FiberTECH

A framework for producing, using and designing with natural fibers

Project Report

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Prepared by

Sang Lee, M.Arch.,RA

Stefanie Holzheu, Dipl.-Ing.

Rotterdam

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Introduction

Various forms of building elements produced from natural fiber materials have been around for a long time. If we look at the widely recognized view of Marc-Antoine Laugier in the eighteenth century[1] that the origin of architecture is the primitive hut born in the forest, a hut built of columns and a roof after the form of the tree trunk and crown. To this primitive hut, various enclosing elements were added, constructed from weaving grass and straws as well as fabric and animal hides. In ancient Greece, a tektôn was a professional carpenter who was specialized in constructing woven wood houses, tekhnê.[2] The woven character of construction is closely tied to the fundamental mode of construction using not only wood but also other types of pliable, fibrous materials such as reed, straw and leather.

In the nineteenth century, Gottfried Semper identifies weaving as one of the primary techniques of construction.[3] Semper suggests four classes of construction in textiles, ceramics, tectonics (carpentry) and stereotomy (masonry).[4] He describes the textiles combined with plasticity (ceramics) and lattices (tubular construction and woven structure) as giving shape that is indicative of the very common straw-mud infill construction in building history on a wider historical view. In addition Semper sees the weaving as the more sophisticated form of architectural envelope. The use of straw exemplified in weaving also includes the dimensions of construction that express communal, social and cultural processes.

What is clear is that the historical use of fibrous materials in architecture has played an important role for centuries. The most predominant source of natural fibers in architecture has been wood. We have used wood for structural as well as decorative purposes. A building may contain wood columns and beams as well as decorative woodcarvings and inlays. The visual qualities of wood grains have been so much appreciated and culturally engrained that we have also produced materials that simulate wood grains. However, for the past few decades we have also become aware of the unsustainable prospect of wood products. Natural sources of wood are dwindling and deforestation has been found to exacerbate environmental problems. Trees take many years to mature and require many different types of imposing industrial processes that are often energy intensive and toxic in order to turn them into usable products.

Therefore it is clear that we need to develop new sources and products that can replace wood even in part and provide comparable level of performance and applicability. In this overall strategy, straws from annually harvested grain plants, most notably wheat and rice, offer a promising potential. First of all the grains are the most common ingredient in the food supply and widely grown in many different regions in the world. Second, the plants are grown and harvested annually, thereby providing short turnaround time. Third, the straws are far simpler to harvest and process, thereby reducing energy consumption and toxic byproducts in the process. In addition, straw is very similar to wood in composition (39–51% cellulose, 30–37% hemicelluloses, 15–17% lignin, and 1–4% silica[5]), thereby making it suitable wood replacement. However, currently the vast majority of straws (for examples in the US 99%[6]) is buried back in the soil or incinerated.

In the past the most common application of straws was for thatching the roofs and by mixing with clay and animal hair for the in-fills of building walls. Especially for the wall plastering the straws provided a similar kind of structural function as today's advanced glass-fiber reinforced concrete [GFRC]. In addition, straws have been widely used to produce household items such as mats and baskets by weaving. Another benefit of using straws is the insulation property. Due to the hollow tube shape and the low thermal conductivity, straws have been used where the protection from cold and heat was needed. This insulation property has in large part contributed to the popularity of straw thatched roofs in numerous cultures of the world as well as used in bedding. The commonly represented scene of the Nativity attests to the culturally embodied use of straws.

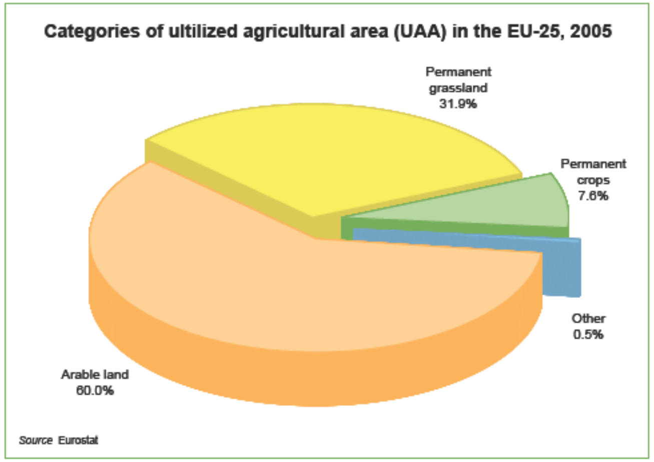
The research project Fiber Tech [FT] aims to investigate and develop a viable application of straws in today's architectural context. It also aims to discover the capacities comparable wood products in building construction such as plywood and at the same time to lower environmental impact as well as to contribute to the conservation of forests in the long run. We believe that the straws and other types of natural fibers, when properly engineered and used, can provide various building components with many positive qualities. During the start-up subsidy, we were able to investigate the current state of straw use in construction and have come to believe that the straws are one of the most underused resources despite increasing disadvantages of wood products.

Basic Information and Statistics

If we look at the wheat straws in terms of the worldwide production, as of 2011 the EU countries occupy close to 20% of world wheat production. And if we assume the ratio of wheat grain to straw to be 1,3:1,[7] that is, every 1,3 kg of wheat grain production leaves behind 1 kg of straw, the amount of straw production in the EU is indeed staggering. In 2010 the total production of wheat in the 27 EU countries added up to 137 million tons.[8] This equates to more than 100 million tons of straws. Of this quantity, the density of raw straws is roughly 130 kg/m^3 [9] and when manufactured as boards ranges 560-600 kg/m^3 [10] which includes the binding agent and other additives from manufacturing. Therefore in manufactured form, the EU's straw production translates to around 172 million m^3 of board products based on the 2011 production statistics. In comparison, according to the European Panel Federation, in 2006 the EU consumed total 60 million m^3 of wood panels.[11]

Based of the cursory statistics, it is clear that in terms of raw quantity straws are abundant and provide a feasible prospect in replacing large part of wood consumption. Especially, considering that the major exporters of manufactured wood products to the EU in 2005 are Brazil (1 million m^3), Russia (nearly 850,000 m^3), China (630,000 m^3), Indonesia (370,000 m^3) and Malaysia (170,000 m^3).[12] Taken together, the five countries exported to the EU roughly 3 million m^3 of manufactured wood products in 2005. And of the major wood exporting countries the fact that Brazil, Indonesia and Malaysia count for their ancient rain forests makes the wood imports from them questionable in regard to the potentially negative environmental impact.

In comparison, the five major wood manufacturing countries in the EU, namely Germany, France, Italy, UK and Poland, produced nearly 60% of particleboard products in the EU in 2010.[13] Even though consistently matching statistics is hard to come by, it is not difficult to consider the potential of straws in design and construction in the EU alone. While the EU produces nearly 20% of the world's wheat, the abundant straws are largely discarded and underutilized. It is undeniable to recognize the role of straw hays for mulch production in order to replenish the soil and to contribute to farming. However, given the vast quantities of straws it appears that the more thorough use of them offers a new area of efficient material conservation and use in regard to the environment impact as well as economic development.



Source: Eurostat

Regional Statistics

In recent years, great quantities of agricultural straw, available worldwide, have been produced after harvest of the crops. For the purpose of keeping the production local our research considers regional if the resources that are harvested, manufactured and distributed within 800 km by automobile or 2,500 km by rail or water. In this criteria of regionality, the prospects for the Netherlands fit well in its economic and geographical position. Wheat straw is harvested regionally in large quantities, and given the Netherlands' geography and strategic position in the EU, the statistics of wheat production should consist of the neighboring countries: Belgium, France, Germany, Denmark and the UK.

The 2010 statistics[14] of wheat production in the Netherlands and the neighboring countries is as follows (million tons):

Netherlands	1,4
Belgium	1,9
France	38
Germany	24
Denmark	5
UK	14
Total:	~84 million tons

Based on the above figures of wheat production in the Netherlands and the five neighboring countries, altogether roughly 84 million tons, we can extrapolate the straw production of around 65 million tons.

Wheat, production

1 000 t

geo / time	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
European Union (changing composition)	104132.7	90637.8	137301.3	124350	117732.3	120074.7	150596.1	138363.4	136631.4	139365.1
EU (27 countries)										
Belgium	1675.1	1692.9	1913.1	1799.4	1719.5	1645.3	1944.3	1978.1	1912.8	1654.8
Bulgaria	4122.8	2003.9	3961.2	3478.1	3301.9	2390.6	4632.2	3976.9	4094.6	4458.5
Czech Republic	3866.5	2637.9	5042.5	4145	3506.3	3938.9	4691.1	4358.1	4161.6	4913
Denmark	4056.2	4701.4	4758.5	4887.2	4801.6	4519.2	5018.7	5940.4	5059.9	5059.9
Germany	20817.7	19259.8	25427.2	23692.7	22427.9	20828.1	25988.6	25190.3	24039.7	22782.8
Estonia	148.4	144.9	196.6	263.4	219.6	345.8	342.5	342.5	327.6	353.2
Ireland	867.2	794.1	1037.2	801.7	801	713.4	992.8	690.1	669.2	0
Greece	1783	1631.7	1773.7	1761	1576.3	1383.5	1939.3	1830	1663.1	1702
Spain	6822.2	6019	7096.7	4026.7	5521.6	6436.4	6831.5	4772.7	5941.2	6900.2
France	38933.4	30481	39692.9	36885.5	35363.6	32769.9	39001.7	38324.7	38194.7	38036.8
Italy	7547.8	6229.5	8638.7	7717.1	7181.7	7170.2	8859.4	6341	6777.3	6622
Cyprus	12.9	14.3	9.9	9.2	7.5	10.7	2.5	14.7	18.9	24.9
Latvia	519.5	468.4	499.9	676.5	598.3	807.3	989.6	1036.4	973	939.5
Lithuania	1217.6	1204.1	1430.2	1379.4	809.8	1390.7	1722.5	2100.2	1708.2	1869.3
Luxembourg	71.7	68.6	80	71.7	75.6	70.5	97.2	90.9	83.5	76.8
Hungary	3910.2	2941.2	6006.8	5088.2	4376.2	3986.7	5630.8	4419.2	3763.7	4129.7
Malta									0 (z)	0 (z)
Netherlands	1056.6	1130.1	1223.9	1174.7	1184.5	1018.4	1366.2	1402	1442.4	1186
Austria	1434.2	1191.4	1718.8	1453.1	1396.3	1399.3	1689.7	1523.4	1517.8	1781.8
Poland	9304	7858.2	9892.5	8771.4	7059.7	8317.3	9274.9	9789.9	9487.8	9339.2
Portugal	413	149.6	292.9	81.5	249.6	102.3	203.3	124.1	82.6	58.6
Romania	4421	2479.1	7812.4	7340.7	5526.2	3044.5	7181	5202.5	5587.5	7192.2
Slovenia	174.9	122.9	146.8	141.3	134.4	133	160	136.5	152.3	153.6
Slovakia	1554.4	930.4	1764.8	1607.9	1342.7	1379.6	1819.5	1537.9	1227.8	1639.3
Finland	569	679	782.3	801.2	684.1	796.8	787.5	887	723.3	980.7
Sweden	2112.6	2282.7	2412.3	2246.8	1967.4	2255.7	2202.2	2277.9	2143	2253.1
United Kingdom	15973	14327	15473	14876.6	14734.6	13220.6	17227.1	14076	14878	15257
Iceland										0.1
Norway	261.5	349.5	406.8	395.4	357	401.1	460			
Switzerland					533.2	540.5	545.2	549.7	523.9	
Montenegro										
Croatia	822.7	506.2	801.4	601.7	804.6	812.3	858.3	936.1	616.3	781.8
Former Yugoslav Republic o Macedonia, the	267	225.3	356.8	333.9	293.3	218.1	291.7	271	243.1	259.9
Turkey	19500	19000	21000	21500	20010	17234	17789	20520	23118	21807

not available   z not applicable

Source of Data Eurostat
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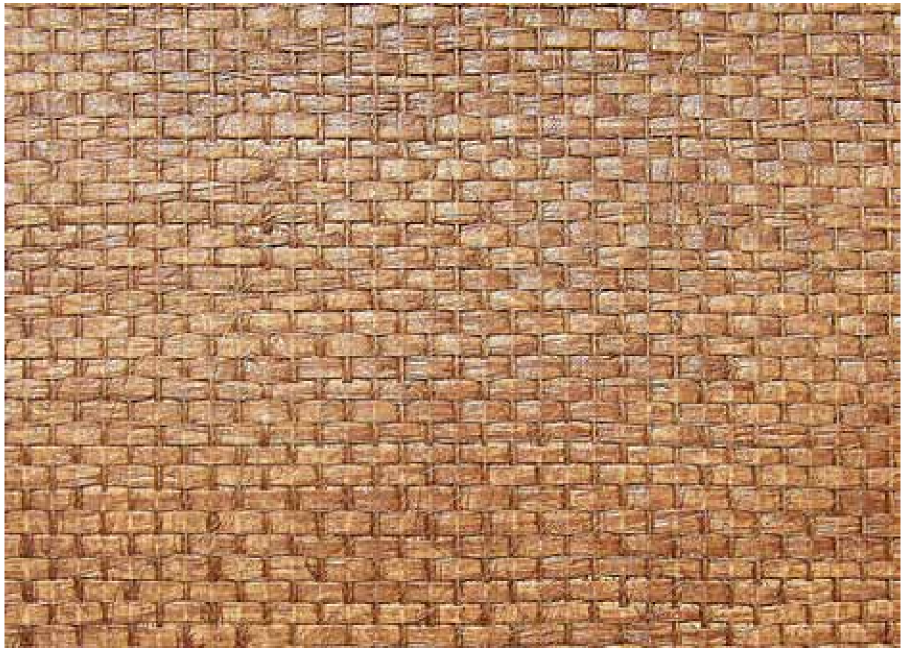
Hyperlink to the table http //epp.eurostat.ec.europa.eu/tgm/table.do?tab table&init 1&plugin 1&language en&pcode tag00033
General Disclaimer of the EC http //europa.eu/geninfo/legal notices en.htm
Short Description Wheat production corresponds to the production of common wheat and durum wheat.
Code tag00033

Examples of Straw Products

Straw as building material usually conjures up thatched roofs, compacted straw insulation or bail houses. However, if we examine the variety of straw products, we find the kind of versatility comparable to wood. Various researches show that straw fiber is already closely incorporated in numerous applications in architectural design. Unfortunately straw carries a negative connotation due to the perception of being low-tech, vernacular and outdated associated with agriculture and rural living. Such prejudice stems from for example undesirable physical or mechanical properties of straw as building material and poor weather resistance that causes various forms of degradation including the potential for spreading fungi.



Source: Wallpaper, www.grassclothwallpaper.com

Following are some examples of various applications of straw in architecture and design:

1. Decorative Wallpaper

Example Sources:

Grasscloth Wallpaper

(http://grassclothwallpaper.com/source/grass_wall_paper_9488-347.html)

Designer Wallcoverings and Fabrics

(http://designerwallcoverings.com/WallpaperStore/index.php?main_page=advanced_search_result&search_in_description=1&keyword=straw)

Élitis

(http://www.elitis.fr/collections/revetements-muraux)

The straw wallpapers are typically made of whole straw strand that are woven in place on paper with fiber or metallic threads. The wallpapers are also produced in square woven form.

Source: Insulation board, image.made-in-china.com

2. Insulation

Example Source:

Strawtec (http://www.strawtec.com/english/english_start.html)

The Strawtec boards are fibrous-felted, homogeneous panels made from lignocellulosic fibers, combined with a synthetic resin or other suitable bonding system, and then bonded together under heat and pressure.[15] For example the insulation boards from Strawtec are used as a heat insulation system for renovation work and conservation of old buildings. It is supposed to facilitate the efficient and effective lining and insulation of exterior walls. The panels boast fast, economical installation, thereby the application of the boards are said to lead to energy-efficient renovated buildings with good sound insulation qualities. Furthermore, the use of a natural raw material is said to result in an improved indoor climate.[16]

Source: Wall Plaster, www.tierrafino.com

3. Wall Plaster

Example Source:

Terrafino (http://www.tierrafino.com)

Tierrafino is a manufacturer of clay-based wall finish material based on the ancient rammed earth technique. Therefore the Terrafino products appear suitable for interior use only. It is utilized as a render coat, a skim coat and sometimes as a finish surface. It consists of sand, clay and straw and can be applied by troweling or spraying. All waste-material can be reclaimed and reused. The manufacturer claims the plaster material can be recycled endlessly because it contains no adhesives. The plaster sets mechanically instead of chemically and the ingredients and production of the plaster are said to be low in embodied energy.

Source: Thatched Roof, commonwealthroofing.com/roof-types/thatched-roof/

4. Thatched Roof

Example Source:

Commonwealth Roofing Corp.

(http://commonwealthroofing.com/roof-types/thatched-roof/)

Thatch is a very old roofing method and has been used in both tropical and temperate climates. It is still employed by builders in developing countries, usually using local vegetation at low-cost, as well as in developed countries as a part of a more environmentally conscious construction method. A roof can be thatched in one of several types of straw or grass. Water reed is the longest-lasting type of thatch with up to sixty years of life cycle. Reed is harvested annually and the best quality reed is more available during certain seasons in different parts of the world, which causes extended production periods. Although no special structural considerations are required for thatch certain architectural features are needed. For example a roof slope of 45 degrees is recommended. Also, because of its thickness, thatched roofs typically have no gutters or downspouts.

Source: TerraDeck, www.naturescomposites.com/index.html

5. Decking and Fencing

Example Source:

Natures Composites

(http://www.naturescomposites.com/index.html)

The deck and fence boards are a combination of recycled high-density polyethylene and wheat straw. According to the manufacture's data they resist water absorption, exhibit a low level of thermal expansion, and will not splinter or crack. The planks come in three lengths and in two profiles: slotted to accommodate hidden fasteners, and solid. Also according to the manufacture, they are available in six colors and said to have better color retention than conventional composites, and do not require painting or staining.

6. Structural Boards

Straw board is a relatively new material in Europe. It can be primarily divided in two categories: pulverized fiber boards and directional fiber boards. The two types resemble the common wood boards, namely MDF and flakeboard. The pulverized straw fiberboard uses finely crush straws that are compressed into boards. This type of boards provides a dense and stable board application. The production of medium and high-density straw fiberboards [MDF and HDF respectively] first requires high quality fibers extracted from the plants. This involves a heating process in which the lignin fibers are chopped, softened and separated from other components such as wax and minerals. In this respect, the manufacture of straw MDF and HDF requires additional processes compared to the boards from wood. According to one report on rice straw fibers,[17] the processing temperature reaches 160 ºC in comparison to 170 ºC for wood. Then the fibers are mixed with a binding agent (typically a resin) and pressed at a high temperature, again around 170-180 ºC, to form a board shape. In this sense, other than the abundant raw material sources, the straw MDF and HDF do not appear to provide overall benefits compared to wood boards.

The second type, called OSSB (oriented structural straw board) is produced by arranging and compressing longer strands of straws in directional patterns without extracting fibers. In this type, the pattern and configuration of the straw strands provide the structural properties in the same way as the flakeboards or plywood. In addition, the OSSB contains no CFC or Formaldehyde and can be manufactured using non-toxic plant based adhesives with no out-gassing. The following section describes the OSSB more in detail.


Source: OSSB, www.novofibre.com

Oriented Structural Straw Board (OSSB)

As construction industry is increasingly expected to be more sensitive about environmental consequences and to provide higher quality services and products, the building and construction has come to bear more responsibility to develop new production technologies and application methods as well as new materials itself in order to help mitigate environmental problems. The decreasing natural resources also caused a change in practice of the building industry. Therefor it is essential to rethink architectural design and construction methods considering that buildings contribute heavily to environmental problems and often continue to pose negative impact during their whole live cycle.

The visual and tactile qualities of architectural materials are the primary agent between the building and its users. Therefor the aesthetic, durable, and sustainable features of materials are of main interest for architects. In this regard wood finishes displaying the grain of the fibers have been highly regarded. However, various problems associated with changing economic, social and political situations in relation to the extraction of natural resources, the cost of wood fiber is constantly rising due to the demand often exceeding the supply. One of the driving forces behind this project is what kind of fiber sources we have in alternative to wood. During the course of a preliminary investigation, straw emerged as one potential substitute. The assignment of this project is to investigate the possible utilization of the agriculture byproduct straw for architectural applications, in particular OSSB.

The following criteria of consideration have been derived from various research publications on OSSB. Here we have also listed the information drawn from one of the premier manufacturers of OSSBs, Novofibre (http://www.novofibre.com).

Material Safety

According to the manufacturer Novofibre, OSSB is made of 100% high quality natural wheat straw combined with the formaldehyde-free adhesive "isocyanate" in order to alleviate the hazardous out-gassing problem historically associated with wood panel products. At the same time the manufacturer claims it to be the strongest adhesive available for this purpose and also to improve the waterproofing qualities of the board. In addition, there exists a research work on soy-based adhesive that is 100% biodegradable and non-toxic.[18] The resulting OSSB product is comparable to wood based oriented strand board (OSB) in both physical and mechanical properties at comparable densities.[19]

Rapid Renewability

The use of renewable raw materials reduces the use of nonrenewable recourses for example fossil fuels. Compared to wood, straw recourses are rapidly renewable, and reduces the impact on the environment. According to the LEED, "Rapidly renewable materials must have a harvest cycle of 10 years or fewer … like bamboo, agrifibers …. Materials for this credit can come from either plants or animals, but they have to be harvested without harming the animal."[20]

Qualification items	Unit	Base Panel OS3
Thickness	mm	5-18
Density	kg/m³	560-600
MOE	Mpa	≥ 3500
MOR	Mpa	≥ 22
IB	Mpa	≥ 0.32
24h Swelling (TS)	%	≤ 15
Thickness tolerance	mm	± 0.8
Squarness	mm	2
MC	%	2 ~ 6
Warp (flatness deviation)	%	≤ 0.3
Emission class	E norme	E_0

Source: OSSB, www.novofibre.com

Key Features

Key features according to Novofibre include:

1. High structural strength stability
2. Load-bearing with excellent strength and weight performance
3. Superior workability
4. Excellent nail-holding capacity on all sides
5. High earthquake resistance and durability
6. Better water resistance than traditional wood-based board
7. Vermin prevention
8. Zero chemical emissions
9. Excellent anti-seismic behavior
10. Short construction periods
11. High durability
12. Effective thermal insulation
13. Low carbon footprint
14. High acoustic qualities

NOVOFIBRE China

China

Novofibre Panel Board Holding Ltd. (China)
GM: Pierre Eloy
T: +86 10 58671900-851
F: +86 10 58671902
A2 Zone, Room A116,
ZhaoWeiHuaDeng Mansion 14 Jiuxianqiao Road,
Chaoyang District,100015 Beijing
China
Authorized region: China
info@novofibre.com

Production Location

The world's first OSSB manufacturing plant by Novofire has been operating in China since October 2009. The straw is regionally harvested and transported to the production plant. While the first manufacturing site is located in central China, new plants are being planned around China, in North America and in Europe.

Source: OSSB Manufacturing Process, www.novofibre.com

Manufacturing Process

1. Straw Quality Control and Preparation

The wheat straw is selected in terms of quality, particularly the impurity content, dimension, shape, color and moisture content. At this stage the straw is screened and stored under special conditions. The straw is then split and finally mixed with adhesives.

2. Directional Mat Forming

The straw is orientated in the mat form to optimize strength and natural appearance. Long straw strands allow for the development of a high strength to stiffness ratio. Furthermore the crisscrossing straw layers reinforce the board and provide a two-dimensional structural strength. The structural strength in the longitudinal and transverse directions are both the same.[21] This makes the OSSB comparable to wood based oriented strand board in physical properties at comparable densities.

3. Continuous heat pressing:

The mat is pressed between heated belts, water is vaporized, transferring heat into the straw. The heat cures the adhesive and causes a series of physical and chemical changes to the pressurized raw materials, which harden into a dense board.[22]

4. Coating

The panels are coated for UV resistance. A wax finish is applied to the top surface of the boards for low-maintenance and repairability if necessary.

The production

1. Quality control of straw:

Control the quality at source — not all straw complies with our manufacturing requirements. Therefore, NOVOFIBRE™ strictly controls the wheat straw quality, particularly the impurity content, dimension, shape, color and moisture content.

STEP 1: Gathering straw › STEP 2: Stone separation › STEP 3: Baler ›

2. Straw preparation:

At this stage of the process we screen the straw and storage it in special conditions. The straw is then split and finally mixed with glue and glues into a uniform.

STEP 4: Transport & storage › STEP 5: Bale breaker › STEP 6: Splitter › STEP 7: Dryer ›

3. Directional mat forming:

Using specially developed mechanical forming techniques, the straw is orientated in the mat to optimize strength and natural appearance.

STEP 8: Cyclone › STEP 9: Blender › STEP 10: Forming bunker › STEP 11: Pre-press ›

4. Continuous heat pressing:

The hot-pressing technique is vital for product quality. As the mat is pressed between heated belts, water is vaporized, transferring heat into the straw. The heat cures the adhesive and causes a series of physical and chemical changes to the pressurized raw materials, which harden as dense board.

STEP 12: Reject hopper › STEP 13: Press › STEP 14: Cross cut saw › STEP 15: Cooler ›

STEP 16: Baling › STEP 17: Collection & delivery › STEP 18: Customer

Source: OSSB Manufacturing Process, www.novofibre.com

Manufacturing Difficulties

1. Straw contains a high level of silica and wax on their surfaces, making them difficult to bond with resin adhesives. Furthermore, when straw is bonded with a resin, the weak interfacial adhesion between the straw and resin has a negative influence on dimensional stability and the mechanical properties of the resultant straw panels.[23]

2. Developing straw based oriented strand board has proven to be a difficult task. To split the tubule, with any degree of length is challenging but a necessary task to produce structural panels from straw. The Alberta Research Council's Forest Products business unit (ARC) has developed a technique in cooperation with Panel Board Holding BV (PBH) whereby a straw tubule can be sheared longitudinally while maintaining relatively long strands. This technology opens up the straw tube to allow even distribution of the binder on all strand surfaces.[24]

3. The OSSB framing and sheathing elements are intended for use in dry service conditions. Even though they can certainly tolerate brief periods of wetting during constructions, they will suffer from mold, stain, and decay under prolonged exposure to high relative humidity and/or liquid water if not treated. Furthermore OSSB is subject to biological attacks due to the chemical composition of the straw material.[25]

Embodied Energy Level and Energy Consumption

OSSB is made of a natural waste material, which is normally either burnt or tilled. By turning straw into a building product, OSSB contributes to a low-carbon footprint. In 2009 the Delft University of Technology in Netherlands worked out the "Delft Report" for Novofibre. The report compared the environmental effects of a light steel structure house made of OSSB with a traditional Chinese brick house.

The TU Delft research found the reduction of:

33 % of the total embodied energy

75 % of grey energy

66 % in the CO2 footprint

50 % in heating demand

25 % in cooling demand.

Product Application

Currently the product is available in Korea, Australia, Europe and Russia. It should be noted that currently the boards have to be shipped long distance from China, which increases the overall embodied energy.

Estimated Life Span

Because OSSB is relatively new product, its long-term performance characteristics are not well known.

Environmental Impact

Straw is an agriculture byproduct with minimal environmental hazard. The reduction of carbon-emissions through the elimination of straw burning and a low CO2 emission production process furthermore reduce the environmental impact. During the manufacturing process only small amounts of wastewater and emissions are produced. "Life-cycle analysis of wheat board by the National Institute of Standards and Technology, Gaithersburg, MD USA, demonstrated new wheat-board products actually have a positive impact on the environment. Carbon sequestered during the raw-materials stage of wheat board's life cycle is said to far outweighs the carbon released during manufacture and transportation of the product combined. Wheat board rated the best for overall environmental impact across 230 products evaluated by the NIST."[26]

It should also be noted that there is a widely held assumption that products derived from corn, soybeans, cotton and straw carry significant environmental burdens across their life cycles due to fertilizers, pesticides, energy use in farming and processing, and soil runoff. It should also be clear that deforestation could still be a significant problem due to the higher demand for straw in a similar manner as the production of biofuel from sugar cane contributed to the deforestation in Brazil.

Social Impact

For farmers the large interest in straw provides an increased income through selling a byproduct of their harvest. Purchasing local products supports local economy as well as helps to reduce the emissions associated with transporting materials long distance. By using straw to produce building panels, OSSB is seen to further create new value in reducing carbon emissions from burning and from brick production. As a low carbon building material, OSSB has recently been proposed for use in earthquake resistant construction and low cost housing for farmers in rural areas in China.

Economic Competitiveness

OSSB as sustainable building products will not become mainstream until they present competitive const benefits. The factors that contribute to the higher cost of OSSB compared to the traditional counterpart OSB include:

1. The non-toxic adhesives are more expensive than the traditional formaldehyde containing ones.
2. The quality of wheat straw depends on the harvest and storage process that require special equipment and controlled environment.

Project Examples

Detached House, Blanden, Belgium

Built in 2001-2002 the two-story detached house is a straw bale house designed by the architect Van Soom Herwig for himself and his family. The wood structure in a 3m x 4m grid, was covered on three faces in precompressed straw bales. The south façade is covered mostly in glass or standard insulation materials. The exterior and interior finish of the walls is a plaster-mix of clay and shredded straw. The metal sheet roof with is lifted above house and serves as rain protection. The compact shape and the lifted roof with a large overhang reduced the risk of water damages, structural complications and thermal bridges. However the weather exposed facade showed water damage after only one year.

The Butterfly-house, Ouwerkerk, Zeeland, The Netherlands

The Butterfly-house by Jan Sonneveld in 1998 was built of straw bales in combination with steel frame structure and a sheet metal roof. It is designed in a unique butterfly shape plan with a large surface area exposed to the environment. The shape caused several complications. The tight radii at the corners of the building were difficult to implement with straw bales because of their inherent shape and size. The solution was an additional wood structure to ensure the stability. Additionally the selected roof structure caused thermal bridges. Due to various reasons the initial lime plaster failed and had to be removed. To protect the structure from moisture and water the plaster was completely removed and replaced with clay plaster.

Straw Fiberboard House, Eschenz, Switzerland

The architect Felix Jerusalem designed the straw fiberboard house in Eschenz, Switzerland. This house combines prefabricated production methods with primarily prefabricated strawboard panels that are affordable and environmentally friendly. Due to the wet subsoil conditions, the structure was raised above the ground on concrete piles. A corrugated plastic exterior protects the compressed straw fiberboards, which is structural and serves as the primary heat and sound insulation. Lightweight panels are used for thermal and acoustic insulation, mid density boards for interior walls and high-density boards for structural elements. All are supposedly emission free, formaldehyde free and fully recyclable. The boards are currently not available on the market.

The Barn at Frank Lloyd Wright's Kaufmann House (aka Fallingwater)

The barn at the Fallingwater, Mill Run, Pennsylvania, was originally built into the hillside, in 1870. (The house by Wright was completed in 1939.) Since 1963 the Western Pennsylvania Conservancy used it as a nature center. In 2002, the architect Bohlin Cywinski Jackson of Pittsburgh was commissioned to renovate the barn, preserving the original characteristics. For the renovation annually renewable materials, including sunflower seed composite panels, were utilized. Straw panels installed on the ceilings were renovated with straw panels that are said to be not only rapidly renewable, but also sound absorbing. This project also incorporates agricultural-waste fiber panels for millwork and interior finishes, plus other salvaged materials such as flooring.

State of Research

This section provides some examples of research works that deal with the potentials of plant fibers. For the practical purpose of this report, we have provided only abstracts and introductions of select work.

Fiberboard and Hardboard Research at the Forest Products Laboratory: A 50-Year Summary (1985)

Forest Product Laboratory, US Department of Agriculture

Summary:

For more than 50 years the U.S. Forest Products Laboratory has conducted fiberboard and hardboard research in three broad areas: processing, properties, and performance. During the 1930's and 1940's only a few studies were completed on raw material evaluations and testing. Activity in the 1950's and 1960's intensified on raw material and board properly evaluations. During the 1970's and early 1980's the emphasis shifted toward processing and structural applications. Readers must be aware that this publication only covers research completed at FPL.

Most of the processing research was carried out in the areas of fiber resources, fiber preparation, fiber treatments, and additives. Many species of domestic and foreign hardwoods and softwoods were investigated. Other sources of fiber were also investigated, including residues from forests and forest products industries, clean wastepaper, fiber from municipal wastes, and fiber from agricultural residues. Fiber preparation investigated various aspects of atmospheric and pressurized refining, plus some chemical cooks. Closely aligned with fiber preparation were studies on fiber yield and characterization. Many items are added to the fibers prior to or during the forming operation, including paraffin wax, other sizing chemicals, and resins. Other fiber additives were investigated with the intention of making hardboard stronger and more stable, fire-retardant, or resistant to decay. Most of the resin additives involved different types of phenolic resins, but there was work done on some thermoplastics and resins made from renewable resources. Different resin application points were investigated.

Fewer studies were conducted on mat forming, hot pressing, and post-treatment. Aligning fibers and adding fiberglass to the fiber mats were investigated as means of increasing strength and stability. Most of the work on hot pressing involved different temperatures and pressing times. Post-treatment investigations were primarily concerned with the addition of oils or other chemicals, and/or heat-treatment, of the hardboard.

Early work in properties and performance emphasized test method development, mechanical fastener performance of cellulosic fiberboards as related to wall racking strength, use of hardboard as facings on stressed-skin and sandwich panels, and fire performance of these fiber-based panels. Later studies

concentrated on basic properties of hardboard and how they were affected by loading and environmental conditions and structural use of hardboard as webs in I-beams.

Results from these studies suggest additional research possibilities. For example, the hardboard I-beam studies indicated that performance criteria such as long-term strength, resistance to creep, and response to humidity variations can be affected by processing variables (wood species, fiber refining, mat-forming, and press conditions). As more of the processing variables are studied and understood, it may be possible to manipulate the processing operation to attain a desired performance, and utilize more fiberbase panel products structurally.

Are Natural Fiber Composites Environmentally Superior to

Glass Fiber Reinforced Composites? (2003)

S.V. Joshia, L.T. Drzalb, A.K. Mohantyb, S. Arorac

Abstract:

Natural fibers are emerging as low cost, lightweight and apparently environmentally superior alternatives to glass fibers in composites. We review select comparative life cycle assessment studies of natural fiber and glass fiber composites, and identify key drivers of their relative environmental performance. Natural fiber composites are likely to be environmentally superior to glass fiber composites in most cases for the following reasons: (1) natural fiber production has lower environmental impacts compared to glass fiber production; (2) natural fiber composites have higher fiber content for equivalent performance, reducing more polluting base polymer content; (3) the light-weight natural fiber composites improve fuel efficiency and reduce emissions in the use phase of the component, especially in auto applications; and (4) end of life incineration of natural fibers results in recovered energy and carbon credits.

Adhesive Properties of Modified Soybean Flour in Wheat

Straw Particleboard (2004)

Enzhi Cheng, Xiuzhi Sun, Greggory S. Karr

Abstract:

The objective of this research was to improve mechanical properties and water resistance of wheat straw–soy flour particleboard by chemically modifying soy flour. Urea and urease inhibitor N-(n-butyl) thiophosphoric triamide (n BTPT) were used to modify the proteins. Boric acid and citric acid along sodium hypophosphite monohydrate were used to modify soy carbohydrates. Sodium hydroxide was used to unfold protein molecules. The combined effect of the chemicals was also studied. Particleboard bonded by urea and high concentrations of nBTPT treated soy flour improved mechanical properties, that bonded by boric acid treated soy flour had better water resis-

tance. The adhesive made from soy flour treated with 1.5 M urea, 0.4% n BTPT, 7% citric acid, 4% NaH_2PO_2, 3% boric acid, and 1.85% NaOH, produced particleboard with the maximum mechanical strength and water resistance.

Manufacture of Straw MDF and Fibreboards (2010)

Sören Halvarsson

Abstract:

The purpose of this thesis was to develop an economical, sustainable, and environmentally friendly straw Medium Density Fibreboard (MDF) process, capable of full-scale manufacturing and to produce MDF of requested quality. The investigated straw was based on wheat (Triticum aestivum L.) and rice (Oryzaesativa L.). In this thesis three different methods were taken for manufacture of straw MDF; (A) wheat-straw fibre was blowline blended with melamine-modified urea-formaldehyde (MUF), (B) rice-straw fibre was mixed with methylene diphenyl diisocyanate (MDI) in a resin drum-blender, and (C) wheat-straw fibre was activated in the blowline by the addition of Fenton's reagent (H_2O_2/Fe^{2+}) for production of non-resin MDF panels. The MUF/wheat straw MDF panels were approved according to the requirements of the EN standard for MDF (EN 622-5, 2006). The MDI/rice-straw MDF panels were approved according to requirements of the standard for MDF of the American National Standard Institute (ANSI A208.2-2002). The non-resin wheat-straw panels showed mediocre MDF panel properties and were not approved according to the requirements in the MDF standard. The dry process for wood-based MDF was modified for production of straw MDF. The straw MDF process was divided into seven main process steps.

1. Size-reduction (hammer-milling) and screening of straw
2. Wetting and heating of straw
3. Defibration
4. Resination of straw fibre
5. Mat forming
6. Pre-pressing
7. Hot-pressing

The primary results were that the straw MDF process was capable of providing satisfactory straw MDF panels based on different types of straw species and adhesives. Moreover, the straw MDF process was performed in pilot-plant scale and demonstrated as a suitable method for producing straw MDF from straw bales to finished straw MDF panels. In the environmental perspective the agricultural straw-waste is a suitable source for producing MDF to avoid open field burning and to capture carbon dioxide (CO_2), the biological sink for extended time into MDF panels, instead of converting straw directly into bio energy or applying straw fibre a few times as recycled paper. Additionally, the straw MDF panels can be recycled or converted to energy after utilization.

Composite Materials from Natural Resources: Recent

Trends and Future Potentials (2011)

Mohini Saxena, Asokan Pappu, Anusha Sharma, Ruhi

Haque and Sonal Wankhede

Introduction

Composites are combinations of two or more than two materials in which one of the materials, is reinforcing phase (fibres, sheets or particles) and the other is matrix phase (polymer, metal or ceramic). Composite materials are usually classified by type of reinforcement such as polymer composites, cement and metal- matrix composites (Chemical and Materials Engineering Department, home Page 2011; About.com, home page, 2011).

Polymer matrix composites are mostly commercially produced composites in which resin is used as matrix with different reinforcing materials. Polymer (resin) is classified in two types thermoplastics (polyethylene (PE), polypropylene (PP), polyether ether ketone (PEEK), polyvinyl chloride (PVC), polystyrene (PS), polyolefin etc.) and thermosets (epoxy, polyester, and phenol–formaldehyde resin, etc.) which reinforces different type of fibre like natural (plant, animal, mineral) and man-made fibre for different application. In metal matrix composites, metal is one of important part of element and other part may be metal, ceramic or organic compounds. Cement matrix composites are made up of cement and with aggregate and basically used in building applications.

Due to increase in population, natural resources are being exploited substantially as an alternative to synthetic materials. Due to this, the utilization of natural fibres for the reinforcement of the composites has received increasing attention. Natural fibres have many remarkable advantages over synthetic fibres. Nowadays, various types of natural fibres (Taj et al., 2007) have been investigated for use in composites including flax, hemp, jute straw, wood, rice husk, wheat, barley, oats, rye, cane (sugar and bamboo), grass, reeds, kenaf, ramie, oil palm, sisal, coir, water hyacinth, pennywort, kapok, paper mulberry, banana fibre, pineapple leaf fibre and papyrus. Natural fibres are largely divided into three categories depending on their origin: Mineral based, Plant based, and Animal based. In general, a mineral based composite is asbestos and is only a naturally occurring mineral fibre (silicate based mineral). In 2006, 2.3 million tones of asbestos were mined worldwide. Russia was the largest producer with about 40.2% world share followed by China (19.9%), Kazakhstan (13.0%), Canada (10.3%), and Brazil (9.9%) (Wikipedia, home page, 2010). The main properties of asbestos fibres are their thermal, electrical, and sound insulation; inflammability; matrix reinforcement (cement, plastic, and resins), adsorption capacity, wear and friction properties (friction materials), brake linings and chemical inertness (except in acids). Asbestos fibres are often mixed with cement or woven into fabric or mats/

sheets (Britannica home page, 2011; Wright, 2005).

Plant-based natural fibres are ligno-cellulosic in nature composed of cellulose, hemicellulose, and lignin, whereas animal based fibres are of proteins, e.g., silk and wool. Natural fibre-reinforced polymer composites have attracted more and more research interests owing to their potential as an alternative for synthetic fibre composites such as glass or carbon fibre composites (Bledzki & Gassan, 1999). Natural fibre composites posses the advantages such as easy availability, renewability of raw materials, low cost, light weight and high specific strength, and stiffness. It is expected that in the near future biodegradable polymers will replace synthetic polymers, at least in some specific applications where a short life of the product will be more desirable. Natural polymers are considered suitable to replace synthetic ones in some specific applications where a long span life is not required. Natural fibre thermoplastic composites are relatively new family of composite materials. In such composites, a natural fibre/filler (such as kenaf fibre, wood fibre, hemp, sisal etc.) is mixed with a thermoplastic (e.g., polyethylene, polypropylene, PVC etc.) to produce the composite. In the last few years, thermoplastics as well as thermosetbased natural fibre composites (NFCs) have experienced a tremendous growth in the auto industry due to environmentally friendliness, renewability of these fibres, good sound abatement capability, and improved fuel efficiency resulted from the reduced weight of the components. These composite materials have received much commercial success in the semi-structural as well as structural applications. For example, interior parts such as door trim panels from natural fibre polypropylene (PP) and exterior parts such as engine and transmission covers from natural fibre-polyester resins are already in use in auto industry. Advantages of thermoplastic NFC over thermoset-based NFC include the greater design freedom as they are suitable for injection molding and extrusion processing in addition to the recycling possibilities.

Performance of Zinc Borate-Treated Oriented Structural

Straw Board against Mold Fungi, Decay Fungi, and Ter

mites - A Preliminary Trial (2012)

Guangping Han, Wanli Cheng, Mark Manning, and Pierre

Eloy

Abstract:

The performance of zinc borate (ZB)-treated oriented structural straw board (OSSB) against mold fungi, decay fungi, and termites was examined in standard laboratory evaluations. OSSB was fabricated with split wheat straw strands and diphenylmethane diisocyante (pMDI) resin. The ZB was added during panel manufacture to achieve preservative levels (wt.%) of 1.0%, 1.5%,2.0%, and 3.0%. It was observed that after a four-week exposure to mold fungi all samples had some mold coverage, but the coverage on the ZB-treated samples was significantly

lighter compared to the untreated OSSB. Decay test showed that the weight losses of ZB-treated OSSB blocks at 1.0% and 1.5% levels were significantly reduced compared to the untreated OSSB and solid wood controls, indicating superior performance of ZB-treated OSSB against decay fungi. The termite mortality indicated that none of the termites were alive at the conclusion of the test for ZB-treated OSSB. The results from these specific laboratory studies demonstrated that ZB retentions of 1.5% and greater provide performance against decay fungi and termites for OSSB panels. In addition, untreated OSSB has high susceptibility to mold due to the chemical features of wheat straw and incomplete removal of kernels.

Physical Properties of Wheat Straw Varieties Cultivated under Different Climatic and Soil Conditions in Three Continents (2012)

Yaning Zhang, A.E. Ghaly and Bingxi Li

Abstract:

Over 500 million tonnes of wheat straw are produced annually worldwide, the majority of which are burnt in the field causing significant environmental and health problems as well as serious traffic accidents in addition to loss of a valuable resource. Wheat straw is abundantly available and renewable and can be used as an energy source in gasification and combustion systems. Proper understanding of the physical properties of wheat straw is necessary for utilizing these materials in thermochemical conversion processes. Wheat straws were collected from Egypt (Africa), Canada (North America) and Guyana (South America) and ground using medium size Wiley Mill. The physical properties (moisture content, particle size, bulk density and porosity) of wheat straws were determined using standard procedures. The moisture contents of wheat straws were in the range of 5.02-7.79%. The majority (56.87-93.36%) of the wheat straws particles were less than 0.85 mm and the average particle sizes were in the range of 0.38-0.69 mm. The average bulk density of the wheat straws were in the range of 97.52-177.23 kg/m^3. A negative linear relationship between the bulk density and the average particle size was observed for the wheat straws. The average porosity of the wheat straws were in the range of 46.39-84.24%. A positive linear relationship between the porosity and the average particle size for the wheat straws was also observed. The wheat straw varieties collected from different countries had different physical properties due to variations in climatic conditions, soil type and used fertilizer. Also, significant differences were observed among the varieties grown under same climatic and cultivation conditions.

Conclusion

Based on the information collected for this start-up research project, it is clear that the wheat and rice straw provides a very good prospect for replacing and reducing the use of wood in architecture and construction. As enumerated in this report so far, the straw provides physical properties comparable to wood while imposing fewer burdens as well as considerably less time in cultivating, harvesting, processing and production. This makes straw an ideal candidate to replace many applications that are now fulfilled by wood products ranging from structural to decorative.

In addition, the expanded use of straw also adds to the value and income from grain farming for the farmers. As already mentioned, almost all of straw is currently tilled into the ground or incinerated for disposal or heating. By reducing such disposal, the use of straw also helps reduce the CO_2 emission. At the same time, there exists adequate expertise to produce straw products for design and construction that are simpler to produce, safer to use, and higher performing. In addition, the fact that straw production also implicates highly cultural dimension. Directly connected to rice or wheat production, the presence of straw represents the agricultural basis of Europe and elsewhere. Therefore the use of straw also contributes to the cultural heritage and its preservation.

The sum of all values straw provides appears quite substantial, while the drawbacks seem readily surmountable. The adverse effects of expanding use of wood products are well known. At the same time it has been also argued clearly that preserving forests contributes to the reduction of atmospheric CO_2 level. Such necessities of reducing wood consumption also add the need for the increased utilization of straw replacements. However it has been also learned that the profit motivations seen in the case of sugar cane and corn farming for biofuel contributes to the diversity in farming and ironically to the destruction of forests.

However one crucial factor distinguishes wheat and rice crops from sugar cane or corn: wheat and rice provide staple food supply and straw is the byproduct of farming for daily food supply chain, rather than being the primary product that is diverted to other purposes. In this sense, it appears that the increased use and profitability of straw can be managed in such a way that the existing farmlands are preserved, and added prospect for profit from the byproduct that is otherwise discarded also motivates increased grain production. In many parts of the world where the versatile wheat and rice crops are grown, the use of straw will be a welcome expansion.

One are of further research in the use of straw building products is obviously application. The influence of vernacular architectural traditions prompted the use of straw in bale form that poses many problems in the long run. Such problems include the lack of climatic durability, potential health hazards from fungal infestation and structural problems from rotting. In this sense, the more scientific research and development of straw components for design and construction will offer the ways to maximize the material's potential. We wish to pursue further research in the application aspect of straw materials in the regular project phase.

Appendix A: Building Evaluation Catalogue

Optimized Site Potential

The adequate site selection, including consideration of the reuse or rehabilitation of existing buildings, the location, orientation, and landscaping of the building that affect the local ecosystems, the infrastructure and the energy use are evaluated here.

Materials

A sustainable building is constructed of materials that minimize life-cycle environmental impacts such as global warming and resource depletion. Environmentally preferable materials furthermore have a reduced effect on human health and the environment. Special attention was also paid to:

1. Recycled Content-reduction of waste during construction as well as reuse and recycling of materials and the application of recycled materials
2. Biobased Content-selection of sustainable grown, harvested, produced and transported products and materials

Optimized Water use

Fresh water is an increasingly rare resource. A sustainable building should use water efficiently, and reuse or recycle water for on-site use, when feasible. Water reduction can, for example be reused through more efficient fitting, appliances and fixtures

Optimized Energy use

It is essential to find ways to reduce energy load, increase efficiency, and maximize the use of renewable energy sources. Here the use of renewable and clean energy, generated on site, energy use monitoring, energy efficient design and construction methods, efficient appliances, systems and lighting etc. are evaluated.

Indoor Environmental Qualities

The indoor environmental quality of a building has a significant impact on occupant health and comfort. Attributes considered are:

1. Appropriate Ventilation for a high indoor air quality
2. Moisture Control
3. Thermal Comfort
4. Daylighting
5. Optimizes Acoustic Privacy

Of importance was also the occupants control over systems such as lighting and temperature.

Appendix B: Green Product Database

By 2050, 70% if the world's population will live in cities. Buildings consume over 40% of energy in the developed world, in addition to enormous quantities of water and raw materials. Therefore, ensuring that the urban environment is designed and operated in an efficient and sustainable manner is of importance.

Eco-structure Magazine:
editorials cover green building from all angles, providing information about rating systems and diverse green building techniques:
http://www.eco-structure.com/

Environmental Design +
Construction Magazine: source for integrated high-performance buildings:
http://www.edcmag.com/

EPA Comprehensive Procurement Guidelines:
promotes the use of recycled materials in the manufacture of new products:
http://www.epa.gov/epawaste/conserve/tools/cpg/index.htm

EPA Environmentally Preferable
Purchasing Program's Database of Environmental Information for Products and Services:
http://yosemite1.epa.gov/oppt/eppstand2.nsf

"Environmental Products and Services Guide" (2003-2004):

http://www.gsa.gov/gsa/cm_attachments/GSA_DOCUMENT2003_4_epsg_ optB(final%20web%20version2)_R2OP1-z_0Z5RDZ-i34K-pR.pdf

Guide to Resource Efficient Building Elements:
http://www.crbt.org/hc3.asp

A Sourcebook for Green and Sustainable Building: a collection of information and sources of materials, assistance and resources in sustainable solutions:
http://sustainablesources.com

Green2Green: compares building materials' environmental performances:
http://www.green2green.org

Notes

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