BaleHaus

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The BaleHaus prototype house has been built as part of a Technology Strategy Board (TSB) funded research project by ModCell, with a number of industry partners - White Design and Integral Engineering Design, and research partners, Craig White from the University of the West of England, Dr. Katharine Beadle and Prof. Pete Walker from the BRE Centre for Innovative Construction Materials (CICM). Craig is the founding Director of both White Design and ModCell and inventor of the system. The research builds on work funded by the DTi that confirmed the potential for mainstreaming the use of straw bale construction through prefabrication. The BaleHaus is a prototype that demonstrates the viability of whole system design for housing using the ModCell System of wall, roof floors and partitions. To date research has been limited to the thermal performance of straw and not its application in high value engineered construction systems that are readily adoptable by designers and contractors.

The ModCell System is the first scaleable use of prefabricated straw in the world. The research methods used to demonstrate its viability are unique. The research covered, acoustic, thermal, moisture, hygrothermal, airtightness, carbon foot-printing, co-heating tests, structural performance, durability, life cycle analysis, fire testing, exposure testing, accelerated weather testing, thermal imaging and process automation for scaled manufacture. The research carried out is the most comprehensive to date and paves the way for scaling the use of renewable materials in mainstream construction. The ModCel System and its method of construction is patented - Patent No. GB2457891B.
Details showing unique construction of the ModCell System
Environmental Significance
The challenge of climate change is significant and driven by anthropogenic CO₂ emissions. The built environment accounts for 45% of those emissions through the design, manufacture and operation of buildings. ModCell was conceived as a system of construction that works within the limits of the natural carbon cycle rather than upon it. ModCell’s constituent materials lime, timber and straw are defined as renewable i.e. they are generated through photosynthesis, absorb CO₂ from the atmosphere and sequester carbon into plant based cellulose and the calcium carbonate structures of phytoplankton that go on to become limestone. These materials can be combined into a high performance and low carbon footprint building system that stores carbon and reduces the carbon emissions from energy used to heat and cool buildings by 90%.

Social Significance
Regulatory - In the UK all new build housing will have to be zero carbon by 2016. All other building types must achieve the same target by 2019. The Energy Performance in Buildings Directive applies across the European Union, driving the same CO₂ emissions reduction requirement. The construction industry is ill equipped to meet these targets using conventional construction techniques. The ModCell System uses local skills, labour and materials and is manufactured in a Flying Factory, allowing the economic benefit of production to be localised.

Economic Significance
The cost of energy continues to rise as availability of fossil fuel reduces and demand increases. The thermal performance of BaleHaus reduces the need for both heating and cooling. BaleHaus reduces fuel poverty, and continues to save energy for all users passively. i.e there is no active technology input required to reduce heating and cooling bills.

Environmental, Social and Economic Significance
Rigour - Coheating and Extensive Monitoring

There are two aspects to the monitoring of the BaleHaus: condition monitoring (durability) of the straw; and, environmental assessment of the overall performance of the building. There are 66 wireless sensors built into the panels that record temperature and relative humidity every 30 minutes. The sensors are located throughout the BaleHaus, with each panel having three in the centre of the panel at three different locations across the thickness of the panel. The ground floor has 18 sensors along the base of the panels on the exterior surface. There are a further nine sensors recording conditions at the junctions of the panels and 12 recording internal conditions within the house. In addition site weather conditions are being continuously monitored.

An environmental model was also created to assess the environmental performance of the house. The data gathered from monitoring will be used to improve our understanding of the building’s performance and to validate computer design models.

Occupancy within the house was also simulated to aid the development of the model further and was carried out over two weeks of every month and provided continuous data over 2 years. The virtual model was created by the Centre for Window and Cladding Technology (CWCT).

Data were obtained to provide information about the ‘standard’ use of a dwelling the size of the BaleHaus. An hourly schedule for four zones within the house has been created and this is used to simulate heat output per hour by occupants, equipment and lighting by using sets of different wattages of incandescent bulbs on nine timer switches.

Data collection and analysis is ongoing and over 3 years worth of continuous data has been collected.
Structural racking tests of two ModCell panels used for the BaleHaus were undertaken to assess their resistance to wind load. Shear racking tests were undertaken on a two- and three-bale panel to simulate the in-plane loading of a building, for the BaleHaus this is in the order of 3.5 tonnes. As the vertical loads of the building are designed to be carried on the upright members of the timber frame, the render, straw and bracing need to resist the wind loading. The racking tests assess if the panels have adequate stiffness and strength to do this. Panels were loaded until a horizontal displacement of height/500, the design deflection limit, was reached. The three-bale panel had a horizontal displacement of just 3.8 mm under an applied load of 3.5 tonnes, comfortably meeting the design criteria. The two-bale panel is roughly half as 'stiff', carrying a load of 1.6 tonnes at the deflection limit.

The results from these tests confirm that ModCell panels are more than adequate to resist the in-plane loads required for the BaleHaus when a two- and three-bale panel are used together on the ground floor façade.
Rigour - Structural

The Balehaus was subjected to a whole building structural test to simulate wind loading. The wind load was simulated using hydraulic jacks which pushed horizontally against the walls with a total force exceeding four tonnes, equivalent to the dynamic force of a hurricane.

The actual behaviour of the structure was assessed through the determination of its overall load capacity and stiffness, under applied loads that equaled or exceeded loads that are likely to act. The BaleHaus was designed using a 3D computer model that is based on the stiffness of the panels. It was important to validate this structural model to ensure that it could be used in the future, confident that it will accurately predict the behaviour of the structural strategy chosen. A horizontal load was applied to the east elevation of the BaleHaus using four load jacks and a scaffolding reaction frame.

The house performs significantly better than the design requirements for an applied wind load of 35kN and a serviceability limit of 11mm. The computer model gave a good prediction for actual behaviour and was not seen as needing to be improved and was recommended for use for the design of future load-bearing ModCell structures. The model was used to predict that the structure could withstand an effective wind speed of up to 63.2m/s, equivalent to a Category 4 hurricane.

Implications: The BaleHaus is approximately 2.5 times stiffer than the sum of the individual panels and therefore there is scope to change the original design parameters to maximise efficiency of the structure by: redesigning the panels to benefit from potential cost savings; redesigning the house as only one three-bale panels is required on the ground floor in each orthogonal direction; or removing or decoupling the internal shear wall. The prediction from the model that the structure could withstand a hurricane means that the design is suitable for anywhere in the UK including the Shetland Islands; excluding extreme height above sea level, for example the top of Ben Nevis.

Large 4.5 x 4.5 m panel wind load testing. Straw bale substrate supports 2000 kg of lime without deflecting
Rigour - Exposure Testing

A set of exposure tests have been set up in Cornwall to evaluate the performance of different constructions of scaled down ModCell panels. The six panels being tested are set up along two sides of a specially designed building. The 'ModHut' is located in an exposed site in Liskeard, Cornwall, where previous exposure tests of ModCell panels were undertaken by Dr. Mike Lawrence from the University of Bath. The panels are approximately 1.1m wide by 1.9m tall externally and all have solid timber frames, with straw bale infill. Monitoring of the straw within the six panels is being undertaken to: condition monitor (durability) of straw within the panels; compare efficacy of different external and internal finishes; and to identify patterns of moisture stratification through the panels. Six temperature and relative humidity sensors are located in all the panels; three of which are in the centre of the panel at three different depths and the other three are at the base of the panel, also at three different depths.

Accelerated Weather Testing

Accelerated weather testing was carried out at CERAM. A ModCell Panel was built into a controlled weather chamber and put through an accelerated cycle through hot and cold testing.

The system passed both exposure and weather tests.

Hygrothermal cycles
The test apparatus is positioned against the front face of the rig, 0.10 to 0.30 m from the edges.

The specified temperatures during the cycles are measured at the surface of the rig. The regulation shall be obtained by adjustment of the air temperature.

Heat - rain cycles:
The rig is subjected to a series of 80 cycles, comprising the following phases:
1- heating to 70°C (rise for 1 hour) and maintaining at (70 ± 5°C) and 10 to 30% RH for 2 hours (total of 3 hours),
2- spraying for 1 hour (water temperature (± 15 ± 5°C), amount of water 1 l/m² min),
3- leave for 2 hours (drainage).

Heat-cold cycles:
After at least 48 hours of subsequent conditioning at temperatures between 10 and 25°C and a minimum relative humidity of 50 %, the same test rig is exposed to 5 heat/cold cycles of 24 hours comprising the following phases:
1- exposure to (50 ± 5°C) (rise for 1 hour) and maximum 30% RH for 7 hours (total of 8 hours),
2- exposure to (-20 ± 5°C) (fall for 2 hours) for 14 hours (total of 16 hours).
A fire test was successfully completed on a ModCell panel by Chiltern International Fire as part of a research project at the University of Bath supported by Carbon Connections and conducted by Chris Gross. The panel measured 3000mm high by 3000mm wide and 490mm thick. The panel was tested in accordance with BS EN 1364-1:1999. Air pressure inside the furnace was increased to 20 Pa above atmospheric pressure at the head of the panel. The temperature in the furnace was increased in accordance with standard procedure to over 1000°C. During this process the surface temperature on the 'cool' face remained below 60°C. After 90 minutes the lime render started to fall away to expose the straw bales; although significantly charred the unrendered bales successfully withstood the fire for a further 45 minutes. The test was stopped after 2 hours 15 minutes (30 minutes exposure was required); failure had not occurred.
Rigour - Thermal properties of the panels and straw bales

A thermal transmittance test was undertaken on an entire panel during a previous research project funded by Carbon Connections and undertaken by Christopher Gross. The test was conducted by the Thermal Laboratory at the British Board of Agrément (BBA) in Watford, according to BS EN ISO 8990: 1996. The panel achieved a U-value of 0.19 W/m²K. This corresponds with the U-value derived from computer models of the panels by CWCT of 0.20 W/m²K.

Co-heating Test

A co-heating test was undertaken towards the end of January 2010 to determine the actual heat loss from fabric and infiltration losses of the BaleHaus @ Bath. This was conducted by heating the interior of the dwelling to a set temperature of 25°C for 17 days so that heat the building’s actual heat loss could be calculated.

Infiltration losses are known as an airtightness test was undertaken on the house prior to the test. The results from the test are currently being analysed and will be able to be compared with predictions from the environmental model created by CWCT. The model will then be able to calculate heat loss for different location and component scenarios.

The results show that BaleHaus reduces heating requirements by 85% over 1990 building regulation standards.
Rigour - Airtightness tests

An air leakage test was undertaken on the BaleHaus @ Bath on the 15th December 2009 by Building Analysis and Testing Ltd. in accordance with ATTMA TS1 and BSEN 13829: 2000. The test was undertaken to establish the performance for Building Regulations, Part L2 compliance, which requires air permeability of less than 10 m3/hr m2. The BaleHaus @ Bath achieved an air permeability of 0.86 m3/hr m2, which was described in the test documentation as being “exceptionally low”.

Thermal imaging

A thermographic survey of the BaleHaus @ Bath was undertaken on the 16th and 17th February 2010 by Infrared Vision Ltd. The survey was undertaken to establish the thermal integrity of the building and identify any defects. The survey involved both internal and external picture being taken, with a pressure difference created during the internal photos by using a fan, similar to that used for the airtightness test. The external images were taken with a temperature difference created by heating the house overnight to approximately 25°C.
The LCA compared BaleHaus built using two methods of construction. The LCA compared a conventional construction method using brick and blockwork with the ModCell System.

To ensure an independent analysis was carried out the LCA was led by Dr Richard Murphy at Imperial College London and reviewed by Professor Roland Clift at the University of Surrey.

The LCA showed that across 8 of the 9 criteria for analysis ModCell significantly reduced impacts. In the 9th, the measure of eutrophication of water courses, the use of nitrates in fertiliser can leach into the river system potentially causing algae blooms. However, because straw is a by product of growing wheat, using straw in construction does not increase its likely hood. The relative difference between traditional construction impacts and those using straw are inconsequential.
Outcomes - Q-mark Certification

The Q-Mark certification now allows for conventional high street mortgages to be applied for. This has led to the world’s first open market, speculative housing going on sale in Bristol.

The 7 BaleHaus development in Bristol has now been featured on national and international television.

http://www.bbc.co.uk/iplayer/episode/b052xw2s/the-one-show-26022015
http://www.zdf.de/ZDFmediathek/beitrag/video/2343484/Europas-gruene-Hauptstadt#
The development of ModCell Core Passiv of a whole house PassivHaus Product Certification building system. The certification will be announced at EcoBuild 2015. This the first straw bale Passivhaus certified construction system in the world.

The product will be offered as part of the UK Government’s Custom Build pathfinder by the developer Igloo Regeneration and the Bristol based developer Connolly and Callaghan.
Awards won for projects using the ModCell System of Construction

Nucleus Building, Hayesfield School, Bath:
'Gold' Green Apple Award 2013 - The Built Environment and Architectural Heritage category.
BaNES Design Quality Award 2012
LABC (Local Authority Building Control) Design Quality Awards 2012: Winner for the Public/Commercial Category

LILAC Co-Housing, Leeds:
Yorkshire And Humberside Constructing Excellence awards ‘Legacy - Sustainability Award 2013’
Winner Best Community or Group Self Build Initiative 2013.
Shortlisted for the Placemaking Awards 2013 - Sustainability category. Pending.

TLC (Think Low Carbon), Barnsley College, Barnsley:
'Gold' Green Apple Award for Building and Construction 2012
Winner of the Energy Award at the 2012 annual Sustain Magazine Awards 2012

Holme Lacy Straw Bale Cafe, Hereford College, Hereford:
National 2011 LABC Technical Innovation Award
Shortlisted for a National 2011 RIBA Design Award
Shortlisted for a 2012 Wood Award

Inspire Bradford Business Park, Bradford:
West Yorkshire LABC building Excellence Awards -Highly Commended

UWE (University West of England) R Block:
RIBA South West Town & Country Design Awards 2011 - Best Public Sector Design award

ModCell Product Awards
'Gold' Green Apple Award. 'The Built Environment and Architectural Heritage’ 2013
Britweek UKTI Design Innovation Award
Offsite Construction Magazine Award - Best product
Sustain Magazine Award - Product of the Year

BaleHaus at Bath:
CIOB International Innovation & Research Awards 2013: Innovation Achiever
CIOB Constructing Excellence SWBE Award for Innovation
Shortlisted British Construction industry awards

This paper describes the research, development, construction and initial testing of an innovative low-carbon, sustainable house built using novel prefabricated straw bale panels. The use of straw as insulating provides an opportunity for value-added use of a widely available low-carbon co-product of farming. The research reported in this paper aims to enhance the understanding and development of modern straw bale construction and is one of the first studies to investigate the performance of straw bale panels and the house. Tests conducted on the panels and house reported in the paper include fire/smoke testing, acoustic transmission testing, air permeability testing and thermal surveys.

Development and testing of a prototype straw bale house

Howard Medal for Innovative Research.
Proceedings of the Institution of Civil Engineers.
Construction Materials 165 December 2012 Issue CM6 Pages 377–384 http://dx.doi.org/10.1680/coma.11.00003 Paper 1100003

The conclusions of the research, development, construction and testing of a low-carbon, sustainable straw bale house are reported. The prototype house built using novel prefabricated straw bale panels for research purposes has low embodied carbon and energy use, and has the potential for value-added use of a widely available low-carbon co-product of farming. A prototype house built using novel prefabricated straw bale panels for research purposes has low embodied carbon and energy use, and has the potential for value-added use of a widely available low-carbon co-product of farming. A prototype house built using novel prefabricated straw bale panels for research purposes has low embodied carbon and energy use, and has the potential for value-added use of a widely available low-carbon co-product of farming.
Significance

The research of BaleHaus as a building system allowed for 20 houses to be built at LILAC Leeds. LILAC stands for Low Impact Living Affordable Community. Without the research originality, significance and rigour this development would not have been possible.

The Balehaus research has also paved the way for a €1.6m research programme funded by the CIP Eco Innovations fund to explore how the ModCell system can be scaled into Europe. EuroCell is a 3 year research programme is currently underway to establish how ModCell can be certified for use across Europe.

ModCell is now working with Skanska on a £750k TSB funded research project to implement the Flying Factory model of near-site off-site prefabrication into their UK construction business.

Another 50 dwelling co-housing development will go on site in 2014 in time for the Bristol European Green Capital 2015.

A number of school projects will start on site in 2014 using the ModCell System across the UK.

The research has demonstrated that the ModCell System of construction is robust, scaleable and reduces the carbon intensity of construction to negative figures through the carbon capture and storage of renewable materials and once deployed goes on to save energy costs and carbon emissions of heating and cooling by up to 90%.

Dynamic simulation modelling: Apartment block built to CTE regulations vs. Balehaus®

The LILAC CoHousing project in Leeds completed March 2013, Quarterly heating bills vary between £7 and £20 thus far.