The I-gro house: the use of bamboo in a prototypical single-family house

Nathan Ryan Metz
Iowa State University

Follow this and additional works at: https://lib.dr.iastate.edu/rtd

Recommended Citation
https://lib.dr.iastate.edu/rtd/19505

This Thesis is brought to you for free and open access by the Iowa State University Capstones, Theses and Dissertations at Iowa State University Digital Repository. It has been accepted for inclusion in Retrospective Theses and Dissertations by an authorized administrator of Iowa State University Digital Repository. For more information, please contact digirep@iastate.edu.
The I-gro house: the use of bamboo in a prototypical single-family house

by

Nathan Ryan Metz

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of
MASTER OF ARCHITECTURE

Major: Architecture

Program of Study Committee:
David A. Block (Major Professor)
Matthew W. Fisher
Michael Martin

Iowa State University
Ames, IA
2003

Copyright © Nathan Ryan Metz, 2003. All rights reserved.
Graduate College
Iowa State University

This is to certify that the master's thesis of

Nathan Ryan Metz

has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy
### TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>THESIS INTENT</td>
<td>3</td>
</tr>
<tr>
<td>BACKGROUND INFORMATION</td>
<td>5</td>
</tr>
<tr>
<td>MATERIAL ANALYSIS</td>
<td>11</td>
</tr>
<tr>
<td>HOUSE DESIGN</td>
<td>29</td>
</tr>
<tr>
<td>EXPLANATION OF THE DESIGN</td>
<td>46</td>
</tr>
<tr>
<td>COMPUTER ANALYSIS OF ENERGY COSTS</td>
<td>59</td>
</tr>
<tr>
<td>CONCLUSION</td>
<td>61</td>
</tr>
<tr>
<td>NOTES</td>
<td>63</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>66</td>
</tr>
</tbody>
</table>
INTRODUCTION

Currently, the world has 6,298,187,677 human inhabitants.¹ The United States makes up only 4.5% of that number and yet is accountable for 25% of total world energy consumption and 25% of total world carbon emissions.² The United States is the world’s largest single source of anthropogenic greenhouse gas emissions. Residential housing generates a large portion of the total energy ticket for the United States both in the areas of energy consumption and carbon emissions with 21% and 19.4% respectively.³ Energy-efficient homes are few in number compared to the overall makeup of houses in the US today. If we could provide more energy-efficient homes, it would have a significant impact on energy and resource consumption. We do not need cutting edge technology to accomplish this feat. An energy-conserving passive approach can be designed for any climate that may, in most cases, outlast a traditional house built today by many years. Consequently, owners will spend less on heating, cooling, utility, and maintenance expenses. The environmental benefits include less fossil fuel usage, conserving resources, and lowering pollution.

By the year 2050, the US Census Bureau projects that the population of the world will reach 9.3 billion persons. The question that often arises is will we be able to sustain a population of that size and if so, how? Many experts already think that we have, at this time, more inhabitants than what we can sustain. The pollution and resource consumption is a major problem today and will be even greater in the future when our population increases by more than half again as much as today’s
total. We are going to have to figure out ways to cut pollution and to conserve energy, if not, we could suffer dire consequences.

Sustainability and Green Architecture implies the following: To build that which we deem necessary and appropriate in order to sustain a meaningful lifestyle for the present and in the future. To replace, if possible, that which we take, and to preserve the circumstance within which that replacement could take place. To minimize, if not eliminate, the degradation to the environment caused by the taking of the needed resources, the processing of those resources, the transportation of those resources, and the placement of those resources.\(^4\)

What I propose as a solution to this problem is to build more homes that are less harmful to the environment through their construction and that conserve energy in their daily usage. This is only one solution out of many, but if it were applied it would have a significant impact on pollution and energy consumption. My goal is to design a house that is low in environmental pollution and has a high ability to conserve energy.

I am going to design a home for a typical four-member family, which is located 3 miles northeast of Ames, Iowa, in the Country Estates housing development. The makeup of the house is going to be passive solar, using as many green (or as close to green) materials as possible. I anticipate that some materials that I believe to be green may in fact not be so green upon further research and may in fact use some materials that are not very green at all (in limited supply) because of the benefits that we may reap from their application. This is where I began in my research and I may discover in the conclusion of my project that some of my ideas are inappropriate or need to be reconsidered.
THESIS INTENT

This thesis started out to be a research and analysis of materials that are used in the construction of a house and that have more environmental benefits than a standard house in America. This thesis has since shifted from that original concept to developing a new construction scheme that would benefit the environment if implemented throughout. The basic premise is that we need to discover new ways to build houses. We need to find ways for homes to conserve energy and resources much more than they currently do. We need to lessen our dependence on fossil fuels and benefit from the solar energy we receive each day. Each material we use has an energy and ecological cost that we need to consider.

I propose to accomplish this with a house that uses materials wisely, collects solar radiation, and makes use of a new construction scheme. I will present material analysis for the components of the house and then compare and contrast the advantages and disadvantages. This house will incorporate bamboo as the main structural element, materials that benefit the environment, and materials that are essential in the collecting and storing of energy.

By incorporating bamboo as a major building element and using solar radiation to our advantage, we will conserve energy and resources. Bamboo can be grown much faster than wood and will re-grow from the same stalk after harvesting whereas wood will not. I believe bamboo can be very attractive as a finish material when the elements are left exposed within a building.

The design of the house will be presented graphically, including plans, details, and perspectives. An explanation of the design will follow including why certain
methods were used and why others were not. This solution is only one of many approaches to the creation of an energy and resource efficient house.

Local resources should be used whenever practical. The longer the distance a material has to be transported, the more energy intensive that material becomes. The availability of materials and labor force can be a positive impact, or a limiting one.

The I-gro house is a prototypical house in the sense that the bamboo structure will serve as a new basis; one that can be modeled after to create new designs using a green material. This house will serve as an appropriate example to showcase the intent of this thesis. This design is specific for the clients and their needs. I believe that no two houses should be identical; each house needs to have its own unique character.
BACKGROUND INFORMATION

DESIGN & LAND USE

When thinking about sustainability in the design phase, it is important to consider the following precepts: 1) *Smaller is better.* Optimize the use of interior spaces in a building so that the size and resource use in constructing and operating it are kept to a minimum. 2) *Design an energy-efficient building.* Use high-performance windows, super-insulation, and tight construction. 3) *Design buildings to use renewable energy.* Passive solar heating, daylighting, and natural cooling can be incorporated into most buildings in a cost-effective manner. 4) *Design for durability.* The longer a structure lasts, the more sustainable it is. To be durable is to be sustainable, spread the environmental impacts of building over as long a period as possible. 5) *Value site resources.* Carry out a careful site analysis: solar access, vegetation, water resources, natural areas, etc. and let this information guide the design. Try to take advantage of existing trees and other vegetation to shade the house. Deciduous trees are very effective because in the summer they provide shade and in the winter they lose their leaves and allow light to reach the house. *Environmental Building News* recommends using “Trellises with vines or tall annuals are effective at providing shade on the east and west sides of a house. Vegetation around a house can also serve to cool the exterior through evapotranspiration. (Keeping the air around the house cooler will reduce conductive gains.)"
NATURAL DAYLIGHTING & SOLAR ENERGY

The sun provides light and heat. This heat may be welcome in the winter, but not in the summer. In planning window and skylight locations, solar-heat gain is as great a consideration as admitting daylight. The rising sun is low, and east-facing windows receive direct light. Max Jacobson of Fine Homebuilding reports: “If you are an early riser, exposure to this eastern light enhances morning activities — waking up, eating breakfast, bathing — as the body responds to daylight by becoming more alert”. Daylighting can help to improve our well-being. Most of us spend ninety percent of our time indoors and natural daylight provides a much better atmosphere than artificial light. This also reduces electricity demand and utility expenses. Reduced electricity demand translates to less depletion of natural resources.

Daylighting and Solar Energy go hand in hand. As the sun fills the space with light, it is also warming the temperature of the space without using energy. The sun’s energy can be stored in a thermal mass within the structure and released once the sun is no longer able to produce energy.

Environmental Building News provided a checklist for a general daylighting scheme: 1) Provide a daylighting scheme that works under the range of sky conditions expected at that location. Daylighting can be optimized for an array of sky conditions; from overcast to cloudy to clear skies, daylighting can be used to provide light to a space. 2) Orient the building on an east-west axis. The best facade for daylighting is the south wall, and the second best is the north wall. By orienting the building in this manner, you are able to receive more daylight and keep out unwanted heat. 3) Provide perimeter daylight zones. The perimeter daylight zone usually extends into a room a distance of 1.5 times the height of a window (from the
By modifying the building geometry, the daylight perimeter zone can be increased. 4) Extend windows high on perimeter walls. The higher perimeter windows extend, the further into the interior the perimeter daylighting zone will extend. 5) Provide light shelves on south-facing windows. Light shelves help to extend light into the interior of a building. 6) Minimize direct-beam sunlight penetration into workspaces. 7) Brighten interior surfaces to help bounce and scatter daylight throughout the space. 8) Organize electric lighting to complement daylight and provide daylight controls on electric lighting. Electric lights should be placed accordingly and sensors should be used to turn off electric lights so that electricity is not wasted when there is sufficient daylight. 9) Use roof apertures and skylights. These will further enhance the effects of daylighting.

**RESOURCE EFFICIENT MATERIALS**

The energy content of a material or its "embodied energy" is an indicator of how close that material is related to the earth. Heavily processed or manufactured products and materials are usually more energy intensive. We should be selecting materials to use that have a low-embodied energy content as long as durability and performance will not be sacrificed. One must take into account the life span and long-term benefits of using any one particular material. A material might take a high energy level to be produced yet save many times its embodied energy value over its life span. Weighing out the positives and negatives may suggest selecting a material with a higher embodied energy due to its savings in application.

Consideration is rarely given to the environmental impact of using these materials, such as what environmental "costs" go into extraction, production,
shipping, and installation. These costs include depletion of nonrenewable raw materials and resources; production of waste by-products; and exposure of toxicity to the air, water, soils, and inhabitants of nearby areas.

For the building industry of the future, it will be good business to use materials that are environmentally friendly, sustainable, and renewable and that contain recycled materials. A building industry that depends upon depletable resources to manufacture its materials will become more and more costly as the resources become scarce. More important, the world in which we build will become more and more uninhabitable because of the toxins and waste left by our present materials and methods of construction. To do its part in keeping the world safe to live in, the architecture profession must incorporate procedures and standards of resource conservation into our design philosophies.\textsuperscript{10}

Manufacturing is very energy-intensive; a product that lasts longer or requires less maintenance usually saves energy, and so we should use durable products and materials. Durable products also contribute less to the solid waste problem. Where possible, we should select building materials that require little maintenance (painting, retreatment, waterproofing, etc.), or for which maintenance will have minimal environmental impact.

**ENERGY & RESOURCE CONSERVATION**

Another main aspect of sustainability is conserving energy and resources. There are many ways to conserve energy and resources such as recycling, using solar energy, and buying locally to name a few. Building products made from recycled material cut energy consumption in manufacturing, reduce solid waste, and
save on the depletion of natural resources. Similarly, we can reduce the amount of waste going to landfills and save natural resources by using salvaged materials.

When dealing with wood, it is wise to use lumber from independently certified well-managed forests so that you know that the wood you are using is harvested sustainably. Engineered wood can be substituted in many cases and is usually stronger than a normal board. Pressure-treated lumber should almost never be used. It is harmful to humans and the environment. There is no safe way to dispose of pressure-treated lumber after it is no longer useful.

Avoid materials that will offgas pollutants. Environmental Building News found that “Solvent-based finishes, adhesives, carpeting, particleboard, and many other building products release formaldehyde and volatile organic compounds (VOCs) into the air: These chemicals can affect workers’ and occupants’ health as well as contribute to smog and ground-level ozone pollution outside.” Avoid ozone-depleting chemicals in mechanical equipment and insulation. Chlorofluorocarbons (CFCs) have been phased out, but their primary replacement – Hydrochlorofluorocarbons (HCFCs) – also damage the ozone layer and should be avoided where possible.

Efficient equipment is an excellent way to reduce the energy load that a building requires. Well-designed high-efficiency furnaces, boilers, and air conditioners not only save money by using less energy, but also produce less waste energy in the form of heat. Water-conserving toilets, showerheads, and faucet aerators reduce water use as well as the demand on septic systems. Reducing hot water use also saves energy. High-efficiency lights and appliances use less energy,
which saves money and creates a lesser impact upon the environment. Often times the local energy supplier will offer rebates for using high-efficiency appliances.

LOCAL RESOURCES

Buy locally produced building materials. The farther distance a material has to be transported, the more energy it is going to use and the more pollution it is going to generate. Look for locally produced materials. Using local craftsmanship and resources is consistent with a low-energy approach. Shorter shipping distance and less travel for workers reduces costs of building.
MATERIAL ANALYSIS

What makes a product green? The challenge is defining what is green. If a designer could see the entire life-cycle of a product and all of its environmental impacts all at once and compare that to other products, then they could see which is better from an environmental standpoint. Designers, however, do not have that luxury. Although there are several efforts that attempt to do this such as the AIA’s Environmental Resource Guide and Green Building Materials by Meadows and Spiegel, we are nowhere close to realizing that goal. An article in Environmental Building News states: “We are trying to weigh the resource-extraction impacts of one product with the manufacturing impacts of another, and the indoor-air-quality impacts of a third.” It is like comparing apples to oranges. Even the most green building will more than likely use products and materials that are not themselves green, but they are used in such a way that reduces the overall environmental impacts of the building. Environmental Building News goes on to say: “Creating a green building means matching the products and materials to the specific design and site to minimize the overall environmental impact.”

This section analyzes materials and presents advantages and disadvantages of the materials and their use. The advantages and disadvantages are based upon the energy content or embodied energy of the material, recyclability of the material, and the performance of the material in its application. The materials analyzed in this section include:
BAMBOO

Bamboo is one of the most widely used plants in the world. In botanical terms, bamboo belongs to the grass category and thus forms its stem in the same way as rhizomes or root-stock growth types. The largest of the grasses, there are over 1600 species of bamboo. Bamboo grows in the form of a long, round, hollow, woody tube with a hard outer skin and with reinforcing nodes spaced along its length (see Figure 27). Because of its hollow form, circular cross section, hard outer coating, and internal cavities bamboo is extremely lightweight and strong compared to the same cross section of wood. Where wood is harder in the center, and softer on the outside, bamboo is hollow in the center and gets harder toward the outside, resulting in a much more efficient structure with denser fibers where there is more stress.

Bamboo is a prime example of sustainability – with respect to both the plant itself and its use as a building material. One thing that makes bamboo a sustainable material is its extremely fast growth rate. "The typical cane length of 2-5 meters is usually achieved in 2-3 months, in tropical regions 20-30 meters or more are common." This fast growth rate means that bamboo can be harvested every 3-5 years compared to 10-20 years for most softwoods. In stating why bamboo has appeal, Colombian architect Simon Velez says: "For one, the ecological advantages:
Bamboo can replace many tropical woods and thus help protect the rainforest. Also, bamboo converts more carbon dioxide than most other plants. In addition, bamboo is very cost-effective and easy to work with. Velez is the most renowned architect using bamboo today. Growing and harvesting bamboo rather than wood can increase timber production per acre, helping to cope with the ever-increasing demand and relieving pressure on our limited forest resources. To give an idea of how sustainable bamboo is, table 1 below compares the energy required to produce a unit of a building material (units are in MJ/m³ per N/mm²).

Table 1: Energy Comparison

<table>
<thead>
<tr>
<th>Material</th>
<th>Energy (MJ/m³ per N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>240</td>
</tr>
<tr>
<td>Steel</td>
<td>1,500</td>
</tr>
<tr>
<td>Wood</td>
<td>80</td>
</tr>
<tr>
<td>Bamboo</td>
<td>30</td>
</tr>
</tbody>
</table>

Bamboo is suitable to a wide range of climates; tropical, sub-tropical, temperate, and there are even some frost-hardy varieties. This makes bamboo a viable crop everywhere in the world except in desert climates. Velez comments on the versatility of bamboo to be grown in different regions: “In southern Europe, certain types of bamboo are flourishing and in northern regions the species that were introduced largely from China are surviving the colder winters.” Its fast growth and tolerance of poor soil also makes bamboo an excellent re-greener for low quality land. Unlike timber, after felling, bamboo canes grow again rapidly because they are serviced by an underground root system. James Leach reports: “Harvesting removes only 30% of culms from the plant, leaving the plant alive, root-structure
intact, and with topsoil in place."¹⁹ In point of fact, processing bamboo produces virtually no waste, since it has no bark to be stripped and the leaves can be used as fodder. A further advantage is that environmentally damaging transport is unnecessary since bamboo can be grown in almost any climate. Also, buildings made of bamboo can be easily dismantled or recycled and it is easy to replace individual components.

Figure 1: Interior of Galeria Quinta in Bogota (Simon Velez, Grow Your Own House (Vitra Design Museum, 2000) 70.)

Bamboo is unique in that it is strong in both tension and compression. While tensile strength remains the same throughout the age of the bamboo plant, compressive strength increases as the plant gets older. Also, bamboo has a slick, waterproof coating. William Porterfield states: “No man-made finish is as soft, yet
simultaneously as hard. The reason for this is the wax and silicon secreted by the epidermis. The waxed surface is the basis of the finish, whilst the silicon hardens."  

Bamboo's unique natural form does result in some problems. It is a much less uniform product than wood. Unlike wood, in its natural state bamboo does not lend itself to a variety of forms. It cannot be milled into dimensional lumber with uniform sizes but must be used as harvested. The only exception is square bamboo (see Figure 3), which is produced by placing a square cover over the bamboo sprout into which the cane grows. The cane will take on a square geometry and will provide larger contact areas for joint connections. The performance and properties of any given bamboo tube are determined by its age, locale, size, section and descent. There is also great variation within a bamboo pole. Each pole is stronger and thicker at the bottom, becoming thinner and more flexible approaching the top, with inconsistent wall thickness and node spacing throughout. Tubes with a smaller
cross-section are proportionally more effective at compression and tension due to a higher ratio of strong outer wall. Bamboo is also highly susceptible to destruction by wood-eating insects, fungi, and fire. Velez responds, “There is an abundance of knowledge on how to treat bamboo against weather and pests. The best protection, however, is a good design.”

Table 2: Bamboo

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightweight &amp; high strength/weight ratio</td>
<td>Susceptible to insects and fungi</td>
</tr>
<tr>
<td>Saves trees for other use</td>
<td>Not a local product</td>
</tr>
<tr>
<td>Very little processing needed</td>
<td>Short life span</td>
</tr>
<tr>
<td>Due to its light-weight, transport and</td>
<td>Susceptible to failure in a fire</td>
</tr>
<tr>
<td>storage cost is very low</td>
<td>Non-uniform</td>
</tr>
<tr>
<td>Fast re-growth rate</td>
<td></td>
</tr>
<tr>
<td>Strength against earthquakes</td>
<td></td>
</tr>
</tbody>
</table>
CONCRETE

Concrete is being used in nearly every aspect of construction. Is it even feasible or possible to design a building without using concrete in some way? There is no other material that can compare or match the benefits and applications which concrete provides. However, concrete is a major polluter. Actually, the binding agent, Portland Cement, is the major polluter through its production. It makes up only 11% of the concrete and yet is responsible for 94% of the total embodied energy during concrete manufacturing. Ready-mix concrete has an embodied energy ranging from 1,137,713 to 2,594,338 Btu/cu yd.

We need to be more efficient in our concrete usage and develop strategies to reduce the amount of energy needed to produce it. We could do a better job of recycling concrete; right now the United States recycles less than 5% of concrete waste. Concrete can be recycled into roadbed fill or coarse aggregates to be used back in new concrete or as clean fill around buildings. Fly ash can be used in place of Portland cement by as much as 30%. This alone would be beneficial to the environment. Fly ash is a fine powder that is a waste product from coal-fired power plants and is available at virtually no cost. Fly ash increases concrete strength, reduces mixing water, and improves pumpability and workability of concrete. We also should not waste concrete. We should accurately measure the amount of concrete needed and have designated uses for surplus waste such as wall block, highway dividers, or retaining walls onsite. Also, finding ways to reduce slab thickness will save concrete. In some applications, a 3.5 to 3-inch slab may replace a 4-inch slab – reducing the amount of concrete used by 12.5% - 25%.
Table 3: Concrete

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longevity</td>
<td>Embodied energy</td>
</tr>
<tr>
<td>Strength - structural</td>
<td>Lack of recycling (solid waste)</td>
</tr>
<tr>
<td>Fire resistant</td>
<td>Pollution during processing</td>
</tr>
<tr>
<td>Durability</td>
<td>Heavy</td>
</tr>
<tr>
<td>Heat storage</td>
<td></td>
</tr>
<tr>
<td>Shapeability</td>
<td></td>
</tr>
</tbody>
</table>

Suggestions:

- **Autoclaved cellular concrete (ACC)**
  - uses fly ash, a by-product of coal combustion
  - aluminum powder additive reacts with lime to create hydrogen bubbles and a lightweight, cellular cementitious material (provides high strength to weight ratio); also self-insulating (R-10 for 8 in. wall)

- The durability of concrete gives it significant advantages in terms of resource and energy conservation. Longer service life – through superior fire and wind resistance, for example – means that fewer resources are lost in demolition and rebuilding.
- Although concrete can be painted or clad with another material, it can also achieve many finishes, textures, and colors on its own. When structural elements also serve as the architectural finish, buildings increase in efficiency of resources, construction, and maintenance.
- In terms of cost and service, the low maintenance of concrete reduces waste, energy, and resource requirements. i.e. No need for periodic coatings or chemical treatments.
- The thermal mass of concrete saves energy over the lifetime of a building. Not only is concrete the material of choice for passive solar designs, but its inherent thermal mass moderates temperature swings, reducing the energy load.

**Typical Concrete**

<table>
<thead>
<tr>
<th>Mix:</th>
<th>(Component)</th>
<th>(% By Weight)</th>
<th>(Energy %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland Cement</td>
<td>12</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>34</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>Crushed Stone</td>
<td>48</td>
<td>5.6</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>6</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
GLASS WINDOWS

Windows are an essential element in our buildings today. They give us light, views, and energy. Windows are extremely durable and can last a long time. Window placement has the highest risk to building comfort, but also the highest reward potential when located correctly. Glass consists of the primary raw materials silica sand, soda ash, and limestone, which are all in abundant supply in the world and can be extracted with minimal environmental impact.

Daylighting can have considerable positive impacts on energy consumption. This reduces the need to run electrical systems and waste the sun’s natural ability to provide light. The use of glass in passive solar techniques will gain energy from the sun and also save energy by not having to mechanically heat the space within.

The main environmental factor in glass production is the large amount of energy needed to achieve the high temperatures required for processing the raw materials; the approximate embodied energy for glass is between 13.5 and 15 million Btus per ton. Raw materials are carefully weighed and mixed, then dumped into the glass tank furnace. The furnace is made out of high-temperature silicon refractory bricks and holds about 500 tons of molten glass. A glass furnace is operated continuously, at a temperature of about 2,900°F (1,600°C) from the time it is first turned on until it is disassembled-typically after about 10 years. Most of the emissions related to glass production come from energy production, though the melting process also releases SO2 and fluoride. The most important fuels for glass melting furnaces are natural gas, light and heavy fuel oil, and liquefied petroleum gas. Electricity is often installed as supplementary heating. Compared to the
potential impact the use of glazing products has on building energy use, environmental impacts from glazing manufacture are minor.

Other factors that contribute to the energy bill for glass include: Fuel combustion emissions from energy use during mining and manufacturing that are put into the atmosphere, runoff from mining operations and tailings piles, and alkaline runoff from soda ash mining. Most raw materials used in glass are in plentiful supply however; fossil fuels used for manufacturing are limited resources.

Glass has a very long expected lifetime; glazing seals, frames, and sealants are usually the weak links. Frequent low-impact cleaning is required; glazing (sealant) may need repair or replacement often. Glass has a one hundred percent recycling capability. Waste cullet within a float glass manufacturing plant is typically recycled back into the melt. Certain types of glass can be recycled into an additive to asphalt or concrete, glass filler for street curbs, ceramic floor tiles, clean fill under pavement and around buildings. Various non-building uses are glass aquarium gravel, and as inert soil fill in landfills. Processes that use recycled glass beverage containers generally cannot use recycled flat glass because of differences in composition and melting properties. Flat glass from windows can contaminate beverage glass and make it less marketable. Glass windows can even be removed from their original location, cleaned and repaired, refilled with argon gas, and resealed. Argon gas replaces the air inside the glass unit. Since it is heavier than air and is not in continuous motion like air, the transference of heat and cold (convection) is greatly reduced. In essence, the Argon gas provides extra insulation. The windows can then be reinstalled in the same location without losing any value.
The vast majority of all glazing material produced in the United States is glass, an inert and relatively benign material environmentally. While considerable energy goes into glass production, on a per-square-foot basis glass has considerably lower embodied energy than other glazing materials. Glass is the only material that we can use that will gain us energy. All other materials are energy losers – some lose energy at lower rates, but glass is the only material that will give us a net gain in energy by collecting solar radiation. Glass provides us with such benefits that we can justify the harm it does to the environment through its production.

Table 4: Glass Windows

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durable</td>
<td>Energy used in production</td>
</tr>
<tr>
<td>Long lasting</td>
<td>Fragility</td>
</tr>
<tr>
<td>Recycleability</td>
<td></td>
</tr>
<tr>
<td>Energy savings</td>
<td></td>
</tr>
</tbody>
</table>

Suggestions:  
- Recycled content windows  
- High efficient, low E glass windows  
- Argon-filled insulated glass windows

- Improvements in energy efficiency in glass-making indicate that energy savings of approximately 30 percent are possible through current available technology.
- Advanced technologies under development could result in energy savings of up to 65 percent.27
ICYNENE FOAM INSULATION

Alex Wilson of *Environmental Building News* states: "Ozone depletion and global warming are two of our most serious environmental problems." The problem with many foam insulations is the blowing agent needed to propel the foam (CFCs or HCFCs), both have a negative impact on the atmosphere (HCFCs are similar to CFCs except they have a less damaging effect in the stratosphere). However, a relatively new foam insulation, Icynene, results from the controlled reaction of polyisocyanate, resin polymers, and fillers in the presence of various catalysts and eliminates the need for CFCs or HCFCs as a blowing agent. It uses water to propel the solution. The presence of water in the polymer solution reacts with the isocyanate to form carbon dioxide. This reaction forms millions of tiny open cells that contain only air. Icynene is 90% air and 10% material.

Icynene insulation is a low-density, semi-flexible, open cellular, plastic thermal insulation. It is modified polyurethane that is typically sprayed into open cavities. Icynene seals wall, floor and ceiling cavities against air movement, including spaces around electrical outlets and light fixtures, and at baseboards where walls meet windows and doors. Instillation requires spraying a thin layer into the cavity to be filled and the Icynene will expand (100-fold) to fill the cavity. Excess is cut off so you have a flat surface.
ENGINEERED LUMBER

Engineered lumber uses wood resources very efficiently. "Junk" wood such as Aspen or Birch can be used or even leftover scraps from other wood products may be used, as they are chipped up, glued together, and pressed to form the desired shape. Glulams, particleboards, plywood, oriented strandboard, and I-beams are some of the products made from engineered lumber.

Engineered I-joists have a high strength to weight ratio. The cross section of the joist is formed like the capital letter "I". The "I" shape puts the wood fiber where the higher stresses are, namely near the outer portions of the cross section. The vertical web of the "I" is usually plywood or OSB. The flanges are usually made of laminated veneer lumber. I-joists provide structural support for floors and roofs using 16% less wood fiber by volume compared to a standard 2" x 12" joist. An I-joist can carry a larger load, thus enabling them to be spaced further apart. If the decking material can span further this system can be even more efficient.

<table>
<thead>
<tr>
<th>Table 5: Engineered Lumber</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
</tr>
<tr>
<td>Efficient use of wood</td>
</tr>
<tr>
<td>Lightweight</td>
</tr>
<tr>
<td>High strength to weight ratio</td>
</tr>
<tr>
<td>Span longer distances</td>
</tr>
</tbody>
</table>
SELF-DIMMING LIGHTS & OCCUPANCY SENSORS

The best kind of lighting is the kind that does not use any energy at all. Common-sense building design can increase the amount of sunlight that comes into a workspace or home. This design concept is called “daylighting”. Because daylighting offers such huge energy reductions without significantly increasing the overall cost of construction, it is often considered the cornerstone to resource efficient or green building design.

Lighting can account for over 40 percent of a building's electrical load. Not only do the lights themselves use energy, but lights also increase the air conditioning load by themselves producing heat from operation. Dimming controls can reduce the output and energy consumption of light fixtures when available daylight provides supplemental light to the task. Photosensor controls match the combined available natural daylight and lighting system output to needed lighting levels.

Self-dimming lights with occupancy sensors would add tremendous savings to energy consumption. Light-sensitive switching devices, called photocells, are used to turn lights on and off or dim lights in response to sufficient levels of daylight. Daylight dimming systems include photosensors wired directly to dimmable electronic ballasts. Some manufacturers provide a photosensor control for each ballast, while others provide controls that operate a number of different ballasts.

Occupancy sensors automatically turn the lights on when someone enters a room and off when spaces are unoccupied. Savings estimates of 20 to 40 percent are often experienced, and even greater savings are possible for spaces used for only a limited time. The two most common motion-sensing devices use infrared and ultrasonic technologies. Infrared sensors require an unobstructed view of motion.
and decrease in sensitivity as the distance between the sensor and the moving person increases. Ultrasonic motion sensors are more responsive to movement toward or away from the sensor and decrease in sensitivity as the distance between the sensor and the moving person increases. Outdoor open spaces are not an ideal spot for these types of sensors because vibrations and strong air currents falsely trigger them.

The self-dimming lights will save energy by lowering or even shutting off the lighting when natural daylight is present. At the same time, the occupancy sensors will cut energy usage by automatically turning the lights off when no one is present in a space. Both of these features help to eliminate the need for us to remember to turn off the lights when there is no need for them to be on.

Compared to on-off controls, dimming controls generally increase energy savings, better align lighting with human needs, and extend lamp life. Such systems can also be used to dim lights for other reasons, such as for presentations. Dimming fixtures by as much as 50 percent may be barely noticeable to building occupants, unless they are involved in tasks requiring visual acuity.

**Applications:** Dimming controls to compensate for daylighting are appropriate for virtually any type of facility where the lights operate much of the time and where a significant quantity of daylight is provided with windows and skylights.
CLAY TILE ROOFING

Clay tiles are a natural and sustainable form of roofing which has the benefits of inherent strength, durability, and a rich color that never fades. The lifespan of clay tiles is 50 years while that of asphalt/fiberglass shingles is only 15-25 years. Clay is an abundant resource of a naturally occurring sustainable primary raw material. The Roof Tile Institute comments on clay: “When used in the production of roof tiles it enhances the built environment by equipping buildings with a durable and aesthetically pleasing product, possessing a proven record of performance and durability.” A recent estimate of the total embodied energy for ceramic tile is 25,161 Btus/sq. ft. The energy required for firing tile is estimated to be 18,500 Btus/sq.ft.

While clay may weigh more than other conventional roofing materials, it has the benefit of not having to be replaced as often. This translates to less waste going to landfill, less material being produced to replace the roof, less energy used to provide more materials, and less labor. Also, once clay is fired, it is an inert material. It will not offgas pollutants.

Today, clay tiles are made to precise measurements which make them easier to lay and can be used with current adhering systems for greater security on a roof. Clay also is important in the production of custom tiles for historic buildings where it is necessary to match the originals.
Table 6: Clay Tile

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durable</td>
<td>Energy used in production</td>
</tr>
<tr>
<td>Long lasting</td>
<td>Weight</td>
</tr>
</tbody>
</table>

- From 70 to 90 percent of tile manufacturers recycle fired scrap, and most manufacturers reclaim any waste dust that is produced, thus deriving full benefit from raw material.
- The durability of ceramic tile means replacement materials will not need to be produced, thus averting depletion.
- Clay and sand, the primary components of ceramic tile, are in abundant supply.
- Energy requirements for firing ceramic tile have decreased in recent years because of improvements in materials and the firing process. 34
STONE TILE

Stone is a great example of a sustainable material. It is a local product in most areas and does not require extensive transportation. Natural stone flooring is a positive option because it is aesthetically pleasing and holds heat well. Major potential environmental stressors associated with quarrying stone are the removal of overburden soil and subsequent restoration of quarry sites and the disposal of waste stone generated by quarrying activities. These stressors result in habitat alteration, soil runoff and erosion, and loss of biodiversity.

In solar design, stone flooring tiles can be used as part of the thermal mass required to store heat. Laying the stone on top of a slab of concrete results in not only an increased functional mass, but also a well designed, aesthetically pleasing feature in the floor. The potential to create patterns with the tile has no limit.

Table 7: Stone Tile

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durable</td>
<td>Energy used in manufacturing</td>
</tr>
<tr>
<td>Long lasting</td>
<td>Environmental stressors</td>
</tr>
<tr>
<td>Aesthetically pleasing</td>
<td></td>
</tr>
<tr>
<td>Stores heat</td>
<td></td>
</tr>
</tbody>
</table>
HOUSE DESIGN

THE “I-gro” HOUSE

The houses we build today need to play a major role in conserving energy and resources. We depend far too greatly on fossil fuels and do not take full advantage of the “solar income” we receive. The design process should account for the energy costs and ecological costs associated with the materials and methods we use. Embodied energy must be acknowledged and an overall low-energy concept should prevail.

The “I-gro” house is an example of a house that attempts to use these ideas in the construction process. This house is passive solar and features a new-to-the-region structural scheme which is centered around bamboo. The idea is that if we start growing and harvesting bamboo at a local level, we would take out virtually the only unsustainable factor of using bamboo in this region: transportation. You could literally grow your own house in your backyard in only a few years.

The design of the “I-gro” house is represented by the following graphics (Figures 4-25).
Figure 4: Site Location
Figure 5: Main Level Floor Plan (Scale: 1/16" = 1'-0")
Figure 6: Upper Level Floor Plan (Scale: 1/16" = 1'-0"
Figure 7: Lower Level Floor Plan (Scale: 1/16" = 1'-0")
Figure 8: Truss Framing Plan (Scale: 1/16" = 1'-0")
Figure 9: House Section (Scale: 1/16" = 1'-0")

Figure 10: House Section (Scale: 1/16" = 1'-0")
Figure 11: Structural Cross Section & Detail
Figure 12: SW Perspective
Figure 13: Bamboo Connection

Figure 14: Bamboo Connection in Truss
Figure 18: Column Base with Bamboo
Figure 19: Column Cap Plate

Figure 20: Pins and Spacer Plate
Figure 21: Column Cap Plate with Bamboo
Figure 22: Truss Support Unit
Figure 23: Web Bracket Elevation

Figure 24: Web Bracket Aerial
Figure 25: Truss Support Unit and Web Brackets with Bamboo
EXPLANATION OF THE DESIGN

SITE

This house is located 3 miles northeast of Ames, IA in the Country Estates housing development (see Figure 4). The site in Figure 4 is lightened against the surrounding plots and the house location is marked with an “X”. The site slopes on three sides of the house and has a line of trees at the south end that follows the “valley” through the parcel of land. The site has excellent southern exposure to take advantage of the solar energy and also provides great views to the south, west, and north. In terms of sustainability, this site may not be the ideal place for a house to be located in that it is away from town and the necessities of life, and thus requires transportation via automobile. However, that was one of the things I learned through this project and this site will still serve as a vehicle for presenting the project.

BUILDING WITH BAMBOO

Much of the design in the I-gro house is centered around bamboo. The challenge was to come up with a structural scheme that would allow the bamboo to be used in this region. I wanted to express the structure of the house so that occupants could see the bamboo and how it was used in the design. In our country, it is very uncommon to find houses made out of bamboo, but in other countries such as Asia, Latin America, and Africa, it is used on a daily basis in houses, bridges, and many other applications. Velez says: “In many places, steel, concrete, and glass have replaced bamboo as a building material or given it the reputation of being the poor man’s wood. However, bamboo has liberated itself from this stigma as the
downsides of Western culture have emerged and people are increasingly turning toward regional, sustainable technologies. In this context, the advantages of bamboo are being rediscovered: its intrinsic structure anticipates the principle of many high-tech materials, it is excellent value for money, and it boasts an attractive appearance."\(^{35}\)

![Figure 26: Hall in Fusagasuga](image)

**Figure 26: Hall in Fusagasuga** (Simon Velez, *Grow Your Own House* (Vitra Design Museum, 2000) 71.)

In the form of bamboo canes, nature provides us with a material whose structure and qualities equal those of a high-tech material: It is sturdy, but thanks to its hollow interior, extremely light and elastic. It is stiff because of its dividing walls and has physical properties which in some cases are far superior to those of other building materials such as wood, concrete, or steel. While wood has a hard core,
and grows softer toward the outside, bamboo is hard on the outside and soft inside – a far more stable structure (see Figure 27).

**Figure 27: Bamboo Characteristics** (United Nations, *The Use of Bamboo and Reeds in Building Construction* (New York, 1972) 15.)

- a) The culm
- b) Vertical section of the culm
- c) Branches of a node
- d) Cross section of the culm

The strength of this plant is convincingly demonstrated by the incredible height of bamboo canes – which may exceed the height of ten-story buildings. The beauty of the stem, its rapid growth, and simple processing make bamboo a noteworthy material (see Table 8).
For building purposes, bamboo must be at least three years old, but is better at five years. Simon Velez uses the species of bamboo called *Guada augustifolia*. He lets the bamboo dry for two to three months, until 90 percent of the moisture has evaporated. Since the greatest disadvantage of bamboo lies in its susceptibility to damage by insects and fungus, numerous methods have been developed to protect bamboo. These methods include immersion, coating with lime slurry, heating, or smoking. According to the United Nations Department of Economic and Social Affairs in *The Use Of Bamboo And Reeds In Building Construction*, "The *Guada augustifolia* species of Peru, Colombia and Ecuador, is reported to have outstanding resistance to attack by insects and rot."  

Bamboo can be used in a similar way to dimensional lumber to create a structural frame. Special care must be taken to detail against wetting and pests, to accommodate for the irregularity of the material, and to deal appropriately with the
unique joining problems of bamboo. "Skeletal constructions made of bamboo can be filled with clay, or walls of bamboo matting can be simply plastered – both processes are readily encountered in low-cost housing projects in Latin America."38

Bamboo parquet, laminated bamboo lumber, and plywood or chipboard of bamboo are further examples of how it is possible to combine advanced technology with bamboo to produce high-quality semi-finished goods.

Velez concludes: "Building with bamboo requires experience and skill, and to date a large amount of time; this has obstructed its use in countries with high labor costs. I can imagine that in the near future, though, new bamboo constructions of a special quality will also appear in these countries. Whether or not superb architecture can be made from bamboo depends entirely on the brains behind the bamboo building process."39

Figure 29: The Luis Salazar House in Manizales (Simon Velez, Grow Your Own House (Vitra Design Museum, 2000) 71.)
Thanks to its flexibility and light weight, bamboo used as a building material can survive earth tremors undamaged, while buildings made of stone or concrete immediately threaten to crack or collapse.

### Table 8: Strength of Bamboo

<table>
<thead>
<tr>
<th>Assumptions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Type of bamboo: <em>Guadua Angustifolia</em></td>
</tr>
<tr>
<td>With cross-section fineness r/t of 3 ≤ r/t ≤ 5.5</td>
</tr>
<tr>
<td>• Testing hall without a/c</td>
</tr>
<tr>
<td>• 10-15% moisture content in the bamboo</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pressure tests:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance to pressure $f_{c,0}$</td>
</tr>
<tr>
<td>Resistance to pressure $E_{c,0}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4-Point bending tests:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean flectional resistance $f_m$</td>
</tr>
<tr>
<td>Mean flectional resistance $f_m$ given ideal drying and/or ideal moisture content</td>
</tr>
<tr>
<td>Mean flectional/elasticity module $E_m$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tensile strength tests:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean tensile/elasticity module</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Connection tests:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean tensile bearing load of connectors tested</td>
</tr>
</tbody>
</table>

THE HOUSE

The I-gro house is designed for a family of four and is centered upon the structure of bamboo. The main elements are the bamboo columns and the bamboo trusses. The columns are made up of six individual bamboo poles with a 4-inch diameter which are arranged together to form one column. Velez describes one such system: "Bamboo has great compressive strength. For high-load-bearing constructions, say, seven bamboo poles are used instead of one." Figure 8 shows the truss framing plan and how the columns are arranged throughout the house. The bamboo column is wrapped with rope at intervals down the length of it to keep the column members from bending outward.

The truss would be the perfect element to take advantage of the strength of bamboo. The trusses I designed for the house have a bundle of 3 bamboo canes that make up the top and bottom chords. Each of these canes is 5 inches in diameter and they are connected by single canes that make up the web of the truss with a 3 1/2 inch diameter. All of the joints in the truss or where members come together would be at the location of nodes. A series of tests performed on bamboo trusses at the Building Material Development Laboratory in Indonesia have provided structural recommendations. One is that the location of nodes at joints greatly increases the strength of the truss. The truss coming from the north would provide a clerestory and help to daylight the house (see Figures 9-10). Figure 11 shows the structural cross section and detail of a truss and how it might be framed.

The house is a collector of solar energy. It incorporates passive solar technology into the design. The house has three levels. The upper level is solely the master bedroom (see Figure 6) with its own bathroom and walkout porch. It is
located directly over the garage, which is 1/2 of a level below the main level so the upper level sits at 1/2 of a level above the main level. The bathroom suite is fairly open. A glass block wall provides translucency, yet a sense of privacy, while it partitions off the toilet.

The main level (see Figure 5) is comprised of the two other bedrooms, (which could be used as office space or some other designated space if another family moved in and had other needs) a bathroom, laundry facilities, kitchen, dining room, and fireplace. Walking directly in the main door and continuing south, one reaches a balcony within the house, which extends to the west wall of the house through the dining room. This balcony looks over and down upon the lower level (see Figure 10). Along the north wall of the main level, there would be slits in the floor or grates covering openings in the floor so that the air could flow in convective loops, transferring heat to the mass or to the rest of the house.

The lower level is intended to be one large open space with different functions in separate locations (see Figure 7). There are columns in the middle of the floor that hold up the main level while providing a defined boundary for the space. The lower level has a living space, fireplace, recreation space, 1/2 bath, and miscellaneous space that could be used for storage, etc. The lower level also serves as the collector of the solar energy in the floor. The floor would have stone tile on top of a 3.5-inch slab of concrete, which together would form the thermal mass necessary for storing heat. From the lower level, one would be able to exit onto the patio. This would be a place for social gatherings or to relax outdoors. It is bordered on the east and partially on the south by a stone wall and has an excellent view to the west. Figure 12 shows a perspective from the southwest.
This section deals with the connections used to join the bamboo members together. A whole host of methods exists for connecting bamboo canes. Many of them, in addition to their practical function, also have an intrinsic aesthetic value. The focus was on designing connections that could be easily manufactured and easy to install. The United Nations deducts: "A fastener that would be more permanent, simpler to install, and make for a more rigid joint is needed. Of course, such a fastener must be economical and easily manufactured." I designed five connections to be used in the house. These connections would be the major elements as well as the most common connections used. They are composed of stainless steel or concrete and have steel pins, bolts, etc. They are: Bamboo Connection, Column Base, Column Cap Plate with Spacer Plate and Pins, Truss...
Support Unit, and Web Bracket. Bamboo can withstand tensile pressure if connected by tensile joints. Simon Velez discovered this by filling the last chambers of the bamboo cane with concrete and setting metal elements into the concrete. The poles could thus be joined with these elements with the tension then distributed through to the chamber walls of the cane. This was the idea behind a few of the connections that I worked on such as the Column Base (Figures 15-17) and Web Bracket (Figures 23-24) and in the connection where the sunshade device is connected to the roof (this was not designed, but you can see in Figure 11 where this would occur).

The Bamboo Connection (see Figures 13-14) is used to connect the webs of a truss to the chords. It is designed to maximize the strength of the bamboo chord by connecting and transferring its load at the location of the node in the bamboo chord. Rather than weaken the member by drilling a hole between two nodes, I chose to create this connection to take full advantage of the strength of the node.

The Bamboo Connection would slip around an approximate 5-inch diameter bamboo pole, at the location of the node, and be fixed in place as it is tightened by the bolt that goes through the steel plates that are at the base of the connection. After the Bamboo Connections are secured in place, the web portions of the truss are attached. The web is made of bamboo poles, which are fastened to the Bamboo Connection by the rod that extends from the Bamboo Connection. The rod extends through the bamboo pole and the pole is kept in place by a pin at the end of the rod. The bamboo web members on one side of the Bamboo Connection angle one way and the members on the other side angle the opposite way, forming a “V” shape at the connection point, thus forming the truss.
Bamboo makes an excellent support, since it has an inherent stiffness owing to the natural subdivisions into individual segments. The Column Base (see Figures 15-18) is made of concrete and is used as the support for the bamboo column, which is made up of six bamboo poles with a diameter of four inches each. The Column Base is used where the column meets the floor. The base itself stands six inches tall and is slightly tapered from the bottom at 16” to the top at 13”. On top of that there are six cones onto which the bamboo poles would fit. The cones would slide into the end of the bamboo pole and be bolted through to secure them in place. The cones are tapered themselves from 4 3/8” at the bottom to 2” at the top to allow for ease of placing the bamboo upon them. The column base takes the load of the column and transfers it to the footings. Also, the Column Base keeps the ends of the bamboo poles elevated off of the ground as bamboo is susceptible to ground moisture and insects.

The Column Cap Plate (see Figures 19 & 21) is used for two purposes. First of all, the Column Cap Plate covers the top of the six-bamboo pole column and helps keep the poles in their vertical position. Also, the Column Cap Plate evenly distributes the load from above to each of the six members below. Secondly, the Column Cap Plate serves as a support for the bamboo truss above. The “U” bracket atop the Column Cap Plate supports the truss with the bottom chord of 5” diameter and keeps it in place. It is bolted on either side of the node through the “U” bracket.

The Spacer Plate (see Figure 20) fits inside of the Cap Plate and keeps the six bamboo poles spaced apart correctly and keeps them from bowing in on each other. The Spacer Plate has 2 rods, which extend partially through two of the bamboo poles and are then bolted from the exterior of the Cap Plate to secure it in
place. The Spacer Plate may be needed in more than one location along the column to prevent inward bowing of the bamboo poles.

The Truss Support Unit (see Figures 22 & 25) would be attached to the top chord of the bamboo truss supported by the “U” bracket. It attaches in the same manner as the Bamboo Connection in which the plate slips over the top chord of the bamboo truss and is secured in place by bolts through the bottom plates. The bottom section of the Truss Support Unit then allows the bottom chord of the roof truss to sit in the bracket. Then the top plate of the Truss Support Unit is affixed over the roof truss’ bottom chord and bolted at the ends into the bottom support and secured in place. The bottom chord of the roof truss consists of three 5” diameter bamboo members. Two of those are on the bottom and one is stacked above them in the middle.

The Web Bracket (see Figures 23-25) is used to connect the webs of the roof truss to the top and bottom chords. The “U” bracket attaches to the 5” diameter bamboo members of the top and bottom chords. The 3 1/2” diameter rods then extend from the “U” bracket and fit into the ends of the bamboo web members and are secured in place with bolts. The rods meet the “U” bracket in the center and it is at this location where the Web Bracket should be placed in line with the node from the bamboo chord. This will maximize the performance of the bamboo member. The “U” bracket is bolted on either side of the node.

These connections could all be formed or manufactured with relative ease. They try to maximize the strength of bamboo as well as provide a unique and interesting composition to look at. They help to showcase bamboo as a structural element and provide a provocative way in which to build with bamboo. As bamboo
becomes more and more popular, the connections will become a major element of the construction process and require a great deal of consideration. The opportunity to produce exciting and unique connection details will unfold. In Germany, a system of tops for bamboo canes has been developed, allowing standardized linkage. Iron bands or connecting elements of other materials such as wood or pressboard are also used to join bamboo canes, as are adhesive methods.
COMPUTER ANALYSIS OF ENERGY COSTS

With the assistance of an energy performance computer program courtesy of Architecture 351, Iowa State University professor David Block with copyrights to Laurent Hodges, I was able to predict the energy requirements for the I-gro house (see Table 9). With general information about the building, climate, and heating system the energy performance program estimates the total annual heating cost for an average heating season (October thru April). The utility costs are computed using the current prices of the particular fuel used to heat the house. The program also estimates the internal heat (cooking, bathing, body heat), useful solar heat, and auxiliary heat (mechanical systems) and the percentages that each of those provide to heat the house.

Table 9: Comparison of Total Annual Heating Costs

| Assumptions: | 83 cents per therm (100,000 Btu) = price of natural gas |
| Natural Gas Furnace – 96% efficient |
| 6874 Degree Days |
| 0.5 Air changes per hour |

<table>
<thead>
<tr>
<th>Typical Custom House</th>
<th>I-gro House</th>
</tr>
</thead>
<tbody>
<tr>
<td>13% (26.5 MBtu)</td>
<td>Internal Heat</td>
</tr>
<tr>
<td>5% (10.7 MBtu)</td>
<td>Useful Solar Heat</td>
</tr>
<tr>
<td>81% (161.0 MBtu)</td>
<td>Auxiliary Heat</td>
</tr>
<tr>
<td>(198.1 MBtu)</td>
<td>Total Heat Loss</td>
</tr>
<tr>
<td>$1,514</td>
<td>Total Annual Heating Cost</td>
</tr>
</tbody>
</table>

The typical custom house figures came from a study that Casper Huizenga did in 1993, so it would be safe to say that due to inflation the cost for that house would be
even greater today. The assumptions are for the \textit{l-gro} house. In a study done by Mercier Associates in 2000 on low-income Iowans, the average annual heating bill amounted to about $1,400. That is the low end of the spectrum and the \textit{l-gro} house is still only $1/3$ of that cost.\textsuperscript{44}
Architects are in a key position to reduce energy and resource consumption. Harry Gordon stated that thirty to forty percent of the energy used in the United States goes to the building industry.\textsuperscript{45} This is a huge number and architects have the opportunity to make a difference on that energy ticket. Finding materials that have lower embodied energy and by using materials in a more environmentally conscious manner are ways in which to help.

The \textit{l-gro} house strives to make good use of its materials. By being a solar collector, it is harvesting natural energy and lessening the demand of energy from the “grid”. The house promotes bamboo as a building material and begins to look at a new structural scheme that could be used if bamboo were to become mainstream as a replacement material.

Compared to wood, bamboo makes sense as the material with which to build. It grows much faster; we can harvest bamboo every 3-5 years while softwoods need 10-20 years. Bamboo can re-grow itself from the same stem after harvesting while wood does not. Bamboo is lightweight and has a high strength/weight ratio. When bamboo is exposed within a building, there is more of an exotic feel than when traditional wood is used.

In order for bamboo to be a reasonable material to use, there are a few things that I think would need to happen. First of all, bamboo would need to be grown in the United States. If not at a local level, even in a more tropical region in the southern part of the country would be better than shipping from overseas. Perhaps a study should be done to compare the monetary and environmental costs of producing
wood locally and shipping bamboo from another country. It could very well turn out that these costs are fairly equal if not in favor of bamboo. Bamboo needs little to no production from harvest to use whereas wood requires a great deal more before it is in its final form. Bamboo would only have to be shipped here and with its lightweight property, the shipping cost might be quite low. So if a study were done, and the results favored bamboo, then just imagine how much more benefit we would reap if bamboo were grown on some sort of local scale.

Bamboo would also need some sort of uniformity so that buildings could be designed to some level of accuracy. In other words, one would have to assume that the bamboo would be relatively the same size with little variance. This would mean perhaps using the same sections of a bamboo pole and leave the rest unused. So there would need to be a system to handle the leftover pieces and use them wisely. Also, connections would need to be developed to handle slight variances of a bamboo cane since the bamboo is slightly non-uniform. I believe there are endless possibilities with what we can do with bamboo and it would be exciting to see it used in mainstream construction.

I am promoting the I-gro house because it is the responsible action to take. We can learn a lot from bamboo, a material that has been considered a poor man's wood, and have it lead us to striking and sophisticated designs.
NOTES


3 United States Country Analysis Briefs

4 David Block, lecture, “Working Definition of Sustainability and Green Architecture,” Architecture 558: Sustainability & Green Architecture, Iowa State University, Ames, IA, Fall 2002.


11 Environmental Building News.


13 Environmental Building News 9-10.


16 Velez 58.


18 Velez 160.


21 Velez 64.


24 Demkin 03100 22.

25 Demkin Mat 08810.

26 David Anink, Chiel Boonstra, and John Mak, Handbook of Sustainable Building (James & James, 1996) 167.

27 Demkin 08810.


33 Demkin MAT 09300.

34 Demkin MAT 09300.

35 Velez 9.

36 Velez 163.


38 Velez 91.

39 Velez 213.

40 Velez 62.

41 United Nations 57.

42 United Nations 79.

43 Huizenga 74.


BIBLIOGRAPHY


