Sustainable Architecture

an overview of equitable and efficient spaces written by garrett moon
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Introduction

Everyday, people are increasingly realizing the choices they make in their everyday lives, affect the people and the environment around them. They are buying local, organic food to reduce the use of pesticides, support their local community, and reduce the fuel costs associated with producing what they eat. They are choosing to ride their bike or take the bus instead of driving a car. In fact, 2005 was the first year since the 1973 oil crisis that more bikes were sold in the United States than cars (Mount). At the forefront of many of these changes, the building industry needs to take the lead. In the United States, buildings account for 39% of the total energy use, 12% of total water consumption, 68% of total electricity consumption and 38% of carbon dioxide emissions ("Why Build Green?").

However, much is changing. We are seeing a push to create buildings and spaces that do not require external energy to heat, cool or power them. There are efforts to reduce the use of materials that have a high embodied energy and to increase the number of recycled/reused and recyclable/reusable materials.

This document is meant to be a survey of the wide array of options designers and builders have to create spaces that are more sustainable, with a particular focus on residential architecture. To begin, we must first explore what sustainability is and in what way it pertains to architecture. Oxford Dictionary defines sustainability as:

> *able to be maintained at a certain rate or level: sustainable fusion reactions.*
> *• Ecology (esp. of development, exploitation, or agriculture) conserving an ecological balance by avoiding depletion of natural resources.*
> *• able to be upheld or defended: sustainable definitions of good educational practice.*

When looking at sustainability as it applies to architecture, there are several aspects of a building that are important to consider: atmosphere, longevity, energy, interface and equity.

The atmosphere of a building is the mood and feeling that it engenders. Is there sufficient lighting, how does one move from one room to the next and how is the air quality? A sustainable building will take into account all of these factors because the health of a building's users is intrinsically intertwined with the use of the building.

The longevity of a building also plays an important role in its sustainability. Spaces that remain of use to their occupants for a long duration are more sustainable than those that are torn down 35 years after they have been built, the current US average; this compared to 50-60 years for Australia and Britain (Birkeland 46). Designing buildings that will last and be of use for generations should be a major goal of any architect.

Reducing the energy impact of a built space is one of the most important considerations to be taken when constructing spaces. Building energy use comes in two forms: embodied energy and operating energy. Embodied energy, the energy required to create, transport and install the materials that make up a building, surprisingly make up a large portion of a building's energy costs (less if the building lasts longer). Operating energy is the energy a building uses everyday to heat and cool a space, run appliances and power any electronics within.

When creating architecture with a conscious effort towards improving sustainability, one must take into account the way a building interacts with its surroundings. How will people connect with their neighbors, their backyard, the streets? A building that interfaces well with its surroundings is one that is more useful and likely to be appreciated for longer. Also of importance is how the building affects the immediate environment, i.e. what plants and animals are being displaced, how much of the local topography will be changed, will weather systems be significantly impacted by the new building (such as from storm water or wind)?

Finally, an aspect of sustainability that is often overlooked is that of equity. Too often money is the solution to unsustainable situations. However if technology and design are too expensive for the average person, they can never be sustainable because they won't be widely adopted (although if expensive technology is embraced, it is likely to become more affordable). Of course one can argue that the true costs are often hidden (environmental, human rights violations, etc.), but this argument does little to encourage adoption. Solutions like home made bidets (which reduce toilet paper usage) and slow sand filtration are low cost alternatives to expensive Japanese toilets with built in bidets and UV light filtration systems respectively. If sustainable architecture is ever to make a significant impact, it must be affordable to the masses.

Energy

Of course the most effective means of reducing a building's reliance on external grid power is to reduce energy use as a whole. This can be done in a variety of ways. Increasing reliance on natural lighting and passive heating and cooling are some of the most effective ways of reducing energy consumption in a home and will be discussed in depth in later sections. When choosing appliances, one can save significant amounts of energy by purchasing the most efficient appliances and only buying needed capacity (for example, purchasing a smaller refrigerator for a residence with fewer people). Looking up an appliance's Energy Star rating, is a good way to estimate its energy use. Using energy efficient appliances can greatly reduce the energy load on a building; oftentimes, if your appliances are old enough, it is more efficient to recycle the old appliances and replace them with newer, more efficient models (and commonly more cost efficient, due to the lower operating cost, if the initial purchase price can be afforded) ("Appliances: Energy Star").

Ultra-efficient washers exist that use less energy and will spin up to ninety percent of the moisture out of clothes, reducing the need for even owning a dryer if room for a clothesline or rack is available. Front loading washers use less water and are often more energy efficient as well. Novel technologies are available in washers, some eliminating the need for soap by using hydrogen ions to remove stains and smells, or greatly reducing the water needs by saving the water from the last rinse cycle for the wash cycle on the next load.

Purchasing an efficient dishwasher can also save energy. One study completed in Germany showed that even the most efficient dishwashing by hand cannot compete with some of the more water and energy efficient dish washers available. European dishwashers are often more efficient than their American counterparts and, if available, are an excellent option (Stamminger). Making sure to only run your dish washer when it is full and allowing dishes to air dry can further reduce energy needs.

Refrigerators are also important to consider. During the seventies, American refrigerator manufacturers, in an effort to create luxurious refrigerators without thought to energy consumption, reduced insulation to increase space and added heaters to the exterior casing of refrigerators to reduce condensation. These design decisions led to refrigerators that were greatly inefficient. Thankfully today's refrigerators are more efficient, but there are still things to look for when buying one.

A refrigerator with the compressor on top is very important; oftentimes compressors will be on the bottom of the refrigerator, to save space at the top, but compressors create heat and because heat rises, it enters the refrigerator – a poor design from an energy standpoint. Although exorbitantly expensive, drawer refrigerators are more efficient because the cold air doesn't "fall out," as it does with doors (again because warmer air rises). As refrigerators are in actuality very simple devices, designing and building one's own is a viable option if one has the time and is generally capable with simple tools. When buying or building a refrigerator, the most important decision one can make is to get a refrigerator that is as small as possible while still meeting one's needs.

Much of the energy used in homes is simply wasted by leaving on lights, fans, heat, electronics, air conditioners, etc. One way of mitigating this energy loss is to create systems that automate the control of these functions and the power supplied to them. Phantom power, the power used by electronics and appliances that are not being charged or currently used, is a large cause of electricity use. In fact, in the average home, 75% of the energy used by electronics is consumed while the product is off or not in use ("Home Office and Home Electronics"). Unplugging chargers, televisions, monitors, printers, appliances with clocks, etc., when not in use can greatly reduce the power usage of these items. Smart power strips are available that can do this task automatically. Leaving on lights in rooms that aren't being used and turning on lights in rooms that are partially lit by daylight can also be a large energy drain. One solution to this problem is to install a combination of light detectors, dimmer switches and motion detectors. Using this configuration, lights can be switched off automatically when there are no people in the room and can be dimmed when natural light is partially lighting a space. To continue to save more energy, one can install a server which can control all of a houses systems. Modules can be purchased that will monitor and control lighting, heating and power. Once controlled, timers and sensors can be set up to turn off heating, cooling and lights when occupants are not present. Open source and free software systems that will interface with this hardware are readily available in so many forms it can be confusing to choose, however a rather mature project entitled LinuxMCE provides a sound option. LinuxMCE's web page can be found here: http://linuxmce.com/.

While using less energy can reduce one's reliance on grid connected energy, most people still need some energy. One of the more popular methods of generating onsite electricity is through solar power or photovoltaics. Solar is the source of all energy on our planet, is in all practicality renewable, "provides 6,000 times more [energy than] consumed by humans" and has the highest power density of any renewable energy ("Solar Power"). Sadly, as of today, photovoltaics are generally not the best option economically. Over the course of its lifetime, it costs more per kilowatt hour than a nonrenewable energy like coal (it is estimated that a 10 MW plant in Phoenix Arizona produces energy at a cost of $0.15 to 0.22/kWh compared to coal at $0.048 - 0.055/kWh) ("Photovoltaics"). When choosing solar, one must take into account economics, sustainability, and site selection (for example solar would be a much better choice in Houston than in Seattle). The good news is that even if solar power is not viable for a current project, it may be in the future. Photovoltaic technology is advancing quickly with thin film solar, and plastic photovoltaics being new fronts of research. Technology is rapidly increasing the efficiency of photovoltaics and reducing their initial cost both monetarily and in embodied energy.

On site wind energy is also a field that is rapidly expanding. Companies are beginning to offer small scale wind generators that can be used even in residential situations. These small turbines, like solar, have a high initial cost but will lower electric bills and grid reliance for their lifetime. However, while wind energy compares to coal favorably on a large scale ($0.04 - 0.06/kWh), on a small scale, buying energy from the grid is often a better choice monetarily (but again wind is more sustainable and these cost estimates often do not take into account environmental costs) ("Cents Per Kilowatt-hour").

Water

Today more than ever, it is imperative that we begin to be conscious about our water use. Water tables around the world are being drained at an ever increasing rate and water shortages are heightening with global warming. Reducing water usage also reduces energy use and the costs associated with building operation; transporting, treating or desalinating water are very energy intensive tasks that are necessary when water is not used carefully.

As with energy, the most sustainable way to manage water usage in a building is to reduce the amount of water used. This can be done using more efficient washing machines, dishwashers, shower and water fixtures and toilets. More efficient shower fixtures mix air with water to produce a similar feel and effect as regular showers while using significantly less water. Along with low flow sinks and showers, water saving toilets can effectively reduce water consumption. There are a wide variety of options when it comes to toilets depending on one's needs and willingness to break with one's cultural influences. Toilets most similar to the classic flush, but that still offer water savings, are those that are simply designed to use less water per flush than traditional toilets (low flow toilets). These types of toilets also use aeration to help reduce the amount of water they need. Another popular design to reduce water usage is the dual-flush toilet. This type of toilet has two flushing options, one is a full flush and the other is a half, giving the user the option of only a half flush if they deem a full flush unnecessary. Finally, the most water efficient toilet is the toilet that uses none: the composting toilet. There are many designs of composting toilets, some of which use small amounts of water and some which use none; all use significantly less than a traditional toilet. Composting toilets often consist of a fixture with a tube that leads down to a holding tank (which has a ventilation tube that prevents smells from entering the bathroom). The holding tank often consists of several compartments or a ramp which separates composted hummus from fresh detritus. Completed compost, if the system is set up correctly, is free of pathogens and can be used in a home garden (although it is not recommended for edible plants due to the risk of the toilet/composting process being set up incorrectly), and generally must be removed on a quarterly, biannually or annual basis.

Along with reducing the amount of water needed for a building to run, supplementing the use of well water, grid water and other nonrenewable or only partially renewable sources of water is a good idea. There are two main ways of collecting water onsite: gray water collection and rainwater catchment.

Gray water collection is essentially recycling water onsite. Gray water is water from sinks and showers and different from black water in that it does not contain a significant amount of pathogens (like that of toilet water) or harmful chemicals. Collected gray water can be used for flushing toilets, watering plants, or can be bioremediated ("any process that uses microorganisms, fungi, green plants or their enzymes to return the environment altered by contaminants to its original condition") on site for use as potable water again ("Bioremediation").

Rainwater catchment is an excellent method towards meeting a building's water needs. Depending on one's location, there can plenty of water to last through the dry months if excess water is stored during wet months. Collecting the water is often simply done by connecting downspouts from a roof to a storage container. There are several options for storing rainwater and many different materials to use in a cistern, however ferrocement tends to offer the most cost-effective option (Ludwig 40-1). Water that is collected and stored in this method is not guaranteed safe for consumption however, like gray water, water from roofs should be filtered or bioremediated to remove unsafe chemicals and pathogens that may be part of the rain water or come from a composition roof for example.

Heating/Cooling

Heating and cooling buildings contributes to more energy usage than any other aspect of a buildings use ("Heating & Cooling"). Creating a building that is well insulated will reduce the energy costs of heating (and cooling) and will be looked at in the materials section. There are many methods to keep a buildings environment comfortable while minimizing energy input including: roof ponds, thermal mass walls, solar chimneys, solar rooms and green roofs. As a result of the lack of energy input these methods require, they are often called passive heating and cooling. All methods of passive heating and cooling rely directly on the sun for energy input. Due to this reliance on the sun one of the most important aspects of a building is its solar orientation. A building that is shaped like a rectangle (with side lengths having the ratio of 1.6 to 1, the golden ratio, being ideal) and elongated in the east-west direction is the optimum shape in all climates (Mazria 80-2).

Roof ponds are a particularly effective method of keeping a buildings temperature constant. To create a roof pond, water is stored in bags inside the actual roof structure. Because of water's high specific heat capacity, water can store hot or cold temperatures better than most materials. During the summer, the bags of water are covered during the day and uncovered during the night. During the night, the water is cooled down by nighttime temperatures and during the day the cool water keeps the house cool. During the winter the exact opposite approach is taken. The daytime heat is soaked up with the water bags uncovered and during the night this heat is released into the building when the bags are covered up. This set up has the potential to keep temperatures nearly constant in even extreme temperatures (Mazria 56-8).

Another option builders have is to take advantage of the greenhouse effect: glass allows solar energy waves (visible light) to pass through it but does not allow heat (infrared) to escape. To take advantage of this fact, builders can create a glass enclosed room containing a material (usually the floor or a trombe wall) with low reflectivity and high specific heat. When light hits this material, the energy becomes heat and is not allowed to escape from the room. Also, because the material has a high specific heat, it is able to store energy and release it over a longer period. Just like the roof ponds, one can selectively cover the windows during different times of day and temperatures to control the space's temperature. Large cement blocks, rocks, and different types of containers filled with water can act as excellent materials for this application.

A growing concern in urban areas today is something called the urban heat island effect. Many may not have heard of this term, however they invariably feel its effects. The urban heat island effect describes why urban environments are often several degrees hotter than the areas surrounding them. This is caused largely by "the lack of vegetation in urban areas, which inhibits cooling by evapotranspiration" ("Urban Heat Island") and the prevalence of massive, darkly colored surfaces, mainly pavement and the roofs of buildings, which absorb rather than reflect heat. Of course the way to decrease this effect is to increase vegetation, which brings us to our next method for controlling the temperature in buildings: green roofs. To implement a green roof one simply plants a building's roof with vegetation. There are two types of green roofs: intensive and extensive. Intensive green roofs often have deep soil, require irrigation, maintenance and are essentially the equivalent of a garden; trees, bushes and vegetables can make an intensive roof their home. The issue with intensive green roofs is the cost associated with the engineering and materials to support the weight of the added soil and plant material. The benefit of an intensive roof is the deep soil adds thermal mass (and a slight amount of insulation) to one's building envelope and allows for gardening in a space that is often not used. Extensive green roofs, with there shallow soils, require less maintenance and engineering costs. The advantage green roofs offer is mitigation of storm water run-off (as the plants and soil absorb much of a heavy rainfall), evapotranspiration to reduce the urban heat island effect, as well as a place to grow food and other plants ("Green roof" and Dunnett et al. 26). Aesthetically, green roofs are often thought to be more attractive as well.

Cooling a space in the summer can be very difficult to accomplish, however even in the summer, shaded areas with cool air can be found. Near building examples can be: under a porch, in a cellar or in an underground parking garage. Fans can be an effective method of drawing this cool air into a building and blowing out hot air, but more energy efficient methods exist. Solar chimneys can often be an effective and natural "fan" that can aid in passive cooling. A painted black chimney will heat up during the summer, hotter than the air below it. This hot air rises and creates suction on the space below. Having an opening somewhere at the bottom of the building that opens up to a cool space (like the parking garage mentioned) creates a convection current that brings cool air from the bottom through the building and the hot air out the top through the solar chimney.

Lighting

Light is a very important aspect of human life; our bodies use it to create vitamin D. Studies have shown that laboratory mice living under a restricted spectrum of light become ill and develop antisocial behaviors. Lighting affects us on a psychological and physiological level (Day 193). Thus it is very important to have good lighting in built spaces. As humans have evolved in daylight conditions, it follows that the human body is best adapted for the varied lighting conditions that are present in natural lighting. Therefore, Lighting a space with natural lighting is considered the best option. Of course caveats exist to placing as many windows in your building as possible. First of all, every window put into a building creates a hole in the building envelope, lowering the overall insulation value of the building. Also, lighting in space should be diffuse; glare from daylight or the sun, reflected or direct, can cause headaches and annoy people in a space. Lighting levels that are too low can cause eye strain. Emulating natural lighting by having light from multiple sources is important; light comes from all directions outdoors. One excellent option for lighting spaces is to use polycarbonate. Polycarbonate is cheaper and insulates better than windows. While light transmission is slightly lower than glass, polycarbonate is a good option for windows that are above eye level and solely for lighting a space. Another option for daylighting a space that has no access to the outside is fiber optics. Fiber optics allow natural light to be passed through a small, fibrous, glass tube. While this option is currently very expensive and it would be better to design spaces that have direct access to natural light through a window, fiber optics are becoming more affordable and are sometimes the only option for daylighting a space. Light tubes, essentially sky lights with mirrors in them that allow one to control the direction of daylight, are oftentimes a more affordable option.

Materials

One of the most important aspects of a building is that of material choice. What one builds the exterior envelope of their space with affects its ability to breath (important for preventing sick building syndrome, an affliction to buildings often caused by mold, dust, and volatile organic compounds which can cause sickness in a buildings occupants), to retain temperatures, the embodied energy cost of a building, its longevity and its strength against earthquakes, etc. Today there are a variety of materials to choose from that meet these goals.

The traditional material of choice for residences in America is wood. Wood is a good option for many builders because it is a material that is known and there are often prescribed codes for building with it (thus reducing engineering costs). Wood buildings generally breath well, do not have high embodied energy (1380 MJ/m3), can last for hundreds of years, if well taken care of, and have a high tolerance to earthquakes ("Measure of Sustainability: Embodied Energy"). Wood framing on its own however does not insulate well and thus must be supplemented with some type of insulation (many appropriate options exist, including recycled cotton fiber from jeans, spray in foam insulation, etc.). The advantage of this setup is that one can choose the amount of insulation to match the buildings surroundings and climate. Wood's disadvantage is its lack of inherent insulation, its susceptibility to weather if not properly protected and its high flammability. When choosing wood for a project, one should consider choosing wood that is FSC certified. The FSC (Forest Stewardship Council) is a nonprofit certification group that ensures the "responsible stewardship of the world's forests" ("Forest Stewardship Council").

For larger buildings and those that require higher strength materials, steel becomes a viable option. While much more expensive than wood, steel offers great tensile strength. Like wood, it is susceptible to degradation without protection and must be supplemented with insulation. Also, steel can create a thermal bridge between the outside of a building's envelope and the interior. Because steel is a conductor, unless it is insulated on both sides, steel conducts heat rapidly, and degrades the quality of one's envelope. Steel also has a very high embodied energy of 251,200 MJ/m3, 182 times as high as wood ("Measure of Sustainability: Embodied Energy"). Steel it seems then, is only suited for applications where strength is of the utmost importance; in other cases, the negatives of using steel far outweigh the positives. If steel is used, using recycled steel is often the most sustainable option and it is readily available.

Another material that is used quite often in buildings today is concrete. Poured concrete with rebar offers a reasonable amount of insulation (although supplemental insulation should still often be considered), has a reasonable embodied energy (3180 MJ/m3), is structurally stable, resistant to earthquakes and has great longevity ("Measure of Sustainability: Embodied Energy"). A disadvantage of poured concrete is that it is hard to recycle or reuse. One benefit specific to concrete is its high thermal mass, which makes this material perfect for sun rooms.

Straw Bale is an interesting material that has been used for a long time to build homes but is seen as an alternative building material today. Oftentimes, straw bale is used as wall infill in conjunction with wood framing to be sure of its stability. In this case the bale acts as a renewable and inexpensive insulation. New research and engineering is now allowing straw bale to be used structurally in cities (though it's been used structurally successfully for over one hundred years without engineering). By putting rebar through the bale and coating it with stucco, it becomes reasonably earthquake resistant and can be used in multistory buildings. Straw bale, while having a very low embodied energy (it is often considered a waste product), is a great insulator, and is highly breathable, has a few issues that must be addressed if building with it. Because bale creation is often unregulated, seeds and nutritional parts of hay may be left in straw bale. This can attract local insect populations that may take up residence in the bale and cause it to become unstable. Mixing borax with bales can help to prevent infestation (Steen et al. 46-47). Another risk with straw bale is its susceptibility to weather. Wet straw bale will rot quickly and become a major problem for a building's stability and air quality. Thus great care must be taken to protect the bale with overhangs, siding, and/or stucco.

Rammed earth (literally earth that has been packed into a form, similar to adobe bricks except walls do not contain individual bricks), another alternative material, has been successfully used by many cultures for centuries. It is very similar to concrete in its thermal properties, however its impact on the environment is much less. Engineering on rammed earth structures has not been done for tall buildings and currently is most likely not well suited for them. Rammed earth is also much more susceptible to erosion from rain than other materials and requires a large amount of labor. If doing the labor by hand, and enough soil is available locally, rammed earth is a material that has one of the lowest embodied energies one can find. Rammed earth can also be supplemented with tires or bottles to make an earthship (compacted earth is placed in the tires, but not the bottles, as the air in the bottle provides good insulation). This has the added advantage of using a waste material in your building and reducing the amount of dirt and therefore compaction necessary.

There are two materials that are currently taking the green building world by storm. SIPs (Structural Insulated Panels) and "Green" CMUs (Concrete Masonry Units, also called cinderblock) are both composite materials that are meant to be easy to build with and provide environmental benefits over traditional materials.

SIPs are essentially a sandwich of a structural member, an insulating core and another structural member. Because the SIP replaces several building components (insulation, studs, joists) of a traditional wood frame building, it makes building with it far easier. This is the main advantage of building with SIPs. "Green" SIPs use FSC certified wood for the exterior structural membrane, and often a renewable resource such as straw or soy for the insulation in the panel. SIPs embodied energy cost is similar or a little higher than standard wood framed buildings and are often more expensive than other building materials but savings in labor can make up the cost. Because insulation runs the course of a SIP, it provides slightly tighter building envelope and thus higher R-values than wood framing combined with insulation (unless spray-in foam is used). SIPs also outperform traditional framing structurally. Most commonly, SIPs are used in combination with wood framing; framing is used for a building's walls and SIPs are used for the roof.

When choosing "Green" CMUs, one has a variety of options. CMUs already have the advantage of being easy to build with, the cinderblocks are stacked, rebar is placed in the holes and concrete is pored to create a column. CMUs that are deemed to be more sustainable are even easier to build with because they are lighter. The blocks are formed by mixing recycled waste wood, which has been mineralized (like petrified wood) or polystyrene beads, with cement. Some CMU manufacturers also fill part of the CMU's cavity with insulation such as rock wool or polystyrene, greatly increasing its R-value. "Green" CMUs are long-lived, breath well, have a relatively low embodied energy (much less than a traditional CMU which has an embodied energy of 2350 MJ/m3) and are structurally very strong ("Measure of Sustainability: Embodied Energy"). The disadvantages of green CMUs are that they can be relatively expensive, and currently are not often available locally so transportation costs may be great.

It is of utmost importance to choose the proper material for a given building. One should not be limited to choosing just one, however. Oftentimes materials will be mixed in a well designed space; for example, steel offering support in areas where strength is required, wood framing used in an outdoor room where insulation is less important, and insulating CMUs used for the majority of a building.

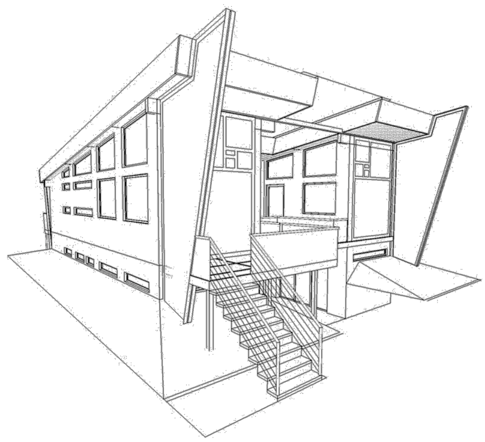
Planning

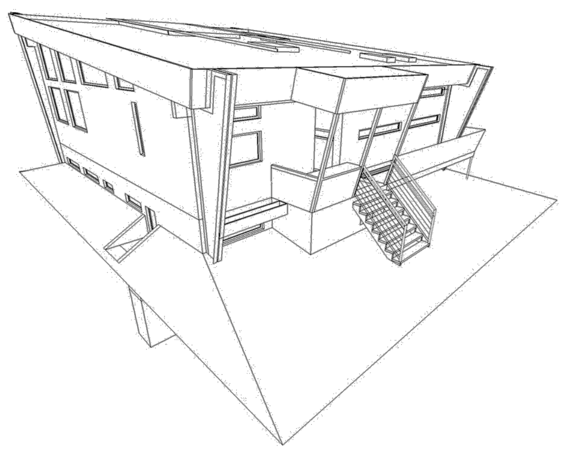
An important aspect of architecture that is often overlooked is that of planning. Planning is the study of how spaces should be laid out to interact with each other. For example, urban planning deals with infrastructure, buildings and services and where they should be located within a city. Architecture and planning are subjects that are often looked at separately but should be considered together for true sustainability. This is simply because architects and builders do not often take into account the surroundings of their building. Decisions such as whether to include a garage in a building design can be directly affected by a buildings surroundings: a garage would most likely be necessary in the suburbs, but not for a building in walking distance of common needs, such as grocery stores and public transportation lines. During planning, it is equally important to consider, architecture. Planning dictates lot size and distribution in cities, taking into account the solar orientation of lots can be a great boon to architects when designing buildings. A poorly oriented lot can make for a huge headache when it comes to designing a building, but conscious planning can create blocks of well oriented parcels which can reduce energy needs significantly for everyone involved.

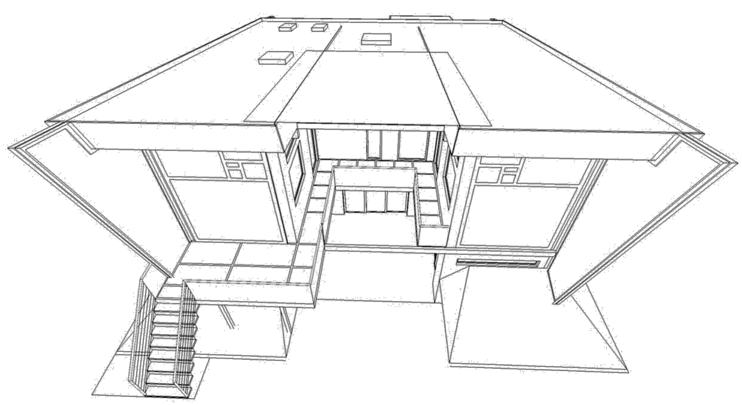
Conclusion

Every day, rising energy costs, global warming, water shortages, limited resources, growing population and an endless number of other factors are pointing to the fact that humans are living unsustainably. As is often said, change starts at home. Our homes, offices, schools, community meeting spaces and all other buildings have the potential to not only be sustainable, but to provide free energy (through solar or wind) and water (through catchment and bioremediation) to other needs (such as transportation and farming). Research and interest such as The Living Building Challenge (a challenge to create a *truly* sustainable building) are out there, but it is up to designers, builders, architects and planners to continue pushing the limits. Studying sustainable architecture and implementing just some of the ideas introduced in this document can bring us closer to a truly sustainable way of living.

Case Study: The Commons







Introduction

When my brother and I bought a home in Southeast East Portland, we were excited about the neighborhood and location, but disappointed with the poor thermal envelope (winter was especially miserable), failing materials (the foundation was falling apart and the back deck was missing), poor solar orientation (exactly backwards) and small size. What excited us the most however was the opportunity to practice something we had studied and were intensely passionate about: sustainable architecture.

Designing and building a home can be a daunting process: choosing materials, creating a floor plan, deciding on lighting, water, and heating and cooling systems are some of the most important decisions you will have to make. Described below are our choices in these areas and the reasons we chose them. It is to be hoped that this will give you ideas and justifications for making you're decisions.

Design Constraints

For this residence, we had several design constraints and goals to consider when going through the design. The first step of the process was to find out what our goals were. We sat down and created a list of rooms we wanted in the house and from there created individual lists of the functions we wanted each room to serve. This allowed us to estimate size needs and have a list for the future that we could refer to continually. Having this list helped us flesh out who we wanted our house to serve and how we were going to achieve our goals. We realized that we wanted the house to work for my brother, his partner, myself, my partner and our parents. To achieve this goal we would have to have three bedrooms (or significantly alter our lifestyle). As a musician, I wanted a space to play instruments without disturbing others in the house. Both my brother and I wanted office space to work on design and other projects and we concluded that our partners might also want the same. A place to grow food was also of great importance to us. To this end we decided that a greenhouse would allow us to grow a greater variety of plants and therefore foods. After deciding upon our goals, we of course had to recognize the limitations we were facing. In our case we had a lot size that was 50′ by 100′, with 5′ setbacks on three sides and 10′ on the front. These are just the beginning of the many building limitations imposed by the city of Portland. These limitations are of course meant to protect the city's residents and provide a consistent look and feel. However, as with many rules, there are good situations that are unforeseen and ultimately hampered by the rules. For example, 20% of the street facing side of a home is required to be windows. In our case, this side, the North side, receives the least amount of sun and therefore windows are less efficient on this side (providing less light while still opening up the buildings thermal envelope). Another disappointment we faced was that gray water systems are illegal in Portland. We only found out about this far into the design process and have had to work around it: the lesson being, that the design process does not end until the last brick is laid.

Materials

Several materials appealed to us for the use on our home. We looked at straw bale, rammed earth, ICF's (insulated concrete forms) and CMU's seriously. We found that if we were to use straw bale or rammed earth, we would run into much higher engineering costs and more issues with the city. We also found that we would not be able to use straw bale structurally so the energy and monetary costs would be greater than a standard framed house (because we would have to frame the bale itself). We found that rammed earth was probably not realistic as well, because the soil we had locally was not likely to be the proper ratio of sand to clay, etc. This would have required us to ship in dirt and would increase the embodied energy of the material, one of its primary benefits. Both straw bale and rammed earth are also very susceptible to weather, Portland has a high total rain fall and is prone to storms. While both materials would have been possible, special attention would have been taken to extending overhangs and being careful to protect the materials.

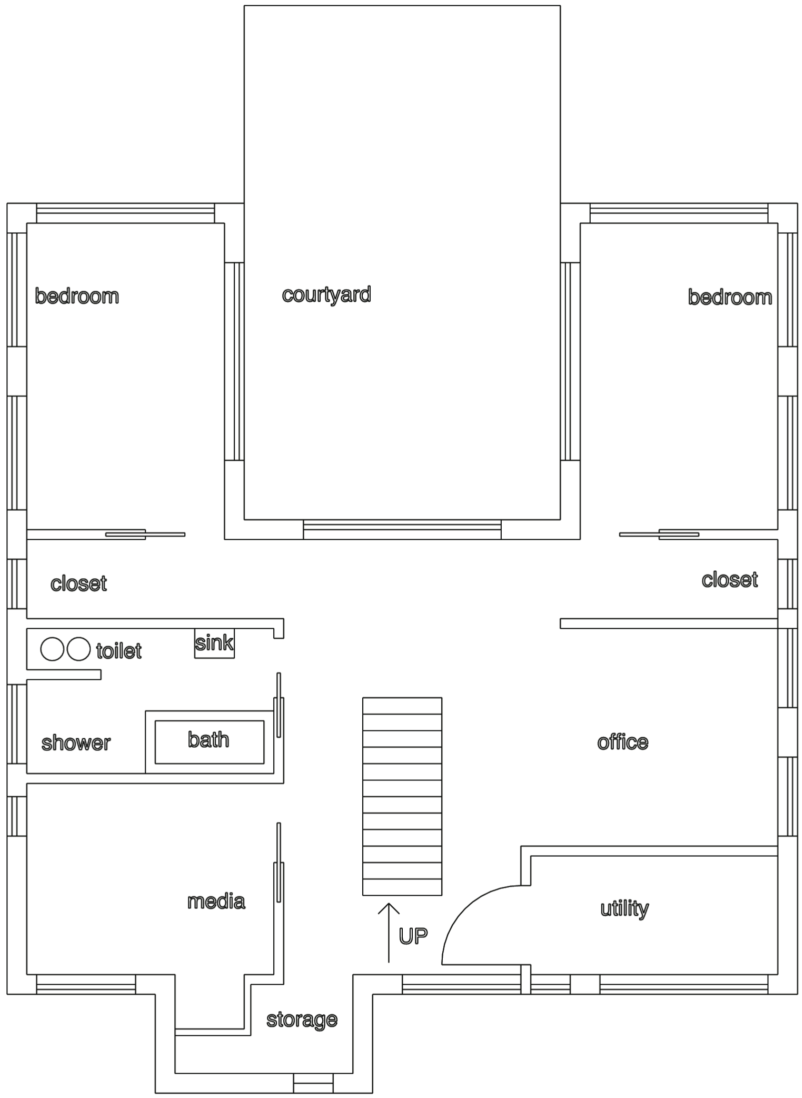
Concrete became an option if we could not find something better, however we found something that more closely matched our plans and ideals. Faswall, a CMU which contains mineralized (petrified) wood and insulation seemed like an ideal solution. The concern of locality was alleviated because a manufacturer recently set up shop less than one hundred miles away. The advantages to Faswall are numerous: great longevity, high R-value paired with thermal mass, use of a waste material, recyclable, ease of use and structural strength all contributed to our decision. The manufacturers offer three types of inserts for Faswall currently, mineral wool, polystyrene, and polyisocyanurate. These are listed in order of R-value and price. The advantage of using rock wool is that it is a waste material, however because polyisocyanurate offered a much higher R-value for a slightly increased price, we felt over the lifetime of the building, it would more than pay for itself in energy savings. Choosing materials can be one of the most important decisions you make when designing your building, weighing all the options and objectively choosing which option is realistic, is very important.

We also wanted to reuse as many materials as possible from the existing building on site. To this end we have concluded that much of the wood in the existing building could be reused for nonstructural elements. Wood floors and interior walls in the new building will be created from the floors, walls and framing of the existing building, a reminder of what was once there.

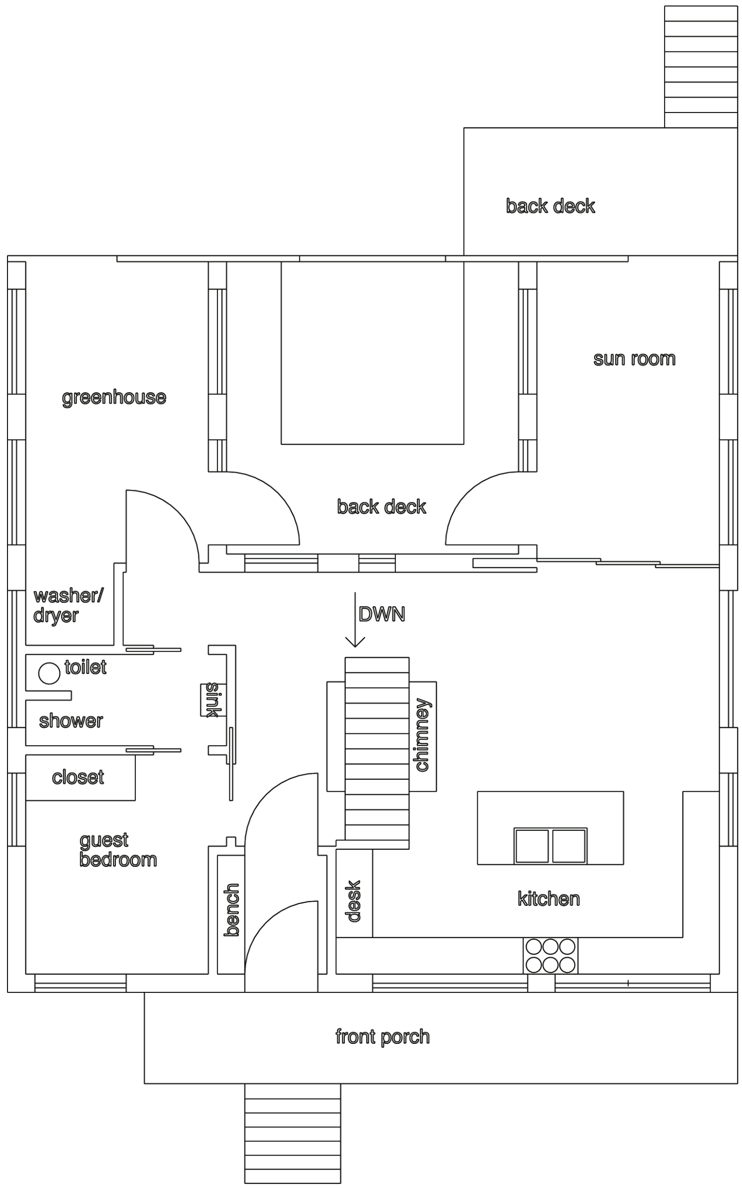
Floor Plan

The floor plan of any home is of great importance as it directly affects the flow of the building as well as the feeling one gets from occupying it. When designing our floor plan we chose to focus on efficient use of space as well as an open feel. To this end we decided to place a staircase in the middle of our floor plan in the hopes of creating a central location that occupants could flow from. We made it so when walking into the residence there was a clear unobstructed view from the door to the back yard. We made the kitchen and office areas open to facilitate users entering and leaving frequently. The floor plan we eventually decided upon was one that we revised countless times, a process that helped us learn and improve our design. Below is the floor plan we decided upon.

Bottom Floor



Top Floor


back deck
greenhouse
sun room
back deck
washer/
dryer
DWN
toilet
sink
shower
chimney
closet
guest
bedroom
bench
desk
kitchen
front porch

Lighting

Good lighting was a very important design decision for us. We wanted to use as much diffuse daylight as possible. To facilitate this we wrapped both floors with windows towards the ceiling. This provided us with diffuse light, but also opened up our thermal envelope and proved to be expensive. Luckily we found a solution for this problem. Polycarbonate, while providing a slightly lower light transmission than glass, provides much greater insulation and is also less expense. Because the polycarbonate paneling shows lines in it, we decided to use it in all the upper windows which would not be visible from the interior. We also decided to use several layers of it to provide a greater R-value while still costing less than a single piece of glass.

When daylighting does not provide enough lighting, we will need an artificial source. We immediately discarded the idea of using incandescent bulbs because of their inefficiency. Second we looked into LEDs, however the technology at this time is prohibitively expensive compared with florescent tube lighting and is far from its theoretical level of efficiency. Florescent tube lighting can also be dimmed and will work well with a lighting system that adjusts to the amount of daylight available. When LED lighting becomes more prevalent and energy efficient (at present most options are not as efficient as florescent tubes or even compact florescent lights), we will most likely convert to using them.

When designing our floor plan we also looked into lighting, attempting to give every room access to at least one window to provide daylighting, but preferably more than one to balance the daylight. Lighting a space correctly is immensely important, affecting mood and productivity. We wanted a space that would lend to these ends.

Water

We faced a potentially catastrophic problem when dealing with the city of Portland regarding gray water systems – they don't allow them. We felt that it was very important to have a water system that could function on its own and only rely on the grid as a backup. To this end we created a water catchment system as well as a gray water system. The water catchment system collects excess water that flows from the roof of our house and drops it to a gutter below the front deck. This initial drop helps to aerate the water and has the potential to help disinfect the water (although we are not relying on this). The water then enters a cistern that is stored below the front deck. This cistern contains a bed of sand that is used to clean the water through slow sand filtration, water slowly filters through pores in the sand where microorganisms live that clean the water. Before the water enters the final cistern, we are considering including a UV light due to regulations. This is the water that will be used in the home for drinking, showering and washing. If this water runs out, we will still be connected to the city.

Our gray water system is quite simple. Water from the bottom floor bathroom will be pumped up to the first floor. Here all gray water from the kitchen and both bathrooms will be pumped to the greenhouse and out into several different staging areas where swamp plants will clean the gray water for use in the garden. In this manner, the gray water does not need to be treated in a sewer plant, which is especially important in Portland where storm water and sewage are mixed and often overflow into the local Willamette River causing serious problems.

One other tool we are using to reduce water consumption is composting toilets. The toilet system we chose requires little water (enough would be supplied by a bidet, which we plan on using in place of toilet paper). Waste is dropped onto a graded platform where it slowly (glacially) moves downward as it composts. By the time the compost reaches the bottom, it will be free of pathogens and able to be used in the garden (although we will likely use it on fruit trees and nonfood crops for safety).

The water system we are putting in place is meant to reduce consumption, as well as increase awareness of our water use. It is also intended to take the load of processing waste water and storm water runoff from the literally overflowing sewer system and localize it. To work with the city's gray water requirements, we have placed a shutoff valve in the greenhouse that will allow gray water to be directed to the sewer as opposed to our gray water system. If in the future, as is most likely inevitable, the city allows gray water handling on site, we will switch the valve, and take advantage of a valuable resource.

Heating and Cooling

Heating and cooling were an aspect of our residence we spent considerable time on. In the end we designed for the integration of several systems to heat and cool the house: solar heat gain, radiant-floor heating and cooling, a solar chimney, a home made solar water heater as well as a wood stove. To best take advantage of solar heat gain we specified that the South face of both the greenhouse and sun room be faced entirely in glass. When the sun's rays go through the windows, the light is absorbed as heat by cement flooring as well as a cement wall. This heat is slowly released by the thermal masses to keep the temperature from fluctuating greatly. During the summer, the windows will be shaded from direct light and so will not heat to the same degree as in winter.

The radiant-floor heating we designed will be connected to each room as well as the wood stove, solar water heater and piping in the ground. Water can be connected or disconnected to each room, the ground, and wood stove based on temperature sensors at each location. Because the ground is a constant 55 degrees Fahrenheit, it acts as a cooling source during the summer. The sun room and green house floors, absorbing winter sun will act as heat sources. The thermal mass with water piping installed as a support column behind the wood stove and the home made solar water heater will also act as a heat sources in the winter if necessary. This system, will have the effect of moving heat around the home and from the ground to keep the residence at a relatively constant and comfortable temperature year round.

A solar chimney will also convectively cool the building in the summer and reduce heat loss in the winter (thanks to a heat exchanger).

Air Quality

Being an allergy sufferer myself, I know first hand that air quality in a home is of utmost significance. We have decided to use products which do not emit VOCs (Volatile Organic Compounds) to start the house out clean. Along with a filter in our heat exchanger, we will also be reducing dust and airborne allergens by installing a living wall (plants that live in a substrate placed on a wall) in the basement around the support columns. This living wall captures airborne particles, provides oxygen and livens up a space. It is most likely that we will create a system that will use gray water or compost tea to feed the green wall.

One of the most important ways of reducing airborne dust and allergens is to not bring them in in the first place. To this end we have created an airlock for our front door where shoes will be removed on a grate, where the dirt will fall below and be swept or vacuumed out. This reduces the amount of cleaning required in the house as well as improves air quality. Having an airlock also reduces the effect a door has on a building's heat envelope.

Conclusion

We have designed our house with a consciousness to several aspects: atmosphere, longevity, energy, interface and equity. We wanted an atmosphere that was comfortable, peaceful and conducive to living. We believe we have achieved this by daylighting, and providing indirect diffuse lighting. We have created an open space that allows for easy access to all the rooms. Air quality is kept fresh with plants, filters and mitigation techniques.

The building will last untold years as long as it is maintained (which is why we will be creating a maintenance manual for residents). Made of materials that are built to last and once not needed can be recycled for further use, we have created a space that materially has much less impact than a traditional building.

Because most of our heating and cooling will come from passive methods (direct solar) or ones that use little energy (radiant-flooring) energy used for maintaining the building temperature will be kept to a minimum. The overall embodied energy of the building will be much lower than a traditional building due to the use of primarily recycled and waste materials. The materials we have chosen also have the benefit of being local, further reducing transportation energy costs.

Our building interfaces with the surrounding property and neighborhood as a residence in Portland should. A garage was not necessary because the neighborhood provides all needed living services within less than a mile as well as close access to public transportation. An open backyard (we have suggested removing the fences) and an ample front porch allows us to better integrate with our neighbors, if they so choose.

In effort to reference economic inequalities we have attempted to use technologies that are affordable whenever possible, technologies that are do-it-yourself as opposed to manufactured and professionally installed. However oftentimes code restrains us from this endeavor. For example, the composting toilet is required to be certified to use, however the manufacturer of the toilet we've chosen readily admits that plans are available to make one's own (and they offer them freely to those residing in economically disadvantaged countries, where coincidentally building codes are less restrictive). Rammed earth and straw bale see less exposure due to the restrictions of building codes as well; regulating bodies do not deal well with things "out of the ordinary." We have however managed to make heating and cooling solutions that are easily implemented by anyone with the time and ingenuity.

All in all our building, while not quite meeting the standards of The Living Building Challenge (although nearly) does push the envelope of sustainable design and will provide a comfortable environment for all who live there.

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