BIOBASED AND BIOINSPIRED MATERIALS FOR A MODERN BUILDING DESIGN – A RESEARCH PERSPECTIVE

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SUMMARY

The current article summarises new classes of materials and their benefits to modern building design. The new and novel materials from bio-based products are identified, in order to study their effects on indoor air quality and reduce the occurrence of sick building syndrome. Indoor air quality is strongly influenced by the emission of volatile organic compounds (VOCs), which can directly influence people's well-being and health. Therefore the work reviewed bio-based materials and experimental techniques to characterize the materials/indoor air quality interactions as well moisture/material interactions.

INTRODUCTION

Modern architecture and modern methods of construction aim to decrease whole building life energy consumption by the improvement of building airtightness, and improvements in thermal insulation within buildings and structures. However interest has turned to the components that have been used in the construction of the buildings, and the materials that they are made from. Materials derived from agricultural and forestry feedstocks offer numerous positives in terms of the environmental benefits, and human health and well-being. The use of bio-based raw materials and biological processing methods, across all industry sectors, could yield CO_2 savings of between 1.0 and 2.5 billion tonnes CO_2e per a year by 2030 (Bang et al. 2009), providing a natural solution enabling us to plan for a fossil fuel-free future and promote reduce CO_2 emissions (Maskell et al. 2015). Bio-based materials can be broadly classified into conventional and emerging categories. Conventional bio-based materials are biodegradable and can be made from either animal materials (for example wool fibres, leather) or from plant materials (including pulp and paper, wood, bamboo, coconut fibres, and bast fibres such as jute, kenaf, flax, and hemp fibres). Whereas emerging bio-based materials are extracted by bio-refining processes or produced from materials with biological origins, for example polylactic acid and nano-cellulose (Pacheco-Torgal and Labrincha, 2014).

Whilst bio-based materials have the ability to replace traditional synthetic materials, the cost of production and therefore cost to the consumer is usually much higher and therefore multi-functionality is desired in the product. To ensure performance across the full range of functions, the materials need to be designed with multi-functionality in mind. For example, if the use of sheeps wool is to be used for the manufacture of household insulation with the added functionality of formaldehyde capture (Curling et al. 2011) the insulation will have to be designed to ensure that VOCs can enter the insulation whilst still retaining a low thermal conductivity. The use of bio-based materials, such as straw and hemp, in construction offers a renewable resource that has the potential of negative embodied carbon. Another source of feedstocks for bio-based materials are cell wall polymers. These polymers provide a renewable source of bulk materials and are beneficial by increasing sustainability of current and future building stock as well as sequestering carbon (Groot and Boren 2010).

All bio-based materials, from building panels made of peanut shells to polymers made from sugar beet, have the potential to reduce energy usage, greenhouse gas emissions and produce fewer toxic pollutants over their lifecycle. However, where novel biobased products are introduced, the methods for durability testing and service life prediction require development, (Ormondroyd et al. 2015; Curling et al. 2015). This is an area of biomaterials design and specification that requires increased attention.

Green building design involves finding the balance between the building of structures and the move towards a more sustainable environment whilst taking into account concerns of economy, utility, durability, and comfort. One can achieve the balance by considering energy efficient designs within a construction system, and integrating plant based raw materials to improve building performance. As the energy efficiency of buildings and appliances increases day by day, embodied energy will become increasingly important. The embodied energy levels in materials will be reduced as the energy efficiency of the industries producing them can be improved. Breathing walls made of vapour permeable and highly hygroscopic materials, such as cement bonded wood fibres and straw bales, can enhance indoor air quality (Wright et al. 2012). Other materials which include benefits to modern design are: plant fibres mixed with concrete replacing traditional masonry systems, insulation materials made from biomaterials such as flax fibres based laminate floors (offers a durable acoustic insulation and a good absorption of impact noises), new synthetic insulating materials made from bio-based chemical intermediates, bio-based coatings, and wood-plastic composites. Combining design and material concepts together as shown in Figure 1 can bring many advantages such as reduction of energy consumption, cost efficient building designs and incorporation of plants within structures providing solutions leading to low CO_2 emissions.

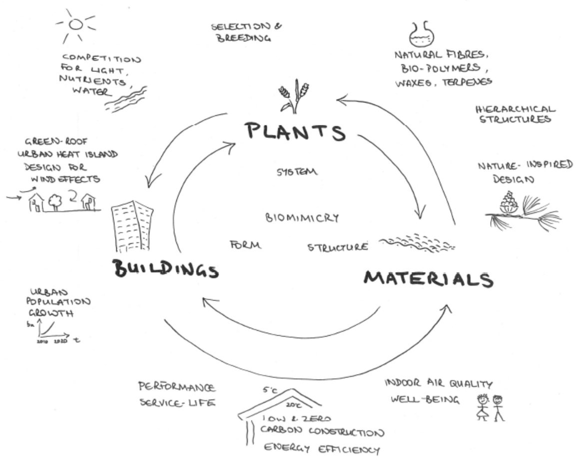

Figure 1. Selected interactions between plants, materials, and buildings which underpin the work within the NRN-LCEE Plants & Architecture cluster research ethos

BIOBASED AND BIOINSPIRED MATERIALS

In recent years architectural designs have been influenced by nature and biology in terms of sensing, reaction, locomotion, adaptation and differentiation, processing of information and energy operation (Biggins et al. 2011). Construction materials often have desirable properties that include high strength, stiffness and toughness, self-healing, self-cleaning, self-adaptability and optical functions, (and as mentioned above materials with multifunctional performance capabilities can be beneficial). Wood used today as a construction material can show improved water resistant/repellent properties, especially after treatment with multifunctional water-borne silane systems containing both hydrophilic and hydrophobic groups. The resulting material has hydrophobic properties (Donath et al. 2006). The best example of bio-inspired design is the so called ‘lotus effect’ where super-hydrophobicity is achieved by the texture of epicuticular waxes on the leaf surface, or man-made surfaces mimic this texture to achieve self-cleaning properties (Solga et al., 2007). A green roof installation can be mimic the appearance of a traditional amenity landscape, such as a park, terrace or garden, but may provide additional benefits such as mitigating urban heat island effects. Similarly, biomimetic and bio-inspired approaches to surfaces and receptors have led to the development of sensors with improved sensitivity and specificity for analytes of interest (Biggins et al. 2003).

The National Research Network for Low Carbon, Energy and Environment (NRN-LCEE) Plants and Architecture cluster is studying bio-inspiration to design and to model novel materials from bio-based sources to develop a material that has bio-inspired properties and perform similar to structural material for building design. Collaboration among the cluster (which consists of a multidisciplinary team of biologists, materials scientists, engineers, architects and structural modellers), aiming to develop novel designs that mimic natural systems using biomimicry principles. The team from Bangor University, Aberystwyth University and Cardiff School of Architecture will bring new materials and designs for future building architectures, or combine architectural principles with agricultural practice for urban farming.

Another challenge addressed by the cluster is the effect of new materials on indoor air quality and human well-being. The industry considers building designs with a “good air quality”, referring to the health and comfort of building occupants, to be of great importance. If the air quality is poor within a building, the deterioration of health in a non specific way is know as sick building syndrome (Stefanowski et al. 2015). The project aims to develop test procedures for evaluating indoor air quality and characterizing and the effect of new bio-based materials on air quality. The gases evolved with the use of new materials in an indoor environment can be analysed using micro-chamber emission tests (Markes Ltd., UK), coupled with experimental methods such as Gas Chromatography–Mass Spectrometry and/or High Performance Liquid Chromatography to evaluate the chemical compounds collected..

Biomaterials have additional properties that are less widely understood and often more difficult to quantify, such as their hygroscopic and hygrothermal properties. Adsorption isotherms can be studied using models such as the Hailwood and Horrobin model, following experimental tests utilising using Dynamic Vapour Sorption (DVS) (Rautkari et al. 2013). To understand the physics of sorption process, physical interpretation techniques can be used such as the Parallel Exponential Kinetics (PEK) model. Other analytical methods like NMR spectroscopy (D_2O exchange), Quartz crystal microbalance with dissipation monitoring (QCM-D), Surface Plasmon Resonance (SPR) can also be used. The relationship between crystallinity, charge density, accessible surface area, and water content can be explored. From the above discussions, bio-materials and techniques available in literature are identified for studying the interactions of material with both moisture and indoor air quality.

CONCLUSIONS

The research perspectives presented in this paper are part of NRN-LCEE Plants and Architecture cluster, and will be applied to various bio-based materials and their use in construction. Also identified are various techniques to study materials interactions with moisture and indoor air quality. The work carried out by the cluster will provide new directions to formulate mathematical models from the experimental data derived from the project (for analysing material/indoor air quality interactions and moisture/material interactions). A future aim of the project is to select materials for investigation for utilization by the construction industry that retain the desired properties of the plant materials.

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