

**Institution: University of Bath**

**Unit of Assessment: 16: Architecture, Built Environment and Planning**

**Title of case study: Bio-based Materials in Construction: development and impact of prototype test buildings BaleHaus and HemPod**

### 1. Summary of the impact

Over the past 13 years the University of Bath has been leading research into low-impact bio-based construction materials, including the construction and testing of two full-scale prototype buildings: BaleHaus (2009) and HemPod (2010) built on campus. The research has directly promoted: the development and wider market acceptance of award winning low carbon construction products (ModCell<sup>®</sup> and Hemcrete<sup>®</sup>); successful delivery of award winning buildings; and the wider sector uptake of these technologies, including in a new school building in Bath. The work has directly benefited industry partners working to meet UK Government policy requirements to deliver low carbon infrastructure and benefited society through the delivery of affordable sustainable buildings.

### 2. Underpinning research

The research on crop based construction materials has been led by Peter Walker (1998-date: Senior Lecturer, Professor) in the Building Research Establishment's sponsored **Centre for Innovative Construction Materials** (CICM), with input from Michael Lawrence (2004-date: Research Officer, Lecturer), Andrew Heath (2003-date: Lecturer, Senior Lecturer), Andrew Shea (2008-date: Lecturer), Katharine Wall (nee Beadle: 2011-13: Research Officer), Christopher Gross (2008-09: Research Assistant), Kevin Paine (2007-date: Senior Lecturer), Andrew Thomson (2012-date: Research Officer), and Ian Molesworth & Edward Hirst (2007-2013: PhD students). The research has also contributed to and benefitted from collaborative national and international links, including: Yates (BRE); De Wilde, Goodhew and Carfrae (Plymouth); Littlewood (UWIC); Morel and Arnaud (ENTPE, France); MacDougall (Queens University, Canada); Dick (University of Manitoba, Canada).

The research comprises two aspects: fundamental scientific characterisation of material performance; and the development of technically innovative construction solutions. The research covered here considers two related fields of work: prefabricated straw bale construction and the development of the test building BaleHaus; hemp-lime construction and the test building HemPod.

#### BaleHaus:



Straw bale construction utilises a widely available agricultural co-product to form highly insulated walls. Walker began by leading novel research on developing the technical understanding of load-bearing straw bale construction in 1999. Based on this initial work, in 2005 ModCell Ltd approached Walker to collaborate in their development of prefabricated straw bale cladding panels. Collaboration started with simulated wind loading tests on panels for the award winning Eco-Depot project in York, and has subsequently led to a series of UK Govt., and most recently EU (EACI) sponsored research projects. At first this work focussed on structural and durability aspects of the panels, leading directly to refinements in panel design for enhanced structural performance (and 20-30% cost savings compared to the pre-research product design) and better understanding of moisture transfer through panels and development of improved specifications.

Directly as a result of this research, it was evident that the panels could also be used to form low rise load-bearing walls. The BaleHaus project included construction and performance testing of a prototype two-storey house on campus at Bath [2]. As well as structure and weathering analysis, tests improved understanding of fire, acoustic and thermal performance. Bath's direct contribution to the development of straw bale construction during the REF period includes: leading grant capture activities (total research investment to date exceeds £3 Million); completing all constituent material and component design & performance evaluations, including structural and environmental performance [5]; developing computer design models; developing novel test protocols and

specifications; leading testing and monitoring of straw buildings [4,6]; product design development.

**HemPod:**



Hemp-lime is a novel bio-based composite formed from a mixture of hemp shiv and a hydraulic lime-based binder. Walker began working on hemp-lime construction in 2002, exploring effects of hemp-binder water exchange on the properties of the composite [3,6]. A DEFRA sponsored project at Bath has been undertaking fundamental work on hygrothermal (heat and moisture exchange) and structural performance of hemp-lime materials [1], including construction and performance testing of the HemPod building on campus. This work has directly contributed to improving thermal modelling of hemp-lime buildings, such as the Science Museum building at Wroughton (2012), and the award of a British Board of Agrément certificate for Hemcrete® (2011). Bath’s research contribution to the development of hemp-lime construction during the REF period includes: leading grant capture activities (total research investment to date exceeding £1 Million); completing constituent material characterisation and development, including binder and mix design; establishing novel test protocols and material specifications; product design development.

Kevin McCloud commented on the BaleHaus project at its opening in November 2009: “Right now there are a number of exciting technologies emerging in construction, but what we lack is the performance data of the different technologies ... it will be really interesting to see how this building performs” (see <http://www.youtube.com/watch?v=7ILMevwSj84>).

**3. References to the research**

1. Gross, C., Walker, P. and Pritchett, I., 2013. [Compression resistance of confined timber stud walls](#). *Proceedings of the Institution of Civil Engineers: Construction Materials*, v 166 (3), pp. 175-183. DOI: [10.1680/coma.11.00047](#).
2. Wall, K., Walker, P., Gross, C., White, C. and Mander, T., 2012. [Development and testing of a prototype straw bale house](#). *Proceedings of the Institution of Civil Engineers: Construction Materials*, 165 (6), pp. 377-384. DOI: [10.1680/coma.11.00003](#). Awarded Howard Medal for best paper 2012.
3. Hirst, E., Walker, P., Paine, K. and Yates, T. Characteristics of low density hemp-lime materials. *Proceedings of Institution of Civil Engineers: Construction Materials*, v 165, n 1, p 15-23, February 2012. DOI: [10.1680/coma.1000021](#).
4. Carfrae, J., De Wilde, P., Littlewood, J., Goodhew, S. and Walker, P., 2011. [Development of a cost effective probe for the long term monitoring of straw bale buildings](#). *Building and Environment*, v 46 (1), pp. 156-164. DOI: [10.1016/j.buildenv.2010.07.010](#).
5. Lawrence, M., Heath, A. and Walker, P., 2009. [Determining moisture levels in straw bale construction](#). *Construction and Building Materials*, v 23 (8), pp. 2763-2768. DOI: [10.1016/j.conbuildmat.2009.03.011](#).
6. Lawrence, M., Drinkwater, L., Heath, A. and Walker, P., 2009. [Racking shear resistance of prefabricated straw-bale panels](#). *Proceedings of the Institution of Civil Engineers: Construction Materials*, 162, v 3, pp. 133-138. DOI: [10.1680/coma.2009.162.3.133](#).

The projects have often been conducted in close collaboration with industry partners and research has fed directly into construction projects prior to completion or publication of the findings. The research grants listed below have had commercial impact in the REF period:

- ModCell: Prefabricated straw bale panels. DTi Technology Programme. (£290k total contract). 2007-2009.
- BaleHaus: a modern innovative low carbon housing system using prefabricated straw bales, Carbon Connections (£150k total contract). 2008-2009.
- BaleHaus: manufacture of sustainable prefabricated straw bale houses, Technology Strategy Board (£700k total contract). 2008-2010.
- Hemp-lime composites for low carbon building, DEFRA (UK Govt.) (£750k total contract). 2009-2012.

- EuroCell. EU Eco-Innovation CIP (€1.6M total contract). 2011-2014.

#### 4. Details of the impact

**Overall Contribution:** Our straw bale research has directly contributed to the market development of ModCell, the award of UK and EU patents and certification of the system [1 below]. The research has shown that the excellent thermal insulation levels provided by straw bale and hemp-lime construction can reduce operational carbon emissions by 70-90% compared to 1990 best practice housing requirements. Using crop materials in place of conventional cavity masonry wall construction can also save around 30 tonnes of carbon per house (equivalent to 10-30+ years operational impact depending on the heating system). These figures are based on the Life Cycle Assessment of the BaleHaus project. The research has supported UK industry in the development and adoption of novel sustainable low carbon building materials and products. Research contributions to new building projects have included BRE Information Notes design guidance, expert advice on material specifications, bespoke performance tests on materials and evidential data from research output to support the building control approval process. Through the very close collaboration with industry partners, research outputs have often had an immediate impact. Over 300 building projects have benefited directly or indirectly from the research (equating to approximately 9000 tonnes of carbon saved) [2, 3 below], and these have won prestigious awards [4 below].

**Benefits and Beneficiaries:** The benefits of the research stem both from improved performance and lower carbon impact of new technologies compared to existing solutions. The embodied and operational carbon reductions of both straw bale and hemp-lime are significant. Direct beneficiaries of the research include industry partners (both ModCell Ltd and Lime Technology Ltd) through increased sales and clients who have procured lower carbon buildings. Clients include: The Science Museum; Marks & Spencer; Tesco; Hayesfield Girls School (Bath), May Park Primary School (Bristol); Hengistbury Head Visitor Centre; University of the West of England; 20 BaleHaus homes for LILAC Co-Housing (Leeds); Inspire Bradford Business Park; Waterfoot Primary School; Think Low Carbon Sustainable Centre; Barnsley College; Holm Lacey College Straw Bale Café; Weydon Secondary School; and HAB (Kevin McCloud's development company).

**Dissemination:** The research activities have been undertaken in close collaboration with industry (ModCell Ltd, and Lime Technology Ltd). This has ensured direct and almost immediate uptake of research findings. Wider dissemination routes have been through conventional publications (journal), presentations (conferences, seminars) as well as CPD activities to promote benefits of renewable materials (workshops; exhibitions). In 2009-10 BaleHaus received substantial media coverage, including on local TV (BBC, ITV), international, national and local radio (BBC), national and international print media and internet exposure [5 below]. McCloud officially opened BaleHaus in November 2009, attracting significant media interest (see quote above). The Lilac Housing scheme, using BaleHaus design, has more recently featured on BBC national TV (The Culture Show; 10.10.12). The CICM's reputation as a leading centre for innovative construction materials research has increased, attracting new staff, students, researchers and visiting academics. In 2010-2011 the Centre completed a Knowledge Transfer Account Fellowship with BRE, aimed at raising awareness and promoting wider uptake of renewable construction materials. This included a series of workshops in the South West at which over 400 participants attended.

**Commercial impact:** *"The research carried out at the University of Bath has been instrumental in the growth of ModCell"* – Director (ModCell Ltd). Since 2008 the commercial value of ModCell projects has grown from £11k in 2008 to over £1.8 million in 2012; over the same time ModCell staff grew from 1 FTE in 2008 to 10 FTE in 2012. The hemp-lime construction market in the UK has grown from a few niche projects to over 250 completed projects, including Kevin McCloud's Triangle Project in Swindon. Lime Technology's turnover has grown from £1 million in 2005 to £6 million in 2012; over the same period Lime Technology's staffing expanded from 12 FTE in 2005 to 57 FTE in 2012. *"We could not have developed as successfully as we have without our collaboration with the University of Bath over the past 10 years"* – Technical Director (Lime

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Technology). These commercial developments have been directly supported by the research outputs from Bath. Wider benefits of this impact derive from employee spending into the local economy. Both main industrial partners have also been developing export markets for their products. Lime Technology has exported materials and technical expertise delivering projects in USA and Australia; and ModCell, supported by the EuroCell project, in Netherlands and Spain.

**Societal impact:** The research has directly supported the delivery of new housing projects (Lilac community housing in Leeds) and public buildings, including four new school buildings (see [www.modcell.co.uk](http://www.modcell.co.uk)). CICM has played a leading role in the Nucleus building, a new science block for Hayesfield Girls School in Bath, the first commercial loadbearing application of the ModCell straw bale panels. Walker supported the school's development committee during the procurement process, advising on technical details and using research data directly to provide reassurance and clarification on performance where necessary.

*"We won't get to an ultra-low-carbon built environment simply by improving on the performance of the same old construction techniques. The BaleHaus certainly hits that button, and could play an important part in enabling house builders to meet their carbon targets."* – Director (Forum for the Future).

### 5. Sources to corroborate the impact

**1. ModCell Patents:** UK Patent GB 2457891B; European Patent application EP1162321A2.

**2. Modcell<sup>®</sup> building projects:** UWE Faculty of Environment and Technology (2010); Mellow Park & Ride (2010); Weydon Secondary School (2011); Castle Park Primary School (2011), Straw Bale Café (2011); Inspire Bradford Business Park (2011); 20 homes, LILAC affordable co-housing (2011-12). See: [www.modcell.com/projects](http://www.modcell.com/projects). **Hemcrete<sup>®</sup> building projects:** Jennings Business Park (2008); The Wine Society (2008); Orwell Housing (2008); The Renewable House (2009); Welsh Institute of Sustainable Education at CAT (2010); M&S (2011); 29 homes, Diss (2009-11); 42 homes, Swindon (2010-11); 16 homes, Blackditch, Oxfordshire (2010-11); 15 homes, Dormary Court, York (2011); 60 homes, Letchworth (2010-11); 16 homes, Watford (2010-11). See: [www.limetechnology.co.uk](http://www.limetechnology.co.uk) & [www.homesandcommunities.co.uk/ourwork/renewable-construction](http://www.homesandcommunities.co.uk/ourwork/renewable-construction)

**3. References to CICM impact in built work:** Thomas, C. The Genesis Project: demonstrating sustainable construction, *The Structural Engineer* 6 May 2008, pp. 39-46.

#### 4. Awards for building incorporating CICM research:

- BaleHaus: SWBE Award for Innovation (2010); British Construction Industry Awards, Shortlisted (2010).
- WISE Building (Centre for Alternative Technology): Building of Year, *Daily Telegraph* (2011); Favourite building of 2010, *Architects Journal*.
- Knowle West Media Centre: The South West C+ Carbon Positive Award for Carbon Positive Communities, Bristol Civic Society Environmental Award (2008); Green Apple Award Silver Award winner South Region (2008); RICS Regional winner for the South West Community Benefit category (2008); Shortlisted for the David Alsop Sustainability Award - IStructE Awards 2009.
- ModCell panels: The Offsite Construction Awards: for Best Product of the Year & Best New Product (2008).
- Long Stanton Park & Ride: Green Apple Award (2012).
- Clayfields Sustainable Housing: RIBA Award (2009).
- The Triangle: RIBA Regional Sustainability Award (2012).

**5. TV programmes featuring CICM work:** Local BBC West TV news (BaleHaus launch), Nov. 2009; Discovery TV - How do they do it, Nov. 2010; Kevin's Grand Design (Channel 4), Dec. 2011; Al Jazeera – Earthrise, Aug. 2012; The Culture Show, BBC TV (Lilac housing scheme), Oct. 2012; BBC 2 - Working Lunch Oct. 2012.