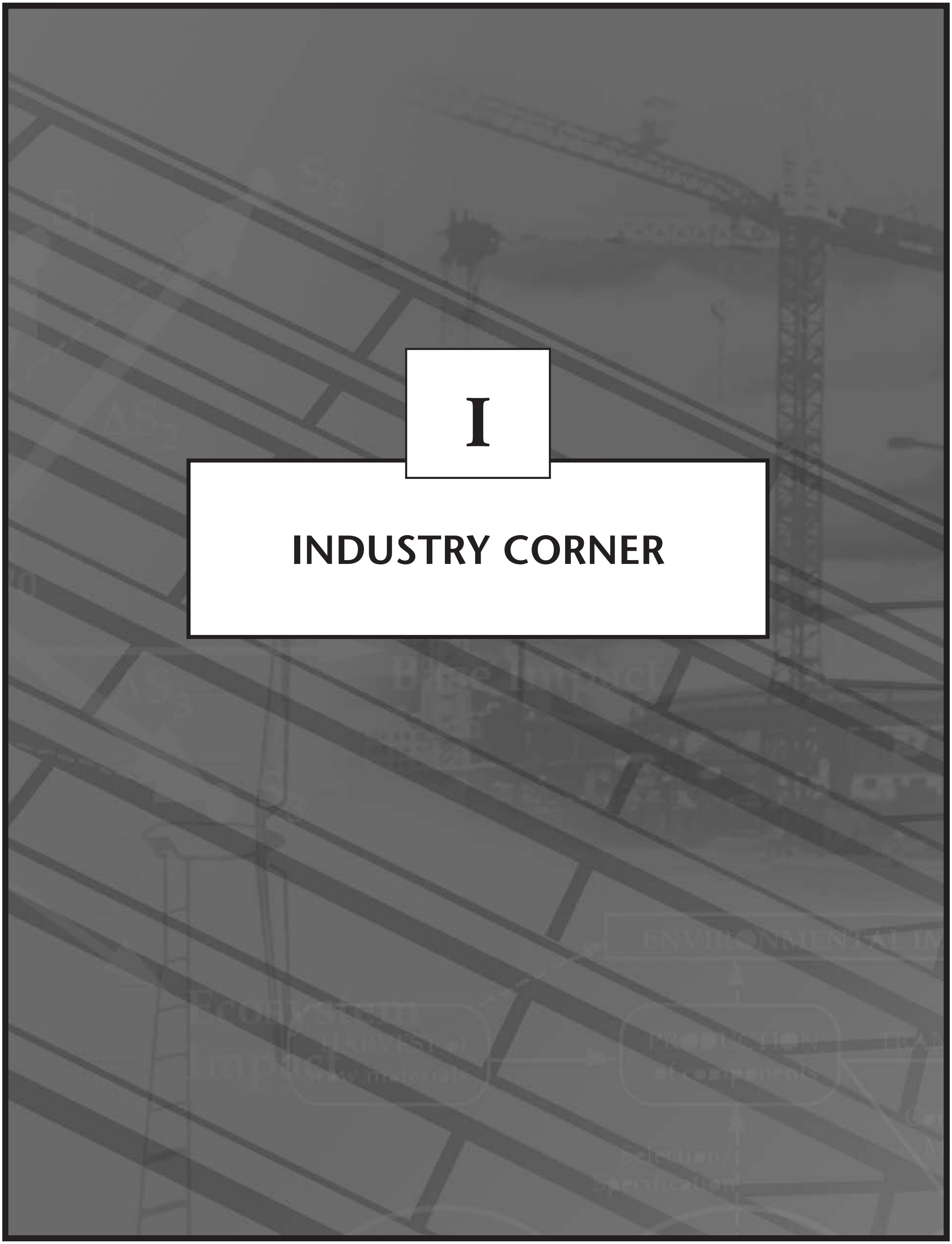

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INDUSTRY CORNER

NATURAL BUILDING MATERIALS IN MAINSTREAM CONSTRUCTION: LESSONS FROM THE U. K.

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INTRODUCTION

The concepts of "green building" and "sustainable construction" have received tremendous interest in North America in the past decade, as shown by the growth in the numbers of L.E.E.D.™ certified projects (Kibert 2005). Parallel to this has been a growing interest in "natural," "vernacular," or "traditional" building materials and techniques. Examples of these include straw bale construction and rammed earth construction. From an environmental point of view, these materials offer a low embodied energy and low embodied carbon alternative to conventional building materials such as concrete and steel (Woolley 2006, Walker 2007). In the case of straw bale construction, use is made of a waste material with excellent insulation properties. Other benefits of many natural materials include their ability to passively regulate humidity in a building, reduced toxicity, high thermal mass, and biodegradability at the end of life (Walker 2007).

There remain many barriers to the use of natural building materials in the mainstream construction industry, including a lack of scientific data to quantify their true performance (Woolley 2006) and lack of experience by the mainstream construction industry in using these materials. This leads to the perception that these materials are low-tech and have poor performance. This perception, however, is changing. There is a growing body of research that is quantifying the performance of natural building materials and showing that they can compete with conventional building materials. There are also some excellent recent examples of the integration of natural building materials in mainstream construction projects.

This paper describes three natural building material products that have been successfully integrated into mainstream construction projects in the United Kingdom: straw bale panels by ModCell; a hemp-lime composite called "hemcrete" and marketed by Tradical; and, rammed earth and unfired clay bricks. The information in this paper is based on interviews and site inspections undertaken by the author during February 2008. Some of the research supporting the use of these products will be described. Finally, some lessons and cautions for the use of these products in North America will be discussed.

A caveat regarding the limitations of this paper is in order. This paper does not claim to be an exhaustive review of natural building materials and their performance. Other references should be consulted for more details on thermal or fire performance, for example.

STRAW BALE GOES MAINSTREAM—MODCELL CONSTRUCTION

Straw bale construction is not a new idea. For approximately 100 years, straw bales have been stacked and plastered to create single storey buildings such as the 4Cs building in Haliburton, Ontario (Figure 1) (Vardy et al. 2006). There are several hundred of these structures in Canada and the United States.

As mentioned previously, straw bale construction offers many advantages, but traditional straw bale construction also has disadvantages that make it difficult to integrate with modern construction. Wall thicknesses and heights are highly variable, making it difficult to obtain level walls and straight corners. Bales must be protected during construction to ensure they do not become wet.

A U.K. company called ModCell has developed a product that overcomes some of the disadvantages of traditional straw bale construction. The ModCell concept was developed by structural engineer Tim

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FIGURE 1. Typical straw bale construction.

Mander of Integral Structural Design and architect Craig White of White Design, and is being marketed by Agrifibre. The concept uses prefabricated panels that consist of a timber frame, straw bale in-fill, steel reinforcement, and lime plaster. Prefabricating the panels ensures that panel dimensions can be closely controlled. The panels can be constructed off-site in a dry environment to ensure bales do not get wet.

ModCell uses a "flying factory" concept. Rather than having a centralized factory that produces the panels and ships them to a construction site, the panels are fabricated at a suitable location as close as possible to the main construction site. Often, it is the farm where the straw bales have been produced since a barn can provide a suitable construction facility. This approach reduces the transportation and environmental costs to fabricate the panels.

Figures 2 to 6 show the construction process for a typical ModCell panel. The panels are surrounded by a 3 metre by 3 metre timber frame shown in Figure 2. ModCell uses cross-laminated timber produced by Eurban, a German company. Wheat straw bales are then packed into the timber frame and trimmed as shown in Figures 3 and 4. Timber dowels are used to hold the bales in place and enhance the shear resistance of the wall. Plaster is sprayed onto the bales to a thickness of 35 mm and finished as shown in Figures 5 and 6. The plaster is a mixture of 6:1:1 lime to cement to sand by mass and has compressive strengths of 6 to 8 MPa at 90 days curing according to Prof. Peter Walker of the University of Bath (Walker 2008).

FIGURE 2. Timber frame for Mod-Cell panels (courtesy of Prof. Peter Walker).

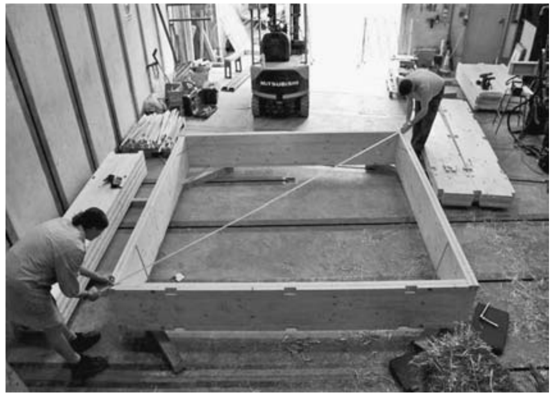


FIGURE 3. Stacking bales within Mod-Cell panel (courtesy of Prof. Peter Walker).

FIGURE 4. Trimming of straw (courtesy of Prof. Peter Walker).

FIGURE 5. Spraying of initial coat of plaster (courtesy of Prof. Peter Walker).

FIGURE 6. Finishing the surface of a ModCell panel (courtesy of Prof. Peter Walker).

FIGURE 7. Transporting ModCell panels (courtesy of Prof. Peter Walker).

Once the plaster is cured, the panels are then transported to the construction site, Figure 7, and can be installed in any type of conventional structural frame, Figure 8, including reinforced concrete, steel, and timber. Unpublished research at the University of Bath has been used to answer questions such as the possibility of damage during transportation of the panels and the need for steel reinforcement (Walker 2008).

Note that vapour barriers are not used in the panels, as would be used in conventional construction. The lime based plaster is vapour permeable, allowing the walls to breathe and passively regulate humidity in the building.

ModCell panels are currently used only as cladding in a load-bearing structural frame. ModCell intends to move into the housing market, in which case the panels would have to be designed as load bearing elements. Testing at the University of Bath is currently being undertaken to quantify the panel strength under vertical load. There is also other relevant research in the literature (U.K. paper) that clearly shows that straw bale panels are capable of supporting the loads typical of a bearing wall.

Knowle West Media Center

This two-storey building, Figure 9, was recently opened in Bristol, England. The total project cost was £3,000,000. It is located in a depressed area of the city, and provides media training and facilities for local youth. The local youth were directly

FIGURE 8. Craning ModCell panels into place.

involved in developing the architect's brief for the project. The youth wanted to avoid a typical institutional steel and glass façade. A proposal was made to incorporate ModCell panels in the structure, and was met with an enthusiastic response from the young people involved.

The primary structural frame for the building is reinforced concrete. Forty-three ModCell panels, Figure 10, provide the exterior cladding for the building. The plaster surface is exposed on the interior of the building, Figure 11. An advantage of using these modular panels is that the building can be expanded in the future if desired. The panels were constructed using bales from farms local to Bristol. Local businesses "sponsored" individual ModCell panels, and were then invited to participate in the fabrication of the panel.

The panels were craned between the concrete columns. It was noted that the construction crews required education in terms of ensuring the panels were kept from direct exposure to driving rain before being installed in the concrete frame.

The building has a number of other innovative green features. The ventilation and cooling in the building is provided through a system that automatically opens and closes the exterior windows. A weather station on the roof of the building senses changes in weather and adjusts the windows as required. Heating is provided by a wood chip furnace. Rainwater is collected and used for toilets.

Torfaen Environmental Building

The Torfaen Environmental Building, Figure 12, was constructed in 2006 in an industrial park located in Cwmbran, Wales. Formerly, a steel framed, single storey light industrial building stood on the site. This building was taken down, and approximately 86% of the materials recycled. The con-

FIGURE 9. Knowle West Media Center.

FIGURE 10. ModCell panels.

FIGURE 11. ModCell panel finish on interior of Media Center.

crete pad was left in place to be re-used for the new building.

The new building was designed to showcase sustainable building design. The walls of the building use ModCell panels, Figure 13. However, in order that the building design is as flexible as possible, the bales were not plastered. The ModCell panels were transported to the building site, erected on the concrete pad, and subsequently filled in with bales. A total of 432 locally sourced wheat straw bales were used for the project. The interior surface of the bales is covered with a fibreboard product called Bitrock. The exterior walls are protected by a vapour barrier and cedar siding. The roof is supported by glulam beams. Straw bales were inserted between the roof beams for insulation. Other features include extensive use of natural light and ventilation, rainwater collection for use in toilets, cellulose and recycled denim insulation for the end walls, and a small solar panel, Figure 14.

The total project cost was £300,000, and the total build time was 20 weeks.

HEMCRETE—CARBON NEGATIVE INSULATION?

Hemcrete, shown in Figure 15, is a composite of a lime binder and the woody core, called hurd, of hemp plants. The hurd is milled to particles of about 10–15 mm in length, and excess fibre and dust is removed. The lime is typically combined with a small amount of cement to reduce the curing time. This lightweight mixture has proven to have excellent

FIGURE 12. The Torfaen Environmental Building.

FIGURE 13. Typical wall panel.

FIGURE 14. Photovoltaic solar panel on Torfaen Environmental Building.

FIGURE 15. Hemcrete.

insulation properties, as indicated by recent research. Arnaud and Samri (2007) indicated that the insulation value of hemcrete, although a function of the relative humidity, is similar to that of aerated autoclaved concrete.

Hemcrete is not a new concept and has been used in France for at least 20 or 30 years. However, it has recently found new interest, and two companies in the U.K. are working to bring it to the mainstream construction market.

Hemcore is a British company that specializes in the production and processing of hemp. They partnered with Lime Technology, which specializes in various lime mortars. They are marketing hemcrete as Tradical. The hemp hurd and binder, Figure 16, are sold in separate bags to be mixed onsite using standard equipment. The mix can then be placed in formwork between the structural framing. Typically this will be a timber frame, but Figure 15 shows an example of hemcrete being placed between cold-formed steel studs. It would typically then be covered with a lime plaster, Figure 17, to protect it from exposure to the elements, although the interior surface can be left exposed, Figure 18. The typical thickness of a hemcrete wall in a building is 500 mm, resulting in thicker walls than conventional construction, Figure 19.

For larger projects, hemcrete is sprayed in place. Shuttering is attached to the structural frame, Figure 20(a), and then sprayed onto the surface using an air-pressurized tank and nozzle, Figure 20(b). The shuttering can be left in place to provide the interior surface, or removed. Many projects in the U.K.

FIGURE 16. Tradical hemcrete: (a) Hurd; (b) Lime binder; (c) Mixing Tradical.

(a) (b) (c)

FIGURE 17. Finishing hemcrete with lime plaster.

FIGURE 18. Exposed hemcrete surface on interior of building.

are using Heraklith-BM for the shuttering. This is a magnesite bound wood fibre board produced in Germany. The Heraklith board is vapour permeable, which makes it compatible with hemcrete, and also provides a good bonding surface for the sprayed hemcrete.

Hemcrete has many advantages. It provides insulation and thermal mass for the building. No vapour barriers are needed for the walls. As hemp grows in the field, it removes carbon dioxide from the atmosphere. Once the hemp is harvested, processed, and placed in the walls of a building, the CO_2 is sequestered for the life of the building. Lime Technology, in fact, markets Tradical as a carbon *negative* product as compared to a typical building insulation system. Some evidence has been presented in the literature to back this claim, e.g., Arnaud and Samri (2007) who compared the embodied equivalent CO_2 emissions for several insulation products. It should be emphasized that this paper presented only final results and did not describe the analysis used. It is assumed the comparison is based on production values for France and so may not be directly applicable to the North American situation.

FIGURE 19. Hemcrete wall.

Hemcore and Lime Technology are pursuing an aggressive strategy for bringing Tradical to the mainstream construction industry. Lime Technology opened a factory in Milton Park, Didcot, Figure 21, dedicated to mixing Tradical lime binder. It has been producing bagged lime binder since June 2007. In addition, hemcrete blocks using Tradical, Figure 22, are produced at the plant. Both load-bearing and non-load bearing blocks are produced. The load bearing blocks can be used in place of typical cement blocks for wall construction, providing a lower carbon option. The non-load bearing blocks are used for insulation in-fill in a structural frame. A lime mortar is used to join the blocks.

Hemcore now processes 3,000 to 4,000 tonnes of hemp straw per year and plans on increasing its production tenfold over the next five years. A new factory is under construction and will process 50,000

FIGURE 20. Spraying hemcrete in place: (a) Shuttering; (b) Spraying (accessed from WISE Web site).

(a) (b)

FIGURE 21. Lime technology plant in Didcot for producing Tradical lime binder.

tonnes of hemp straw per year. The number of employees will grow from 11 to 35, and gross revenues of the company are anticipated to grow from £1.3 million per year to £13 million per year over that period. According to Hemcore's Managing Director, Mike Duckette, the driver for this growth is the anticipated interest in the use of Tradical by the construction industry.

The largest projects for which Tradical has been used to date have been the Adnam's Distribution Centre and the Three Gardens project in Elmswell, Suffolk. Adnam's Distribution Centre was a £6,000,000 project with a structural steel frame and glulam roof beams. The steel frame was infilled with 1000 m^3 of hemcrete, which provides all the insulation for the building. The Three Gardens project involved 26 affordable housing units. Each unit was timber construction and infilled with hemcrete.

Centre for Alternative Technology (CAT)

The Centre for Alternative Technology (CAT) is located near the town of Machynlleth, in western Wales. The centre was started in 1973 as a means of showcasing green technologies. It is now one of the most visited tourist destinations in Wales.

In 1993, a Graduate School of the Environment was started at the CAT facilities by several professors from the Department of Architecture at the University of East London. The program offers a Master of Science (M.Sc.) in Advanced Environmental and Energy Studies and an M.Sc. in Renewable Energy and the Built Environment. Approximately 100 students are currently enrolled in the program. Although all teaching takes place at CAT, the degree is offered through the University of East London.

A new facility, Figure 23, to house the graduate program is currently being constructed. Called the

FIGURE 22. Hemcrete blocks.

FIGURE 23. Architectural rendering of WISE building.

Wales Institute for Sustainable Education (WISE), this £6.2 million project will include a lecture hall, residences, and a laboratory. The walls of the residences are under construction. They are a timber frame with hemcrete being sprayed for the insulation, Figure 24. One of the leading construction companies in Wales, Frank Galliers, is undertaking the construction and gaining important experience in the use of hemcrete in a large construction project.

Lime Technology Office

Construction on the Lime Technology office, Figure 21, in Didcot Park was undertaken in 2006. The existing building was a typical steel framed industrial building. The ends of the building were offices using conventional cement blocks and brick for the infill walls. These walls were removed and replaced with a 500 mm thick wall of hemcrete. The hemcrete was subsequently covered with a lime plaster. The resulting modern offices, Figure 25, are currently being monitored for temperature to assess the thermal performance of the building. It is anticipated that the results of a full year's monitoring will be published by Lime Technology later in 2008.

FIGURE 24. Residence walls under construction.

FIGURE 25. Interior of typical office in Lime Technology office.

UNFIRED CLAY BRICKS AND RAMMED EARTH

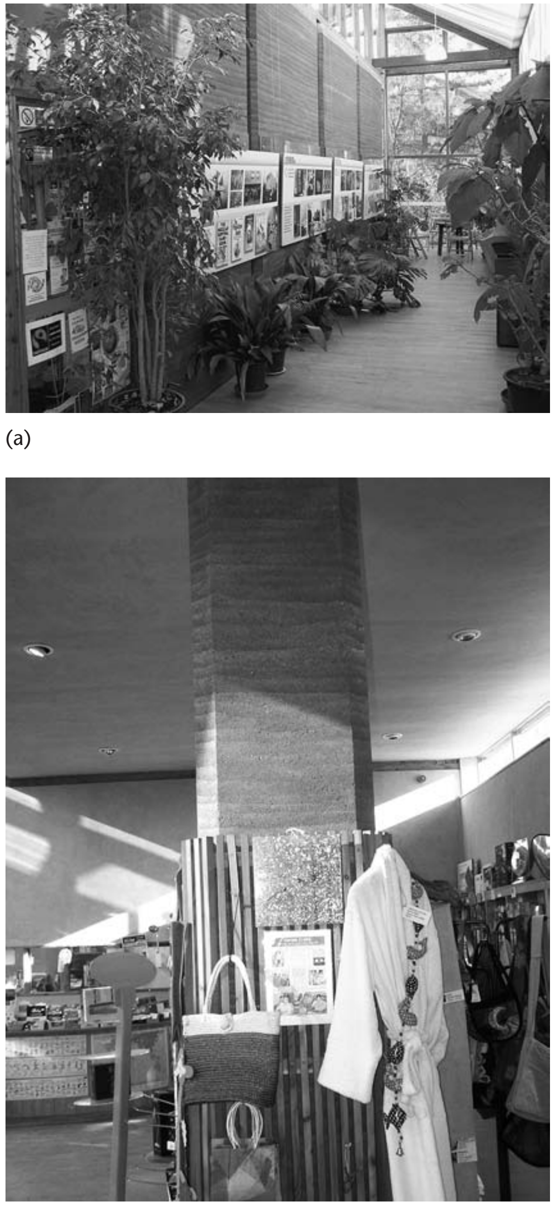
Unfired clay bricks and rammed earth are two more ancient technologies that are finding increasing use in modern sustainable buildings. Clay and sand are mixed with water and then placed in formwork to either form bricks, Figure 26, or walls or columns, Figure 27. Often soil from the building site is used, resulting in an extremely low embodied energy structural element with high thermal mass. Conventional fired clay bricks require large amounts of energy for their production and result in the release in large amounts of carbon dioxide.

Unfired clay and rammed earth must be protected from exposure to the elements, so in most cases they are only used for interior elements. Figure 28 shows the use of rammed earth for interior walls and columns in the CAT. These elements have been located in the building to take full advantage of their thermal mass. The main lecture hall of the

FIGURE 26. Unfired clay bricks.

FIGURE 27. Rammed earth wall.

FIGURE 28. Rammed earth at the CAT: (a) Interior wall; (b) Interior column.



(a)

(b)

FIGURE 29. Formwork for rammed earth walls of WISE lecture hall.

FIGURE 30. Unfired clay bricks being used for partition walls in Lime Technology office.

WISE centre will have rammed earth walls. These walls are currently under construction, Figure 29. Unfired clay bricks were used for interior partition walls of the Lime Technology building, Figure 30, and subsequently covered with a lime plaster.

LESSONS AND SUMMARY

In many respects, the state of "green" and "sustainable" construction in the U.K. is similar to that in Canada and the United States. Most companies tend to ignore it, or if they do consider it, it is in terms of making marginal improvements. The integration of natural materials such as straw bale, hemcrete, and rammed earth into designs offers real opportunities to design truly low carbon buildings.

The U.K. examples provided in this paper prove that natural building materials can be successfully used in large-scale, mainstream construction projects. ModCell and Tradical hemcrete have shown that it is feasible to integrate natural materials with modern materials such as concrete, steel, and engineered timber to take advantage of the best each material has to offer. These materials have been used in a wide range of applications and project sizes, from residential housing, to single storey industrial buildings, office buildings, and large-scale warehouses. These projects range in value from a few hundred thousand pounds to several million pounds.

The development of Tradical hemcrete is of particular interest. The fact that Lime Technology and Hemcore are willing to make significant investments over the next five years to develop the infrastructure to bring this product to the mainstream indicates that they have confidence that this material can make inroads. Lime Technology recently partnered with U.S. Heritage Group to import Tradical to North America. Tradical Hemcrete can now be obtained in North America through American Lime Technology.

One of the lessons clear from the U.K. experience is the need to fund the research needed to develop and understand a natural material so that engineers and architects will have the confidence to use it.

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COMPANIES AND GROUPS CITED

American Lime Technology
www.americanlimetec.com

Building Research Institute Centre for Innovative Construction Materials
www.bath.ac.uk/ace/BRE-Welcome/

Center for Alternative Technology (Wales), Wales Institute for Sustainable Education
www.cat.org.uk

Eurban
www.eurban.co.uk

Hemcore
www.hemcore.co.uk

Integral Structural Design
www.integral-sd.co.uk

Lime Technology
www.limetechnology.co.uk

ModCell
www.modcell.co.uk

Tradical
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White Design
www.white-design.co.uk

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