, each site is different and asks to be considered in certain ways.

Needless to say, the project prompted many questions about methods of interpretation and space making.
theory and concept: Beak of the Finch

“Taking advantage of the [researcher's] masses of data Dolph [Schluter, PhD student] programmed the computer to run a more realistic simulation. He asked it to calculate the beaks that should have evolved on a dozen islands of the Galapagos, given the seeds that are actually found on each island. With just three factors, beak size, seed size, and competition the computer predicted correctly the divergent paths of evolution for the beaks of finches on every one of the islands.”

---Jonathan Weiner Beak of the Finch p. 154

Published in 1994, Beak of the Finch is a chronicle of a group of researchers lead by Peter and Rosemary Grant who have studied the finches living on the Galapagos Islands. Based on years of careful observation, they have demonstrated that in a competitive environment, evolution occurs by the generation, even by the hour, and can actually be observed. Each generation they can watch as the population of finches changes to match its environment.

The link between form (what the various finches' beaks were shaped like) and the set of parameters affecting that form (seed size and competition) is striking. Seed counts vary seasonally on the islands. As one of the researchers working with the Grants, Dolph Schluter was able to model the complex relationship between seed production and finch success and use this model to make an accurate prediction about a population. He had essentially created a parametric system, a series of inputs and outputs for analyzing a complex system. The system proved to be extremely accurate based on field observation of actual conditions.

The significance of the methods presented in Beak of the Finch are in the fact that they resulted in deductive information. Unlike pure observation or the aforementioned “data of perception,” the information gathered by the researchers could be used to make accurate predictions and draw conclusions about the entire system of environment, flora and fauna. The Grant’s and their gaggle of graduate students are, of course, researchers rather than designers but their understanding of form as it exists within a complex system would be the envy of any architect. Imagine spending twenty years on site analysis. Jonathan Weiner’s detailed explanation of the Grant’s remarkable work lead to the exploration of other sources. In D’Arcy Thompson’s On Growth and Form the author looks more specifically at form and more generally on organisms, cells and inanimate objects. Specifically, it raises the question of how these rigorous methods can be adapted to design.
Image of mericarps or seedpods found on Galapagoes islands next to image of various beak forms of Galapagos finches. As the primary food source for the finches, the fluctuating availability of the different mericarps directly affects the success of different species of finches. mericarps: p. 61   finches:  p. 41  Beak of the Finch
theory and concept: On Growth and Form

“...when we have learned to comprehend and to define the sphere, the catenary, or the parabola, we have made a wonderful and perhaps a manifold advance. The mathematical definition of a ‘form’ has a quality of precision which was quite lacking in our earlier stage of mere description...we are apt to think of mathematical definitions as too strict and rigid for common use, but their rigor is combined with all but endless freedom.”

-D'Arcy Thompson On Growth and Form p. 269

In this statement Thompson addresses a critical concern for the designer: Within the pragmatic framework of scientific analysis is there an ability (or even reason) to appreciate form for its aesthetic value? Here he concludes that the appreciation for form can actually be enhanced by this method of thinking. Elsewhere, he differentiates between description and analysis and suggests that analytical thought facilitates both comprehension and imagination. When he describes freedom in the last sentence it is almost as if he is presenting a scientific definition of creativity.

A similar conclusion is reached in a project presented by graduate students at the Architectural Association’s Design Research Laboratory although in a much different context.

“This brings this up the discussion of beauty vs. elegance. Both are quite different concepts. One is either beautiful or not. Technique comes to play its major role to transform what is considered not beautiful to beautiful similar to plastic surgery. It allows us to push towards beauty by producing elegance. Elegance is therefore achieved as kind of problem solving process, an ability to articulate complexity, and multiple agendas into a resolution. It’s an elaborated condition whereas beauty is a lucky hit; elegance is a resolution of multiple agendas into complex articulated and resolved conditions. The random production of using force in the hair systems experiments produced the first step of elegance, the use of logics, continuities and algorithms, laws for differentiation, were all part of the first step towards elegance. It really become virtuosity when we no longer use computers and technology but creatively solve the interpolation and inter-articulation into the organic domain a process that happens through evolution and trial and error and cross interpretation of subsystems all leading to production of elegance.”

--From Beauty vs. Elegance, mrgd.co.uk

The following diagrams are, appropriately, analytical, descriptive, even beautiful.
Left: drawings of pelvis bones of related bird species. Middle and right: method of ‘cartesian transformation to demonstrate formal change. Images: Thompson, *On Growth and Form*
theory and concept: Design With Climate

“...living organisms occupy a field of force which...is of immense complexity. As sometimes in physics the knowledge of form leads to the interpretation of forces that molded it, at other times the knowledge of the forces at work guides a better insight into the form itself. Therefore, the conception of form is ultimately the understanding of the forces that gave rise to it, as a representation of a form is a diagram of forces in equilibrium.”

--Victor Olgyay, Design With Climate, p. 84

Olgyay acknowledges the bi-directional nature of the relationship between force and form: one can either inform or be informed by the other. Of most value, however, are the diagrams graphically demonstrating the relationship between airflow (the ‘force’) and the placement of various solid objects. The images actually show the varying velocity of air around the objects. While Olgyay has only explored very simple geometries the pure compositional patterning created by air movement in the images is actually very sophisticated and, in its own way, ordered.

It is specifically this order that is of interest. Move one object (i.e. change one parameter) and the system rearranges itself to show the new airflow conditions. The diagrams shown are only descriptive—hence the simple geometries—but it easy to imagine other possible conditions. A long, narrow shape would allow cause less disruption. What might the flow patterns look like over an air foil? These diagrams are also useful because they clearly illustrate the term ‘wind shadow,” that area of relative calm on the lee side of an obstruction. Also they are empirical, that is they are based on experiment and observation. This places them in the same realm as the work of Peter and Rosemary Grant and D’Arcy Thompson. Observation is used to test intuition.
Images: Olgyay, Design With Climate, p. 101
theory and concept: establishing parameters

parameter n (1656) 1 a : an arbitrary constant whose value characterizes the member of a system. 2 : any of a set of physical properties whose values determine the characteristics or behavior of something.

The Galapagos Islands and specifically Daphne Major, where most of the Grant’s work takes place, are incredibly harsh environments. On Daphne, for example, the tiny amount of rain that does fall over the course of the year lands on sun baked lava and either runs down the slopes into the sea or evaporates. Only cactuses and short grasses can survive in the minimal soil of the islands. As a result both biodiversity and population of the islands’ fauna are extremely limited. This is a distilled environment where subtle differences decide a species’ survival. It is not because of their rich history as the birthplace of evolutionary theory that the Grants travel to these islands year after year but rather the fact that there are so few individual birds living under such tremendous pressure. It was easy, relatively speaking, for the Grants and their researchers to isolate the critical factors (the ‘parameters’) in a finches survival.

A research facility, then, designed for the express purpose of understanding wind as an energy source would benefit greatly by being located in an environment defined by consistent powerful wind. Like the finches dying in a drought on Daphne Major, slight imperfections in design are more quickly revealed in a harsh climate. The concept of a form being so clearly linked up with its environment is especially interesting when considered in architectural terms. Exploring work conducted in biology was inspirational but prompted many questions about the architectural implications of this idea. What are the ‘beak size, seed size, and competition’ (from Beak of the Finch) of a building? A drought was shown to completely physically restructure a population of finches: How do changing climate conditions affect how a building is shaped? With countless parameters at play in the design of any building how do we decide what forces are relevant? (Bill Rea estimates that number at approximately 150,000) Most importantly, how does the human element interact with pragmatic systems, that is, how does architecture allow itself to be influenced by science while truly expressing itself as an art?

As both Jonathan Weiner and Victor Olgyay would agree, the factors determining how something works in its environment are site-specific. It can be argued that every architectural project involves certain ‘general parameters’-sun path, insolation, prevailing wind direction and average speed, etc. These are considered a critical part of the design process and are included in the site analysis section of this document. The more critical question though, is what are the parameters specific to this site and program?

As the climate data shows, wind is the truly unique quality of this site. For better or worse, it is very much a part
Livingston’s sense of place. Based on the program, wind interacts with this project in three ways: It is captured for integral power generation, it is diverted around outdoor spaces, entries and access points and it is controlled for passive ventilation during warmer months. These three interactions, along with the general parameters of site and program, can form the conceptual basis of a design.

The 65 kW turbine erected by Gordon Brittan in 1984 east of the Mission Creek drainage. This turbine produces 130,000-180,000 kWh of electricity every year, more than any other 65 kW turbine in the United States.
theory and concept: snow, wind and light

Whether considered to be a form of mapping or observation or analysis, the following images, taken a few miles west of the site for this thesis in wind-whipped Bozeman Pass seek to convey visually the abstract compositional quality of a purely pragmatic system: snow shaped by wind revealed by sunlight. These images also serve as the foundation for a geometric language of wind morphologies: attenuation parallel to the wind direction, lines that end in surfaces, sharp shadows, blended surfaces and curvilinearity. All images: Spring 2008.
The site for this thesis is a flat piece of land northeast of Livingston, MT. Heading east on Interstate 90, one quickly notices some unique aspects of the landscape. In addition to the damaged highway signs wracked by the almost perpetual wind whipping northeast down the valley, there is the distinct lack of major vegetation on the hills to the south and east. Only grass covers the landscape between the interstate and the mountains. The second unique aspect is the presence of the Absaroka-Beartooth dominating views to the southeast in the form of Livingston Peak’s broad flank. The Absarokas are one of the only major north facing mountain fronts in the region. Because of its aspect and ruggedness, the north facing slopes are either treed and braided with avalanche chutes or bare and snow covered at higher elevations. Just east of Livingston the interstate drops back into flats along the river. East of the interstate is the now-abandoned site of Livingston’s old airport. One might assume they closed up shop after one too many wind-bungled landings. To the west, between I-90 and U.S. Highway 89 is the proposed site for this thesis. It is a relatively flat site approximately 2,300 feet long in the northeast-southwest direction by 1,300 feet long in the northwest-southeast direction. Currently for sale, it lies northeast of a small industrial park, a series of metal buildings huddled in the wind. One of the buildings is the headquarters for Park Electric, a strong supporter of wind power in the area. It is vacant except for a few storage containers and farm and construction equipment parked out in the grass.
map: USGS, Livingston, MT quadrangle
Importantly, this is a relatively linear site with its long dimension in the northeast-southwest direction—perfectly aligned with the prevailing wind direction. And the wind does prevail on this site: According to detailed wind data gathered at the old Livingston airport just to the east, average annual wind speed was 15.7 mph. For comparison, average annual wind speed at the Bozeman airport was 7.8 mph. Of the 50 data sites around Montana, this site has the highest average annual wind speed. Judith Gap, for example has an average annual wind speed of 13.1 mph. The only site in the state with a higher wind power rating is the “Livingston Candidate Wind Turbine Site,” where the Livingston Municipal Wind Farm was eventually located. Just to the southeast of this site, it has an average annual wind power of 876.4 watts/square meter vs. 510 watts/square meter at the old airport site. Obviously, this is a very good location for a Wind Technology Center.

The site for this thesis was originally conceived as being located south of Interstate 90 where Mission Creek flows out of the foothills of the Absarokas into the Yellowstone Valley. After a site visit and meeting with Gordon Brittan on March 27, 2008 this location didn’t seem to make much sense. As the program had developed into a relatively large industrial facility, the proposal for such a structure in a purely agricultural landscape made little sense. The new site is still very much defined by wind and spaciousness. It is a rural location to study wind use in rural state. It is a rugged piece of property along a highway, interstate and railroad where a large building and large machinery are entirely appropriate. It is accessible and very visible to workers, industry specialists, visitors and the general public.

Significantly, the site lies in the heart of “Yellowstone Country.” This is a truly unique landscape. The fifteen miles between Paradise Valley and Sheep Mountain is one of the windiest places in Montana and probably the United States. The Yellowstone River itself is the longest undammed river in the United States. To the south is the northern boarder of the Greater Yellowstone Ecosystem—a vast region of remote mountains stretching hundreds of miles into Wyoming. This region includes the expansive Absaroka-Beartooth Wilderness the borders of which lie just outside of Livingston. Stretching for 80 incredibly rugged miles to the east, it is one of the largest wilderness areas in Montana and home to Granite Peak, the highest point in Montana at 12,799 feet above sea level. It also includes the Beartooth Plateau, one of the largest areas in North America higher than 10,000 feet above sea level and a rare example of a true tundra environment in the contiguous United States. The many superlatives used to describe this region, however, could never convey the experience of backcountry skiing in the Mission Creek drainage in early spring or watching the sun break over Mt. Cowan on an October elk hunt. It is a landscape best experienced first hand.

In its harshness and rugged beauty this landscape is representative of one of the fundamental reasons for pursuing
background image: Google Earth
sustainability in the coming years. The presence of wild and untouched places is constant reminder of why we should collectively reduce our impact on the natural world through development of renewable energy sources and passive design strategies.

Livingston and the Yellowstone Valley’s infamous winds are a product of both the Paradise Valley to the south and Bozeman Pass to the west. The town lies at the mouth of a narrow opening where the Yellowstone River flows out of Paradise Valley. Air moving north out of the Greater Yellowstone Ecosystem is forced through this notch creating the prevailing southwest winds of the region. West winds also sweep down off the rough summits of the Bridger Range through Bozeman Pass and on to the Yellowstone. Through the idiosyncrasies of Geology and climate this region possesses a tremendous wind resource.

On Monday, March 3, 2008 I met with Mission Creek rancher and MSU professor Gordon Brittan to discuss the region and wind power in general. Gordon owns and operates a wind turbine on the juniper flanked ridge east of Mission Creek. It is a 65kw generator and produces 130-180,000 KwH of power per year—enough for 10-15 households. Brittan put the Danish designed generator up in 1984. It has produced power for almost a quarter century now with minimal repairs. The extra power it produces is sold back to the power company. According to Gordon, it outperforms every other similar model in the United States. I asked Gordon if that was an indication that this stretch of the Yellowstone Valley might be the windiest place in the country and he responded with “That’s certainly the view I hold.”

My conversation with Brittan revealed some interesting aspects of the landscape beyond its pure physical qualities. Gordon pointed out the 50kV line running southwest-northeast through his property. As the only line supplying that particular area it is inadequate for transmission from a large wind farm. Here is the key reason no major wind power development has taken place east of Livingston. In this sense, this region is representative of the plight faced by the entire state of Montana with regards to wind power development: it possesses tremendous potential for power generation with limited transmission infrastructure. According to Gordon, Montana would benefit greatly if it focused on development of electricity-based industries such as hydrogen fuel and fertilizer production or other manufacturing rather than invest money in transmission just to export electricity to other states. In other words, Montana should work to design an entire system of energy production and use so that wind farms are not limited to existing power line corridors. This certainly casts a new light on the concept of research and development in Montana. It presents a conceptually different design problem, to determine how to best use available energy rather than simply how to produce the most energy. It is from this rich and varied context that the program for this facility sprouts.
View to south across site with industrial park and Absaroka Range. March 2008.

View to southeast across site towards Livingston Peak. March 2008.
Livingston is only 30 miles east of Bozeman but it is noticeably drier. It is said to be in a rain shadow. This epitomizes a climate condition found throughout the Rocky Mountain west where dry arid regions at lower elevations abut areas of high elevation and precipitation. Though not as pronounced as some rain shadowed regions, the few miles and few thousand vertical feet from Bozeman Pass to Livingston often make the difference between blowing and drifting snow and sunshine in the winter.

This data, taken from the Western Region Climate Center seeks to summarize the conditions in Livingston. The average low temperatures during January, the coldest month of the year is 16.7 degrees Fahrenheit. Average high during this time is 34.7. During July, the warmest month of the year, the average high is 83.9 and the average low is 51.1. During January there are an average of 1214 Heating Degree Days Base 65. The average in July is 42.

Average annual precipitation is 15.7 inches, vs. 18.61 inches in Bozeman. Livingston receives an average of 63.8 inches of snow every winter. The aforementioned average wind speed and power are possibly the most significant aspect of Livingston’s climate. As any long time Livingston resident will confirm the wind never seems to stop blowing in this little town on the edge of the Rocky Mountains. On the following page are two wind data maps taken from windmaps.org and produced by NREL. They show how the Livingston area stands out regionally as a high wind area.
Wind Power:
orange-fair
pink-good
purple-excellent
red-outstanding
blue-superb
map: www.windpoweringamerica.org

wind speed:
cooler colors-slower speeds
warmer colors-faster speeds
map: www.windpoweringamerica.org
Of this firm's many environmentally sensitive projects, this is perhaps the most obviously shaped by its site. The obvious referencing of its surroundings is as much out of necessity as it is an aesthetic strategy: The shed roof runs downhill into the wind, its slope parallel to the direction of the wind as it deflects upward off the straight of Juan de Fuca. In fact, the angle of the roof is very close to the angle of the tops of the trees bravely growing on the most exposed part of the bluff. Similarly, the rough stone wall in front of the house matches the texture of the treeless coastline but provides an essential windbreak for the porch area in the front of the house. The house rests on a site between the barren coast and the forests of the islands interiors and forms a sort of threshold between the two contrasting environments. The form and structure of the house is also a product of the unique conditions. Like several other Cutler Anderson projects, it features a sod roof. Here the sod serves as a sponge to absorb the significant rainfall of northern Washington. It is supported by a heavy timber frame that is independent of the enclosure of the building. As a result, the various programmatic spaces underneath can turn to face specific views independent of the structural grid of the building. The result is a clear relationship to the site on several levels: climate, view sheds and materiality.
precedents: Svalbard Research Center

Svalbard Research Center
Jarmund/Vigsnæs Architects
Spitzbergen Island, Svalbard, Norway, 2006
Center for Atmospheric and Environmental Research, Norwegian Polar Institute, 25,500 s.f.

The epitome of a building shaped by its harsh conditions, this research center is located on Spitzbergen Island approximately 360 miles north of mainland Norway. At 78 degrees north latitude the settlement on this island is the second most northerly permanently inhabited place in the world. Only Alert in Nunavut, Canada, with five permanent residents is farther North. The incredibly harsh landscape has influenced the architecture in several ways: First, the building’s copper skin is continuous from wall to roof. This was a conscious referencing of the anorak, a heavy shell worn by indigenous people in this environment. Minimizing eaves and overhangs allows the perpetual winds to easily slip over the building without creating opportunities for heat loss. In fact, the angular geometries of the building were generated by studying wind patterns over the barren site. Second, the building is raised on 390 steel posts. This is both a response to the permafrost—raising the building up on posts allows it to ‘float’ on the unstable ground and keeps the internal heat of the building from melting the ground—and a response to the snow that swirls around the building for much of the year. Raising the building up off the ground allows wind to continuously clear snow from around the building rather than depositing enormous drifts in the lee of the building. Another environmental response occurs on the building’s interior: The light colored spruce interior finishes are a conscious effort to make the interior as bright as possible in the face of the extended darkness of the polar night.
National Wind Technology Center, NREL
Boulder, Colorado

This is a government building and very limited architectural information is available. However, because of the similarity between this thesis and the Center, a detailed analysis of the program is important. NREL's Wind Technology Center actually consists of five facilities: Advanced Research Turbines, Building 251 High Bay, a Dynamometer Test Facility, an Industrial User Facility and Test Pads.

The Advanced Research Turbines facility consists of two turbines known as Controlled Advanced Research Turbine 2 and 3 (named for their respective number of blades). These and accompanying facilities are used to test control mechanisms for wind turbines while maximizing energy transfer. In other words the, turbines are permanent but various drive and control systems can be switched in and out for testing.

As the center of NREL's Wind Technology complex, Building 251 contains administrative and research support offices and conference rooms. The High Bay Lab contains 225-kW dynamometer as well as equipment for conducting static and dynamic load testing on small turbine blades. It also houses an environmental chamber for exposure of components to extreme weather conditions.

In addition to the High Bay Laboratory NREL also has a dedicated 7,500 square foot Dynamometer Test Facility. Used to test drive trains and gearboxes the facility is able to conduct lifetime endurance tests in a few months time that accurately simulate 30 years of use. Designed to operate continually for extended periods the facility contains a monitoring system know as Supervisory Control and Data Acquisition (SCADA). The facility also contains a 50-ton electric bridge crane for handling large parts.

The Industrial User Facility consists of office space for industry researchers, experimental laboratories, computer laboratories for digital analysis, and component assembly space. This is also the site for blade endurance testing where turbine blades
up to 50 meters long are subject to stress cycles to predict their performance. This is the only facility of this type in the world.

In addition to CART 2 and 3, Test Pads are provided for testing turbines developed by private companies including Atlantic Orient Corporation, Bergey Wind Power, Southwest Wind Power, Northern Power Systems, the Wind Turbine Company and Global Energy Concepts. Unlike Cart 2 and 3 which are permanent fixtures of the Advanced Turbine Research Facility, various turbines can be assembled, tested in real wind conditions and disassembled. This thesis project will feature such test pads which will also augment electricity currently produced by Livingston’s municipal wind farm.
precedents: Hawaii Gateway Energy Center

Hawaii Gateway Energy Center
Bill Brooks, AIA, Ferraro Choi and Associates
Kailua-Kona, HI, 2005
Offices, Interpretive Center, Assembly, 3600 s.f.

As one of only 33 buildings worldwide that is certified LEED Platinum by the United States Green Building Council, the Hawaii Gateway Energy Center is among the upper echelon of Green Buildings. It is a net-zero energy building with several sustainable features specific to its environment. Located on the south coast of the big island, a photovoltaic-powered pump extracts seawater from 3000 feet below sea level. The water, which reaches the building at 45 degrees Fahrenheit is pumped through a set of coils. Air is drawn across the coils through natural stack effect (with the aid of integrated thermal chimneys) and cooled to 72 degrees Fahrenheit. Moisture that condenses on the coils is harvested for flushing toilets and irrigating landscaping. The angled space frame supporting the 20-kilowatt grid-tied photovoltaic array is perhaps the most obvious architectural feature of the building. It is questionable whether or not the array will produce anywhere near the embodied energy of the frame and panels but when considered holistically, the array is a critical part of the system. Additionally, a visitor survey showed that 70 percent of the visitors to the building come because they notice the unique angled space frame. Sustainability is increasingly an element of our culture. A building’s ability to express this (while increasing its functionality) and become a flagship for sustainability is important to its long-term success and to educating the public about the value of sustainability in architecture. In addition to the active solar systems in the building, careful design has allowed for natural day lighting and the passive ventilation system.
Academic Paper: House for a Fashion Designer (project)

Ali Rahim Contemporary Architecture Practice
London, UK, 2002
Program: Residence, 6,000 s.f.

An anomaly among the projects presented here, this unbuilt project represents design and architectural thought purely as a product of technology. It is a snapshot of architecture in the 21st century, as much product of our culture’s obsession with technology as it is of Rahim’s ability as an architect. Years from now this work may occupy the same cultural and historical space as the revolutionary ipod classic, Pixar’s breathtaking animation work and the original Toyota Prius. A representation of this era’s internalization of technology as an permanent element of our existence. It is presented with stinging criticism as well: This is fictional architecture. These look like images of a building but they are not.

The inability or unwillingness of the architect to actually construct these spaces perplexing. I do no believe that it cannot be done: Delta Marine is designing and fabricating fiberglass resin hulls for luxury yachts at its yard in Seattle with tremendous craftsmanship and control. Using Rhinoceros 3D modeling software and CNC milling machines they have simultaneously eliminated the time consuming shop drawing process and opened themselves to an unlimited variety of complex surfaces. The abstract beauty and scale of the unpainted hulls in their shops is breathtaking. Additionally, these are structural forms.

That said, the design process demonstrated here is parametric and warrants discussion regardless of the project’s digital/actual existence. Using animation software Maya as the primary design tool, the architect was able to systematically program site conditions into a vector grid. View sheds, circulation throughout the site and other factors exist in the schematic design as ‘pressures.’ These forces result in variation of the vectors, which are arranged in a regular grid on the site. Because of the use of vectors, both direction and speed/emphasis are accounted for. The resulting shaping of building and site, then, is a manifestation of the conditions specific to that place. The shape of the spaces—openings towards view sheds, orientation of building aligned with circulation, etc.—is performative. Arguably, it is equally a product of the idiosyncrasies of digital modeling, the architect’s intuition and personal choice...and that ever-present griffin hovering over every architect’s desk: chance.
Images: Rahim, Catalytic Formations
Program: A Wind Technology Center for Montana

This building will be a laboratory for design and analysis of wind-based technologies located in the Yellowstone Valley in southwest Montana. It will facilitate research of wind technologies to accommodate Montana and the nation’s burgeoning wind energy industry but will focus specifically on challenges specific to Montana. The critical question facing wind development in Montana is how to overcome limitations in transmission and economically tap into Montana’s tremendous wind power potential. How do we ‘embody’ energy contained in wind. The function of this facility will be to provide design and testing of traditional wind turbines and to conduct research and development of alternative uses for electricity generated by wind. It is located along the I-90 corridor and will also serve as an educational facility, providing information to the public about wind generation in Montana through an on site visitor’s center.

It is in this sense that this project differs significantly from The National Renewable Energy Lab’s Wind Technology Center in Boulder, Colorado. Importantly, this facility will be a visual icon for wind energy in Montana. As the dramatic form of the wind turbine unquestionably is, the building itself should be a product of wind and climate specific to this unique part of the world. Architecturally, the Hawaii Gateway Energy Center is representative of the iconic quality of sustainability. Though it obviously differs in site and program from this project, it should be noted that 70% of its visitors stop because they notice the unusual and striking shape of the space frame supporting the photovoltaic array. That is, they go out of their way to visit the building because of its architectural expression. As a result, they become more informed about sustainability and its importance to architecture. This project could do the same thing, informing visitors about the value of alternative energy and the importance of design in confronting global warming and rising fuel costs.

High Bay Lab 1: Turbine Blade Testing
Quantitative:
7500 s.f.
8 lab technicians/engineers
Facility will conduct fatigue tests on turbine blades and will accommodate blades up to 150 feet long with an overhead crane for loading and unloading. Space should be approximately 30’ high to accommodate crane, test stands and blades. Service access should be ‘pull-through’ to allow standard semi trailers (trailer dimensions 45’ hitch to rear, 8’6” wide 12’ high) to be
loaded and unloaded by the overhead crane.

Qualitative:
Space should express the ‘doing’ of things. The blade being tested, supported on the testing cradle will certainly be the determining factor in the layout of the space. The space will be defined by the unique form of the turbine blade. The equipment and process are highly technical and the space should be well lit to accommodate efficient and continuous activity. Like all work spaces, natural day lighting is important. Livingston has significantly more sunny days per year than Bozeman and the architecture should take advantage of this. High ceilings and large square footage will undoubtedly lead to an industrial quality. The overhead crane, testing cradle and monitoring equipment can all become architectural expression. Given the classified nature of the equipment and processes, access should be tightly controlled. Like the Boeing plant in Renton, WA, an isolated viewing platform could allow privileged visitors to look down onto the laboratory floor. Lighting might come from high windows or through translucent glazing.

High Bay 2: Drive Trains
Quantitative:
6000 s.f.
8 lab technicians/engineers
Contains dynamometers to conduct torque and life cycle tests on gearboxes and drive train systems. Space should be approximately 30’ high to accommodate crane. Because of continuous operation of equipment for months at a time, there should be a monitoring system similar to NREL’s SCADA as well as sound protection. Should also provide access pull through for semis.

Qualitative:
Like High Bay 1, spatial quality is about the activities that taking place in the space rather than the unique form of the turbine blade. Unlike High Bay 1, though, many separate processes may be taking place simultaneously at the various test
stations rather than all activity revolving around a single piece. Safety is a concern considering the power and movement inherent in dynamometer testing. Also like High Bay 1, access should be tightly controlled, although the opportunity for touring the facility should be considered. Like the design of the parts the space will be testing, the space should be carefully organized and purely logical. Should express the “beauty of mathematics” described by Thompson. Should also be naturally day lit.

Test Pads
Quantitative
5 pads with three in continuous operation
2 full time test pad managers
Site will provide five test pads and towers to allow long term testing in high wind conditions. Pads approximately 30’ square with bolt-down hardware and grid tie-in for electricity production. Small monitoring/service station (300 sf) to accompany pads. Five pads will allow three to be in continual operation while one tower is being assembled and one disassembled. Power generated from test pads will provide energy for the building and surplus will supply city of Livingston. High Bay 1, 2 and the test pads will provide complete and thorough testing of any current manufacturers turbine design in both simulated and real world conditions. Location for test pads is to the southeast across Interstate 90. The wide open foothills of the Absaroka range are free of obstructions and are significantly windier than the valley. They are also intermittently visible from the interstate and site.

Qualitative:
The wind turbine can be an extremely graceful and iconic object. The sculptural quality of the turbine should be considered integral to the facility’s purpose of developing wind energy in Montana. The placement of the turbines on the a positive area within view of the facility will be critical. Located along I-90 to the east, the turbines and activity surrounding them can serve as a constant visual element in this dramatic landscape. The presence of three turbines, their constant movement and the host building can serve as its own abstract composition, attracting visitors to this unique facility.

Low Bay: Alternative Energy Uses/Hydrogen Electrolyzer Lab
Quantitative
Primary focus will be on alternative uses for electricity produced by turbines including hydrogen production and subsequent use, fertilizer production and other manufacturing (mission critical facilities?). Lab should have a visible and electrical connection with test pads and only controlled access from visitor’s center. Although electrolyzers are not large pieces of equipment, (approximately 6’ tall) the space should have a concrete floor to and 12’ ceilings to accommodate forklifts. Should also have access to service drive.

Qualitative
Given the unique hardware necessary for Hydrogen production, the space will be defined by what is in it. Electrolyzers, internal combustion hydrogen engines and the long, thin steel tubes used to store pressurized hydrogen comprise a series of unique forms occupying the space. Natural daylight is important as is a visual connection to the outdoors.

Offices
Quantitative
1500 s.f.
12 engineers/facility managers
Provide space for industry specialists and employees to conduct individual research and communicate with others in the wind energy industry. Series of 12 individual offices at 60 to 100 square feet should be provided. The labs will also be the location for digital modeling and simulation in association with the High Bay Labs.

Qualitative
Natural day lighting should be provided throughout spaces. Because of the importance of Montana’s landscape to the facility, views to the northeast (Crazy Mountains) and southeast (Absaroka Mountains) should be provided. The office spaces
Program: Quantitative and Qualitative (continued)

should have visual and physical connection to outdoor spaces, both distant and immediate.

Break room
Quantitative:
300 s.f.
Allow for 16 people to use at any time
Space should be adjacent to offices and should have a connection to a sheltered outdoor area as well. Should have small kitchenette with a sink and microwave and a table and chairs.

Janitor's closet
100 s.f.
1 full time custodian

Conference room
Quantitative
800 s.f.
Space for gatherings of up to 30 people
Space will be used for group presentations as well as handling groups visitors (students, industry groups) touring the facility and should have appropriate seating and projection equipment. Should be adjacent to both offices and the visitor’s center.

Qualitative
Space should be considered a display space for the activities taking place at the facility and may contain permanent images, posters and displays describing what takes place there. Light control will be important for projections but the opportunity for passive lighting controlled with shades should be pursued.

Restrooms
2 sets @ 150 s.f.
matrix:

<table>
<thead>
<tr>
<th>High Bay 1</th>
<th>High Bay 2</th>
<th>Low Bay 1</th>
<th>Low Bay 2</th>
<th>Test Pads</th>
<th>Offices</th>
<th>Break Room</th>
<th>Janitor's Closet</th>
<th>Conference Room</th>
<th>Rest Rooms</th>
<th>Visitor's Center</th>
<th>Mechanical</th>
</tr>
</thead>
</table>

Legend:

- Critical Adjacency
- Non-Critical Adjacency
- Critical Separation
- Visual Connection
- Controlled Access
**Program: Code (International Building Code, 2006)**

**Zoning:**
Outside of Livingston City Limits but in the “Donut Area,” placing it under jurisdiction of town of Livingston. Site is zoned Industrial.

Applicable Permitted Uses for Industrial (I) (from Park County Zoning Regulations)

(12) Manufacturing, compounding, processing, packaging of electronic components
(6) Electrical central power stations
(18) Laboratories, research and testing

**Area Requirements:**
- Front Yard Setback 20 feet
- Side Yard Setback 10 feet
- Back Yard Setback 20 feet
- Yellowstone River 200 Feet

**Building Height**
Maximum building height is 40 feet or three stories.

**Code Requirements By Occupancy**
**2006 IBC**

- High Bay Lab 1 7,500 sf
- High Bay Lab 2 6,000 sf
  Total: 13,500 sf **Group F-1**

[**306.1 Factory Industrial Group F**. Factory Industrial Group F occupancy includes, among others, the use of a building or structure, or a portion thereof, for assembling, disassembling, fabricating, finishing, manufacturing, packaging, repair or processing operations that are not classified as a Group H hazardous or Group S storage occupancy.]
Construction Type: Type V
Allowable Building Area:  14,000 sf
Floor Area per Occupant:  100 gross sf
Occupant Load:  135
Means of Egress:  2 exits required
Width:  Minimum:  44”
Plumbing fixtures:  1 watercloset
               1 lavatory (male)
               1 watercloset
               1 lavatory (female)
               1 drinking fountain

Offices 1,500 sf
Low Bay Lab  1,500 sf
Conference Room  800 sf (exception under Group A)
Break Room  300 sf
Total:  4,100 sf Group B

[304.1 Business Group B
Laboratories: testing and research
Special Requirements:
SECTION 420 - HYDROGEN CUTTOFF ROOMS
[F] GASEOUS HYDROGEN SYSTEM. An assembly of piping, devices and apparatus designed to generate, store, contain, distribute or transport a nontoxic, gaseous hydrogen-containing mixture having at least 95-percent hydrogen gas by volume and not more than 1-percent oxygen by volume. Gaseous hydrogen systems consist of items such as compressed gas containers, reactors and appurtenances, including pressure regulators, pressure relief devices, manifolds, pumps, compressors and interconnecting piping and tubing and controls.]

Construction Type:  Type V B
Program: Code (continued)

Allowable Building Area: 9,000 sf
Floor Area per occupant: 100 gross sf
Occupant Load: 41
Means of Egress: 2 exits required
Width: Minimum: 44"
Plumbing fixtures: 1 watercloset
1 lavatory (male)
1 watercloset
1 lavatory (female)
1 drinking fountain

Visitor’s Center 3,000 sf
Total: 3,000 sf Group A-3

[303.1 Assembly Group A. Assembly Group A occupancy includes, among others, the use of a building or structure, or a portion thereof, for the gathering of persons for purposes such as civic, social or religious functions; recreation, food or drink consumption; or awaiting transportation.

Group A-3
Museums]

Construction Type: Type V B
Allowable Building Area: 6,000 sf
Floor Area per Occupant: 11 gross sf
Occupant Load: 272
Means of Egress: 2 exits required
Width: Minimum: 44"
Plumbing fixtures: 1 watercloset
1 lavatory (male)
1 watercloset
1 lavatory (female)
1 drinking fountain

Mechanical 1 (located adjacent to High Bay Labs) 300 sf
Mechanical 2 (located adjacent to Visitor’s Center) 300 sf

[Table 508.2
INCIDENTAL USE AREAS
Furnace room where any piece of equipment is over 400,000 Btu per hour input. Provide 1 hour separation or provide automatic fire-extinguishing system.]
project: site plan

Livingston Peak

Crazy Mountains

background image: Google Earth

Livingston, MT Quadrangle Map, U.S. Geological Survey

Montana Wind Energy Atlas, 1984

site location

Livingston Peak Crazy Mountains
project: floor plans
entry lobby interior
visitor's center interior
project: renderings (continued)

shop/viewing platform interior
shop exterior
project: model
Abstract


Based on discussion with Gordon Brittan, March 27, 2008 in which Mr. Brittan noted that of the numerous 65kW wind turbines of a particular model throughout the country none produce more than 120,000 kWh of electricity per year (these are located in very good wind country in California). The 65kW turbine owned by Mr. Brittan that is located on the east side of the Mission Creek Drainage produces 130,000 to 180,000 kWh per year.

Theory and Concept


Maurice Merleau-Ponty, *The World of Perception and the World of Science*, p. 44.

Program


