SB&WRC Project

R&D protocol – Prototype 3

April 2018

Abstract of the project

The SB&WRC *(Sustainable Bio&Waste Resources for Construction)* project, an undertaking of more than two years, aims to conceive, produce and test three innovative, low-carbon, thermal insulation materials from agricultural co-products and recycled waste. The project is supported by the development program Interreg VA France (Channel) England and its budget, estimated to be 1.8M€, is co-financed by the ERDF (European Regional Development Fund) for 69% (1.26M€ contribution).

This project, led by Nomadéis, is carried out by a cross-channel partnership which gathers academic research laboratories, private research and consulting companies, manufacturers and professional non-profit organisation of the building sector:

- Nomadéis;
- Veolia Propreté Nord Normandie;
- University of Bath;
- Ecole Supérieure d'Ingénieurs des Travaux de la Construction de Caen (ESITC Caen);
- Construction21;
- UniLaSalle;
- University of Brighton;
- Alliance for Sustainable Building Products.

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1. Introduction

The SB&WRC project aims at designing and producing three prototypes of thermal insulant for buildings, made from bio-based and waste-based raw materials. The three prototypes will be produced from underexploited renewable resources available in the Interreg area: rape and corn stems, textile waste (from duvets) and wheat straw. The main objective is to obtain materials which carbon footprint is at least 25% lower than that of conventional insulants, such as glass wool or rock wool. The research and development process also aims to produce competitive insulants with usual insulating materials, in terms of energy efficiency mainly but also indoor air quality, durability or cost-effectiveness.

Work Package 6 aims to produce and characterise prototype 3, the straw bale based insulation material. This document initially presents a manufacturing protocol to produce the prototype, followed the proposed characterisation protocol of the raw material (at small scale), corresponding to Work Package 3. Finally, this document sets out a larger scale testing protocol to characterise the prototype based on physical, mechanical, thermal and hygric properties. As additional material properties, fire resistance and Indoor Air Quality (IAQ) performance will be considered in the material test protocol. All these parameters have been chosen in order to be compared with the current state of the art materials. This test protocol indicates the procedure that will be followed for the various tests as well as their time schedule.

2. Production of prototype 3

The prototype will be used as a non-load-bearing material for a wall application. The targeted density is around 110-120 kg.m^{-3}, to provide robustness in transport, stability and fire resistance, which is close to the minimum density recommended by Jones (2002). The proposed dimensions for the prototype are initially 600 x 600 x 100 mm, but they might be subjected to change, depending on the manufacturing and testing. The proposed dimensions have been selected to fit in with common stud spacing for timber frame construction, whilst a 100 mm thickness ensures convenient mass for handling and allows multiple layer build up to achieve desired insulation.

2.1 Manufacturing of the prototype

In the prototype, the straw will be intentionally orientated perpendicular to the heat flux through the wall. This is in order to optimise the thermal insulation properties of material, as previous testing has shown that this orientation minimises thermal conductivity, allowing thinner walls compared to conventional straw bale walls.

The prototype is to be made in a specialist compaction mould, simulating a baling machine, with two slots cut into the sides to allow the baling twine to be wrapped around the straw and knotted after the compaction of the straw with a hydraulic press. Figures 1 and 2 show compaction is still undetermined, though the time whilst the maximum pressure is applied to generate the higher relaxed density might be between 1 and 3 minutes (Mewes et al. 1958, Osobov et al. 1966) The prototype will then be used vertically within the walls.

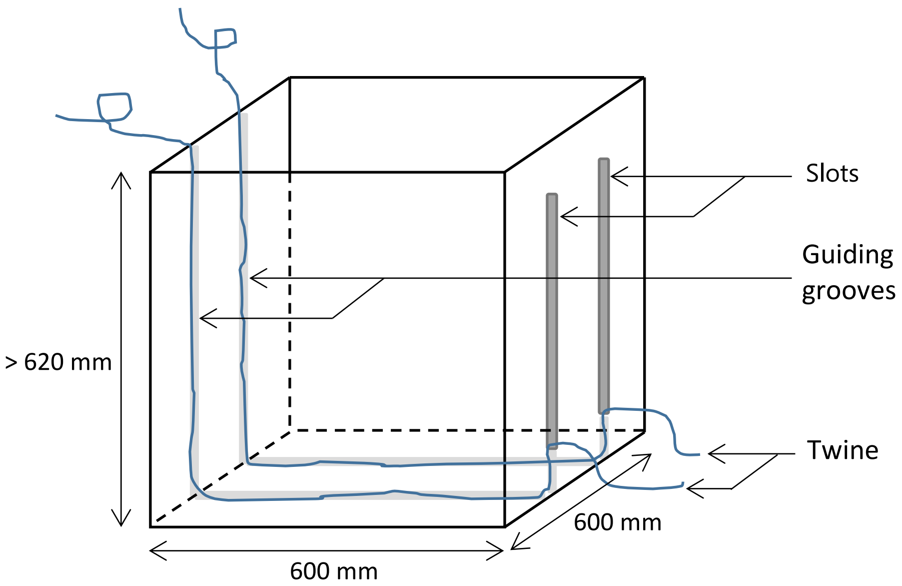


Figure 1: Mould and twines to manufacture the prototype

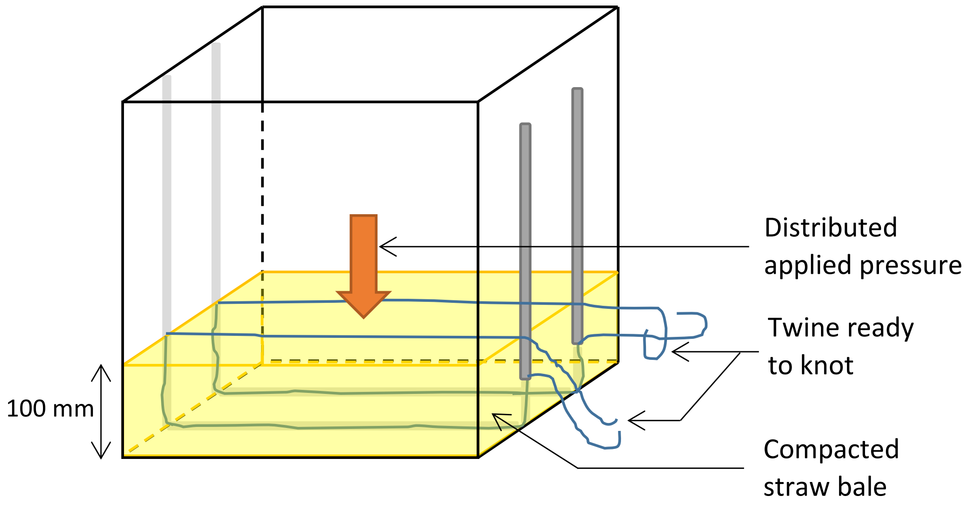


Figure 2: Prototype manufacturing process

2.2 Preparation of the control bale

In order to highlight the improvement due to the straw orientation, a second bale, with a different straw orientation but the same density, will be produced. This bale will not be the final prototype, but will be made to be representative of current straw bales used for construction (Figure 3).

These bales will also be manufactured with a hydraulic press, but directly in the vertical position so the straw particles will be parallel to the main surface. Therefore, the loose straw will be compacted in layers, the mould required would be too high otherwise (Figure 4).

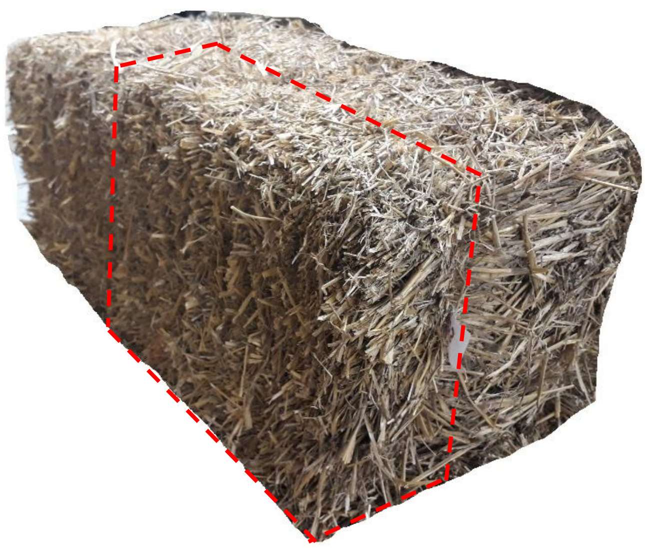


Figure 3: Part of the bale represented with this straw orientation

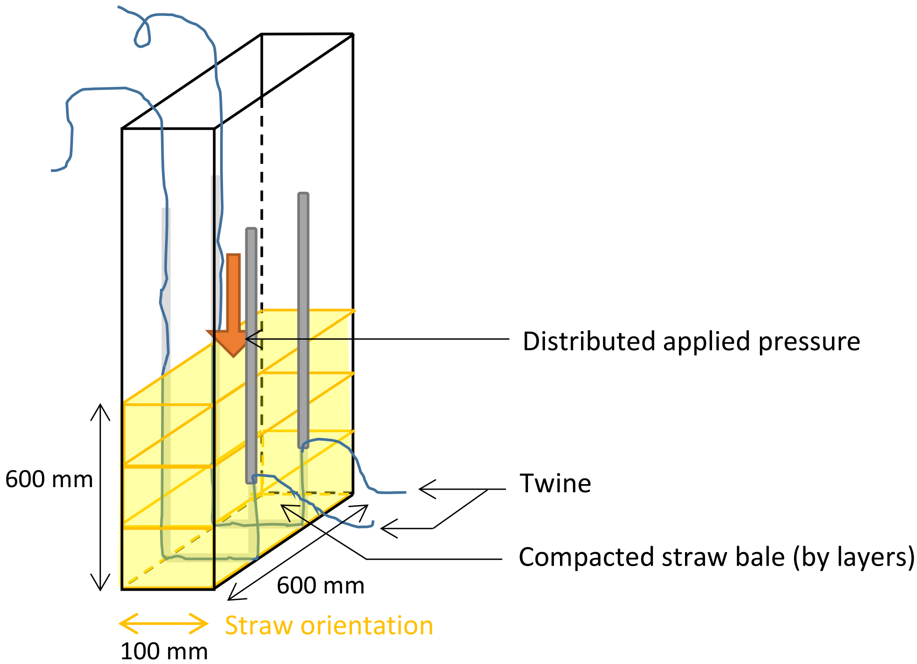


Figure 4: Control bale manufacturing process

3. Raw material characterisation

3.1 Physical properties

- **Bulk density** (kg.m^{-3}): the density of a material is defined as the ratio of its mass over its volume. The bulk density of the straw particle can be measured by mercury intrusion porosimetry (MIP), though the bulk density of loose straw (or tapped density) is generally more useful, and can be measured according to Amziane et al. (2017).
- **True density** (kg.m^{-3}): density of the solid part of the straw can be measured with a helium pycnometer, according to the RILEM TC 236BBM.
- **Porosity** (%): represents the void fraction of a straw particle. It can be estimated by means of MIP, derived from bulk and true density, according to BS 1902:3 (2016).
- **Moisture content** (%): is calculated from the gravimetric measure of the loss of mass after drying at 103°C (until a constant mass is reached) over the mass of the dried material. This test is done according to EN 322.

3.2 Chemical properties

- **Biocomposition**: determination of the parietal components (cellulose, hemicellulose, lignin, extractives) is to be done by Unilasalle according to AFNOR XPU44-162. The Van Soest procedure (1991) is to be used.
- **Thermogravimetric analysis** coupled to differential scanning calorimetry (TGA/DSC): measured according to BS EN ISO 11357-3 (2013). The heating rate is 10°C/min until 900°C, under nitrogen atmosphere.

3.3 Hygric properties

- **Water absorption** (%): is the ratio of the increase in water (after an immersion of 48h and spinning) over the dry mass of the material. This can be determined according to RILEM TC 236BBM.
- **Sorption-desorption isotherms:** the gravimetric method can be used to determine the sorption capacity of a material. After drying at 50°C, the straw is placed in different relative humidity values (first increasing and then decreasing) while keeping a constant temperature. The moisture content of the material is calculated for each step. This is done with the Dynamic Vapour Sorption device (DVS), using the same procedure as Hill et al. (2010).

4. Prototype characterisation

4.1 Physical properties

- **Bulk density** (kg.m^{-3}): defined as the ratio of mass over volume. Determined according to EN 1602.
- **Porosity** (%): is void fraction, calculated from the true density of the straw and the bulk density of the prototype.
- **Moisture content** (%): can be measured by gravimetric method and estimated using a moisture probe (Balemaster).
- **Structure**: can be assessed by CT scan (computerised tomography) which is a method combining many X-ray measurements to produce cross-sectional images. This test will be done on the two different types of bales (with the two different straw orientations).

4.2 Mechanical properties

- **Compression resistance** (N.mm^{-2}): a force is applied at a given rate of displacement and the maximum stress supported by the specimen calculated. If no failure is observed before 10% strain, the compressive stress at 10% strain is calculated and reported. This is measured according to EN 826 and EN 1605.
- **Flexural resistance** (N.mm^{-2}): a force is applied, at a given speed, in the middle of the supporting position in an axial position to the face, according to EN 12089.
- **Modulus of elasticity** (N.mm^{-2}): calculated by using the slope of the linear region of the load-deflection curve.

4.3 Thermal properties

- **Specific heat capacity** (J.kg^{-1}.K^{-1}): thermal storage property corresponds to the amount of energy needed to change the temperature of 1 kg of the substance by 1°C, measured according to ASTM C1784-13 and Ruuska et al. (2017).
- **Thermal conductivity** (W.m^{-1}.K^{-1}): density of heat flow rate is measured for a given temperature difference by means of a heat flow meter, according to ISO 8301 and EN 12664. The test will be done at the dried state but also might be done depending on the moisture.

4.4 Hygric properties

- **Water vapour permeability**: the determination of the water vapour diffusion resistance factor (kg.m^{-1}.s^{-1}.Pa^{-1}) will be done according to EN ISO 12572, with the dry cup method. This is a gravimetric method in which two faces of a sample are exposed to different relative humidity, which creates a vapour flow checked by regular mass changes until a steady state is reached.
- **Water absorption coefficient** (m^2.s^{-1}): corresponds to the change in mass of the specimen of which the bottom surface is in contact with water, according to EN ISO 15148.

- **Moisture Buffer Value** (MBV) ($g.m^{-2}.\%RH^{-1}$): one surface of the material is exposed to a cyclic relative humidity which allows to assess a regular moisture adsorption-desorption content per unit of surface, according to the Nordtest protocol (Rode et al. 2005) or to ISO 24353.

4.5 Potential additional testing

The following additional tests might completed (depending on time and resources available to this project).

Fire resistance

The laboratory of the University of Bath is not equipped for fire tests. Such tests should then be done by the BRE or the partner Unilasalle.

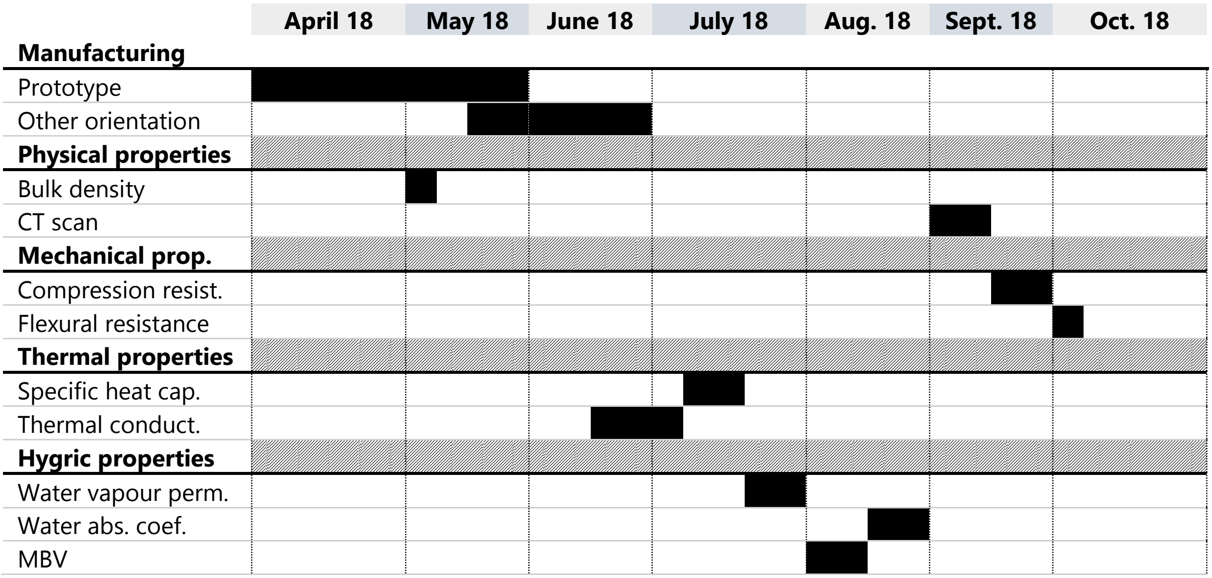
- *Radiant cone test*: according to ISO 5660-1.
- *Temperature increase/exposure time* ($°C.min^{-1}$): according to EN1363-1 and to EN1364-1.
- *Degradation characteristic*: BRE test, visual.
- *Time to ignition* (min): BRE test.
- *Ignitability*: measured by Unilasalle according to ISO 11925-2.

Indoor Air Quality

- *Formaldehyde emission rate* ($\mu g.m^{-2}.h^{-1}$): according to ISO 12460-5, EN 717-3 and to ISO 16000-9 / -3.
- *VOC emission* ($\mu g.m^{-2}.h^{-1}$): according to ISO 16000-9 / -6.
- VOC re-emission (FLEC): according to ISO 16000-10 / -6.
- VOC absorption properties: according to ISO 16000-9 / -6, and the gravimetric method followed by Mansour et al. 2016.
- *Concentrations/emissions of additives and health impact*

5. Project schedule

The following Gantt chart shows the time frame of the prototype manufacturing and tests that should be done.



6. Conclusion

This document presents a R&D protocol concerning prototype 3. Some of the values obtained after applying this protocol will then be compared to the specifications defined in the design sheet (D3.5.1) in order to validate the specification list.

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