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Lime Hemp

A potential solution to a concrete problem?

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A provocation

"We can't solve problems by using the same kind of thinking we used when we created them."

Einstein

This article is intended to act as an exploration and provocation. Why do we build the way we do, what effect does that have? Could we for instance, design and specify buildings that actually benefit the Environment rather than burden and pollute it as currently. Is it possible that the construction of a house could *absorb* CO_2 thereby transforming new housing estates or apartment buildings into giant absorbers of carbon dioxide? Imagine Ireland being able to count commercial constructions or new housing among its 'carbon sinks', in place of Siberian forests or the carbon credits that the Government will have to trade for at tax payers' expense, to meet the Kyoto Protocol targets? Why not? It's all possible!

Cement in the limelight

Cement and its derivatives (mass and reinforced concrete, concrete blocks, mortars and renders) are ubiquitous. Concrete, clear float glass and steel have become the badges of modernity. High-rise New York, the great bridges of Denmark, the Three Gorges Dam of China or the masterpieces of Mies, Foster or Ando are inconceivable without them. The Developed World uses these materials without question, without stop, and the business people, politicians and town builders of the Developing World see them as the mark of civilisation and progress.

Ordinary Portland Cement (OPC) was invented as an artificial hydrated lime that allowed mortar (made from it) to set under water. It was patented in 1824 and was an expensive specialist product till the first decade of the Twentieth Century due to requirement and cost of grinding it in industrial plants. Initially cement mortars were as flexible as lime mortars but over time their specialist use for engineering structures encouraged stronger mixes. Today it is a very different material to hydrated lime or other lime-based products.

Lime has been used as the preferred binder of building materials in many cultures throughout history. Up till the middle of the last century it was the base ingredient of mortars and renders everywhere *because* it could be made almost anywhere using local limestone sources in local kilns. This advantage had the attendant drawback of quality varying from place to place. In general lime production remained a cottage industry. The requirements of 'total war' and the new world order that followed WWII created a bias towards industrial processes and an insatiable demand for large scale civil engineering and housing projects. Everything was to be uniform, strong, progressive and modern. OPC fitted this view but lime did not. It would appear that by the early 1960's lime was totally supplanted in the Western World and knowledge of its uses and application had begun to be forgotten.

At what cost success?

The Irish Concrete Federation, which will be giving a paper at the forthcoming Irish Sustainable Building Show, is correct in stating that '*After water, concrete is the most used material on earth*' (go to seminars at www.sustainablebuildingshow.com). But at what cost has this growth occurred?

The Green Building Handbook, Volume 1 (edited by Professor Tom Woolley of University of Ulster) states that cement manufacture is the main significant contributor to CO_2 emissions after fossil-fuel burning and is responsible for 8-10% of the world's annual CO_2 emissions and rising. Ian Pritchett of Lime Technology Ltd states that 280 billion tonnes of CO_2 have been released into the atmosphere from the consumption of fossil fuels and cement production since the start of the Industrial Revolution, more than half of this since the mid-1970's.

As we all now know CO_2 emissions and climate change are directly linked. The *Intergovernmental Panel on Climate Change* recommends a global reduction of more than 50% in CO_2 emissions by 2050. The *International Symposium on the Stabilisation of Greenhouse Gases*, based in the Hadley Centre (UK), reported in early 2005 that 'large scale, irreversible system disruption' was likely after a 3° rise in temperature. Various sources estimate that within 4-10 years time the volume of CO_2 particles in the atmosphere will be sufficient to result in a permanent rise of 2°C worldwide. This means action in all sectors of society is needed *now*, particularly in the energy generation and construction industries. It clearly can't be put off for a further decade.

The gravity of *The Green Building Handbook*'s information in this context seems wholly at odds with the Irish Concrete Federation's claim that there is a '*negative perception of concrete which has been carefully cultivated by various interest groups*' with regard to concrete's sustainability (see weblink above). OPC Concrete may be an amazing material but it is *not* sustainable. Surely all of us, even those who currently specify it, must form part of the 'interest group' that wishes to curb climate change.

Across the Irish Sea the British Cement Association (BCA) is beginning to face up to its role in environmental degradation. Its report from 2002, '*Cement, Concrete & Sustainability, A report on the Progress of the UK Cement and Concrete Industry towards Sustainability*', comprehensively lists various effects of cement and concrete production from employment, to transport to emissions. It also explains how they are trying to reduce a wide range of negative effects. The extract from Table 1 of that report, for instance, shows a 10% reduction in CO_2 emissions in 7 years.

BCA's efforts are a good example of an organisation trying to incrementally reduce the negative effects of its products. While their efforts are laudable, they are only intermediate steps and not fast enough in the context we are facing. Indeed the whole Construction Industry must strive to adopt *beneficial* practices and materials, and not be content to focus on reduced negative effects. It is easier for all of us to continue doing what we know: we just can't afford to.

So what are alternatives?

I agree with Ian Pritchett's view that as a first step cement and concrete should be restricted to their unique selling point: high-strength and specialist uses. Even in that niche use reduced cement content and reduced emissions are possible. As I hope to show there are other low-energy alternatives to OPC in concrete that could become the mainstay of commercial masonry construction, especially where that construction is low-rise or mass housing.

Directly comparable alternatives include 'eco-cements', limecrete, geo-polymeric cements and magnesium carbonate compounds. Among the brand names of these are 'Carbunculus' and 'Tececo'. In recent years Ecocem a DublinPort-based company is manufacturing a strong, white-coloured cement by grinding granulated blast furnace imported from the Low Countries. As the blast furnace slag is a waste product from steel manufacture the CO_2 penalty has already been paid. Its real value is the OPC production it can offset. Further alternatives are timber, bamboo, lime-hemp, cob, adobe bricks and rammed earth. All of these could also be developed as lower energy, sustainable alternatives for various characteristics of cement-based products. Lime-hemp composites seem to be particularly exciting alternatives to concrete. Pat Borer in Wales, Tom Woolley in Northern Ireland, Ian Pritchett near London, Lawrence Brown in Normandy are just some of the people investigating lime-hemp in wall construction in this part of the world.

Given the conservatism of the mainstream construction industry one strategically-sound approach to effecting change is to relate it to current building and design practices. An example of this is retaining block-work construction as a construction methodology, but moving to low energy or low emission ingredients. In that way for instance blockies need only minimal re-training to lay lime-hemp (or other) blocks, engineers need adapt the figures they input, but not their understanding of transfer of load in a wall, and quantity surveyors can still estimate volume of masonry per length of wall etc. This is the approach Limetec are taking. They are currently conducting trials into engineered, load-bearing lime-hemp blocks. They hope these will be commercially available within a year.

Materials in construction- cement

In cement's early day it shared many characteristics of hydraulic lime, it was less strong than the blocks it bound and it had some flexibility. However as civil engineering projects grew more ambitious and as the ready-mix concrete industry developed cement was made to be increasingly strong, and with that increasingly brittle. While my parents' solid wall house, constructed in the early 1950s of cement mortar and concrete blocks, has never cracked or leaked, the same design would have been at risk by the early 1970s due to this change in cement composition.

For the first time mortar joints were found to be stronger than the blocks themselves. This meant that where movement occurred it could crack the blocks as quickly as the mortar joint. The lack of flexibility also meant that even small amounts of wall movement could lead to permanent cracks. Increasingly during the 1960s cavities became popular in block-work wall construction to reduce the risk of water penetration to the inside face of the wall.

Expansion joints were introduced into block-work walls, and into the cement render finish even where a movement joint in the block-work was not required due to this inflexibility. A whole range of new ties, restraints, de-bonding sleeves, expansion joint beads, external leaf lintels etc were invented and popularised to accommodate these changes. After the second Oil Crisis insulation was increasingly inserted into these cavities and the partial- and full-fill insulated cavity wall systems were born. I have ample experience that these forms of construction are difficult to build right and have read studies of their poor thermal performance. Perhaps we need to re-discover solid wall construction?

Materials in construction- lime

The following are some of the reasons lime lends itself to solid wall construction. It is weaker than masonry blocks, which means it accommodates whatever movement is necessary. When cracks *do* occur they occur as multiple tiny fissures, not one large crack. Debris, dust and tiny pieces of mortar lodge in these fissures over time, which coalesce back into a solid lime mortar with the help of the next rainfall. This ability is called 'autogenous healing'. Because of its hydroscopic characteristics walls breathe through the lime mortar and lime render. It has been shown that masonry in walls with cement mortar have a shorter life span because the only way the wall can breathe is through the masonry not the mortar.

Ian Pritchett of Limetec also highlighted three environmental characteristics of lime mortar:

1. It has approximately 30 to 50% lower CO_2 emissions than OPC overall. This is because it is fired at a lower temperature, but it also re-absorbs back a greater amount of the CO_2 it emitted than cement.

2. It also has a lower embodied energy input than OPC. Between 50 & 70% less energy (depending on lime type used) goes into making a lime-based standard type IV masonry mortar compared to a cement-based one.

FIGURE 1

Image Courtesy of Lime Technology

He feels one of its greatest advantages is its ability to act as a binder of low energy, sustainable materials such as earth, wood-wool (from timber chippings) and hemp

Materials in construction- hemp, and lime-hemp

Hemp is another material with remarkable properties.

a) Hemp can grows from seed to 3 metres in six months, it therefore grows faster than any other plant except bamboo. Per acre it generates far more biomass than commercial forestry.

b) As it does not take from the soil, land does not need to lay fallow after harvest. Irish farmers can therefore grow a crop, part of which becomes a construction material and another part of which can become clothing, cosmetics, paper etc *in rotation with* their usual food crops. Imagine construction in urban centres having a direct positive impact on nearby rural economies!

c) Hemp, like all plants absorbs CO_2, it then emits the oxygen and uses the carbon as a building block of its growth. Pritchett states that one kilo of plant material typically uses 1.7kg of carbon dioxide in its production.

d) Pat Borer's team researching the best materials for the Centre for Alternative Technology's WISE Building has obtained a K-value of 0.10W/mK in the first stage of development of their lime-hemp blocks. They have high hopes that they will obtain a value of 0.07 W/mK. In my calculation I use 0.10W/mK in relation to Pritchett's blocks which may be an over-simplification as denser lime-hemp blocks will be physically stronger but thermally weaker.

[research since this article was published has shown that a wall of 350mm thickness of hemp-lime sprayed or cast around a timber frame, finished with render and plaster will give a U-value of ~0.27W/mK^2. Note that decrement delay, due to its thermal mass, should give a thermal performance far exceeding this – see below]

FIGURE 2

Image Courtesy of Lime Technology

A final remarkable characteristic is that lime-hemp walls retain heat longer due to their specific heat capacity, so they can have some of the thermal characteristics of insulation and some of the thermal mass characteristics of heavy mass materials, like concrete. This was seen to good effect in a BRE study of the Haverhill lime-hemp houses in Sussex.

CO_2 Sequestration

In an as yet unpublished paper, *Ecobuild Chapter on Lime and Low Energy Masonry* Pritchett posited the idea that due to lime and hemp's special characteristics lime-hemp masonry walls could act as carbon sinks. I found this idea fascinating and, as Pritchett had sent me a lime-hemp block sample, decided to work out how significant the absorption might be.

As a way of teasing out the environmental value of load-bearing lime-hemp construction for mass housing, I endeavoured to:

1) Establish a wall construction that was buildable and could meet various U-values, starting with the minimum thermal standard under the Building Regulations.

2) Estimate the volume and mass of 1sqm of wall and then quantify the associated CO_2 emissions, using Pritchett's figures.

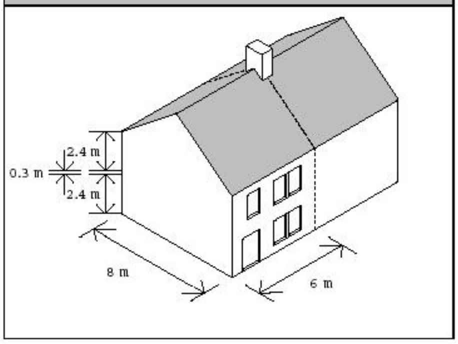
3) Compare the walls of two houses of the same design, but different constructions, for their effect on CO_2: one being a concrete block cavity wall, the other lime-hemp solid wall construction.

I deliberately chose the design of a typical two storey semi-detached house shown on page 63 of Technical Guidance Document L (2002) to the Irish Building Regulations (see diagram above). It features partial-fill cavity walls on strip foundations. I designated this Version 1. I felt that if I were to maximise the carbon sequestration benefits of hemp and the solid wall potential of lime the second house, Version 2, should be of thick solid wall construction. It therefore has the same design and external area but thicker solid 450mm lime-hemp walls (see diagram below). These walls result in 6.4% less space internally (or 2.5sqm less per floor). I judged this could be a reasonable sacrifice for a householder to bear if I could prove that the benefits were sufficient.

FIGURE 3

Image courtesy of TGD L

Diagram 34 *Para. E.1*
Semi-detached house



Buildability & thermal performance

As you can see the bond I propose is a variation on the English Bond. Like all good masonry bond patterns the first priority is to ensure a good overlap of blocks and the reduction, wherever possible, of a line of vertical joints through the wall. While there is more block-work in this wall than a cavity wall, the blocks are lighter and there is a complete lack of complication, i.e. the traditional bug-bears of partial fill cavity walling (cavity cleaning, fixing of ties and perfect positioning of insulation) are all absent. It must therefore be simpler to build and possibly as fast.

From a supervision or certification point of view there is very little to go wrong. The lower level of skill may suit it to the self-build market as much as mass housing. It was even suggested to me that the technology may be suited to wall-building machines.

Finally the omission of various ties, and lintels to the outer leaf should help to offset the cost of the greater number of blocks. A detailed cost comparison would be interesting.

Using the U-value calculator 'Uvaluate' (freeware from Xtratherm Insulation company) one can quickly establish figures for the two walls. The partial fill cavity wall meets the $0.27W/m^2K$ standard with no allowance for on-site error. However using Pat Borer's initial test results of 0.10W/mK, I found that the lime-hemp wall had a U-value of $0.21W/m^2K$, *without* the thermal contributions of insulation, render or cavity! The addition of only 60mm of Rockwool insulation is enough to bring it to the 'super-insulation' standard of $0.15W/m^2K$. For the sake of finishes and waterproofing an external render and internal plaster would be used in any case.

Comparing the role of CO_2 in the walls of the two houses

I immediately ran into the problem of verifying data. Several of my sources differed, with the cement industry tending to give more conservative figures. In some cases the opposite occurred: Professor Woolley wrote in a 1997 book that *'the manufacture of cement from chalk or limestone involves a chemical reaction in which carbon dioxide is given off at a rate of 500kg tonne^{-1}'*. Due to BCA-reported improvements of 13% between 1996 and 2001 I had initially revised his figure downwards by the same amount. However Pritchett informed me that a leading UK cement company told him recently that they had just dropped below 1000kg CO_2 per tonne.

I also was unable to get certain kinds of figures from anyone. Some kinds of data, such as the embodied energy of lime-hemp, simply haven't been calculated yet. It must be seen therefore

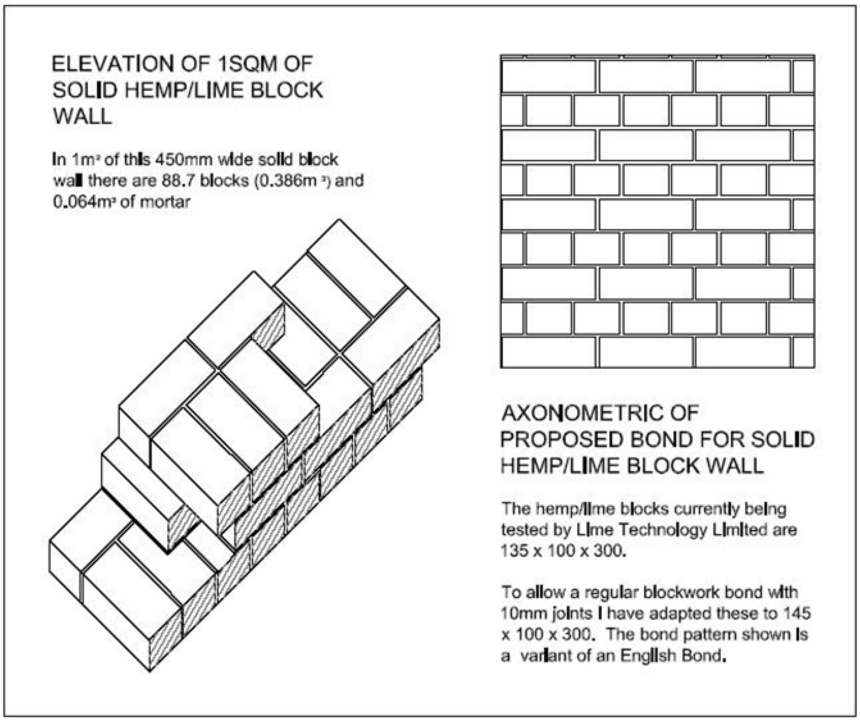


FIGURE 4

Elevation of 1sqm of solid hemp/lime block wall

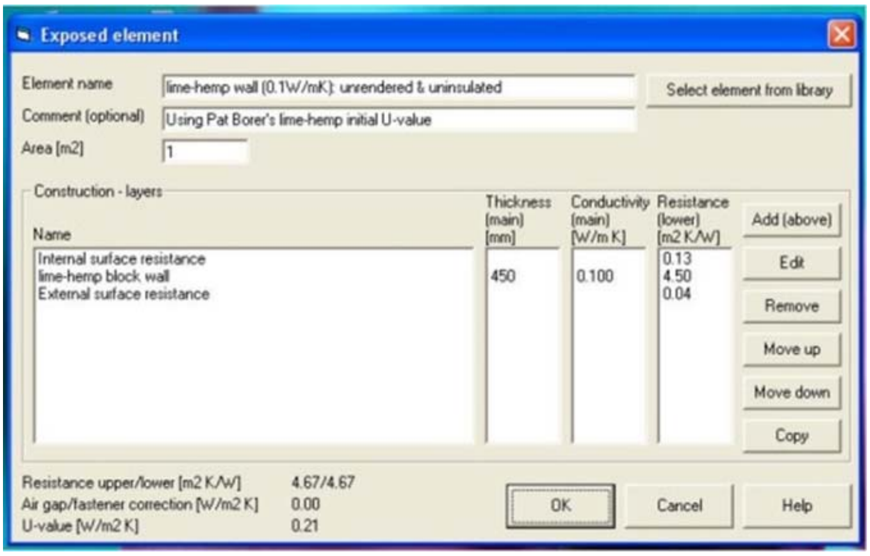


FIGURE 5

Image from Uvaluate, courtesy of Xtratherm

that my calculations (see Appendix 1 on the 'Construct Ireland' website version of this article) are illustrative rather than conclusive.

It is worth noting that my focus has been on establishing the CO_2 emissions associated with *manufacture* of lime and OPC (including, mining, packaging and initial transport), and the CO_2 sequestration of hemp and lime-hemp.

I have relied heavily on Limetec's information for this (see Appendices 2 & 3 on website). I have not focused on the embodied energy of transporting these materials to site, on actually building the houses or the CO_2, or embodied

energy, of any other building materials that would be built into those houses.

This is due to the limited time, the imperative of dealing with CO_2 and the difficulty I experienced in getting figures for all the 'actors in the play'. All of this could do with a great deal more study. Obviously a truly sustainable design approach would not stop at a 3 bed semi-D or a low-carbon specification but would include orientation, building type, urban planning, transport connections etc.

Results

I found in my quick study that the manufacture of blocks for the OPC concrete block house (Version 1) *emitted 6.44 tonnes* of CO_2, but the manufacture of the lime-hemp blocks for the Version 2 house *sequestered between 14.2 or 4.7 tonnes* of CO_2. The latter figures depend on whether one assigns the CO_2 associated with the whole plant or the shiv (its woody core) only to this construction material (see Appendices 1, 2 & 3 on website version).

For the sake of argument it is therefore possible, due to the change in block specification alone, that a 100-unit housing estate of the same 3 bed semi-Ds could result in 2.06 KTonnes less CO_2 in the Atmosphere. This is based on the following simple calculation: (100 x 6.44T) + (100 x 14.2T) = 2,066T. This is because the OPC-based emissions were prevented and the lime-hemp substitute absorbed further atmospheric CO_2.

But are these figures significant? Given that www.guardian.co.uk lists the UK's annual CO_2 emissions as 556.9 Mtonnes, it can be seen that the blocks of my 100 houses will not change current trends on their own. It would take the manufacture of building blocks for ~270,000 housing estates to equal the UK's national emissions figure! What I think is powerful about lime-hemp as a material is that the substitution creates (1) an environmental *benefit*, (2) an easier form of construction, (3) a higher thermal performance and (4) even gives local farmers the ability to grow 'building supplies' in rotation with food crops. How many materials can boost equivalent advantages?

Moving Forward

Believe it or not a few materials can! Limetec is also conducting research into compressing earth blocks *on site* from the material excavated during the build process and significant research and test cases are underway elsewhere for other materials such as cob and earth-hemp composites. Due to the environmental penalty I believe we need to replace OPC-based concrete in non-specialist applications as soon as possible. If Limetec's trials proceed as planned there will be reliable, commercial and environmental alternatives to OPC concrete blocks available in the UK within 2 years and hopefully in production in Ireland shortly after. The alternatives to OPC-based poured concrete (listed above) are currently available as a niche market but this can change if designers and clients start specifying them.

I hope this study shows that one can create an environmental design and lower impact structure from the very first block on site. It is not necessary to wait till expensive, high performance insulation, sophisticated claddings, building management systems or energy generating devices are installed to see an environmental benefit. We can get it right, indeed we *need* to get it right, in every phase of the building, housing estate or town's construction, right from the first block or pour. While these materials could and should be integrated into sophisticated low-energy (or low-carbon) buildings, heavy, simple and dumb also has a lot to offer!