

4.1. Final Publishable Summary Report

4.1.1. Executive Summary

BioBuild was a three and a half year project funded by the European Commission. The aim of the project was to develop biocomposite materials for use in construction applications which would have a lower embodied energy than existing construction materials. The project was coordinated by NetComposites Ltd who assembled a consortium of thirteen partners involved in the research, development and manufacture of biocomposite materials.

Embodied energy is the sum of all the energy required to produce a component from raw materials. It includes the energy needed to extract or harvest the materials, refine them, convert them to intermediates and then manufacture parts. This is then associated with or “embodied in” the final component. The energy used by a building during its life is only one to three times that used to construct the building (including the energy needed to produce the construction materials). Thus there is a need to reduce the energy embodied in construction materials.

This can be achieved by using composite materials and biocomposites in particular. Biological materials absorb carbon as they grow and so have a far lower global warming potential (GWP) than materials made from minerals and petrochemicals. Wood is widely used as a building material but is expensive and is not always harvested in a proper sustainable manner. Biocomposites can be produced from crops grown in a sustainable way with minimal impact on food supply.

The use of biocomposites is not widespread as there are concerns about their long term durability and resistance to fire. However, wood can also degrade and burn, yet mankind has learnt design and technical solutions which mitigate these shortcomings.

BioBuild produced full scale building components using biocomposite materials. This was done to prove that such components could be made and would have properties that would enable them to comply with the requirements of the application. The parts were subjected to full scale component tests. Panels and coupons of the materials were made and were tested in the laboratory to demonstrate their performance. Single Burning Item fire tests were conducted.

The materials made in BioBuild used jute and flax fibres. The resins were either a part bio-based polyester resin or a polyfurfuryl alcohol resin. A fully biobased polyester resin is not currently possible as there is no cost effective route to synthesise styrene from a biological precursor and the styrene replacements are not proven. Polyfurfuryl alcohol resin is derived from agricultural wastes rich in hemicellulose. It has a very low GWP and has no impact on food supply. The project developed fibre and resin treatments to reduce water swell, increase mechanical properties and improve fire retardance. Coatings were also employed.

BioBuild was able to produce biobased materials which achieved EuroClass B in SBI tests and also had the required mechanical properties and weather resistance to enable their use in construction applications. It was shown that these materials had lower embodied energy than competing materials. In the case of PFA based composites the target of a 50% reduction could be achieved.

4.1.2. Summary Description of the Project Context & Main Objectives

The aim of the BioBuild project was to use biocomposite materials to reduce the embodied energy in building facade, supporting structure and internal partition systems by at least 50% over current materials with no increase in cost. This will lead to a step change in the use of sustainable, low carbon construction materials, by replacing aluminium, steel, Fibre Reinforced Polymers (FRP), brick and concrete in new-build and refurbished structures.

The construction industry in the EU provides enormous benefits to society by providing homes, infrastructure, public and commercial buildings and the built environment in which we live. It is also the biggest provider of jobs in the EU, employing 16 million people and contributing over 10% of the GDP for the EU27 countries. However, it follows that it is also an enormous consumer of energy. The construction industry is responsible for about 40% of the total EU energy consumption, 36% of Green House Gases and 50% of the CO₂ emissions. It is now recognised that energy use and the resultant generation of CO₂ emissions is having an effect on the global climate and there is international agreement that CO₂ emissions must be cut in all industries to mitigate the effects. It follows that the construction industry can make huge contributions to these reductions.

Therefore, there is now a focus on the analysis and subsequent reduction in the embodied energy of buildings, led initially by legislation and environmental targets but increasingly driven by the commercial need to compete on environmental credentials. Embodied energy is the sum of all the energy required to produce a component from raw materials. As the science of Life Cycle Analysis is relatively new the categorisation of embodied energy is still being refined but the principle is that it includes the total energy used in the lifetime of a product. It includes the energy needed to extract or harvest the materials, refine them, convert them to intermediates and then manufacture parts. This is then associated with or “embodied in” the final component. Embodied energy is distinct and different to inherent energy which is the energy that would be released when a material is burnt.

Embodied energy can be used as a measure of the CO₂ emissions associated with the manufacture of materials or components. The actual level of emissions depends on the energy mix used (nuclear, coal, gas etc.). Traditional building materials such as bricks, concrete, steel and aluminium have a high embodied energy because of the high temperatures required to produce these materials.

Embodied energy is usually expressed in terms of MJ/kg. This is a simple unit for the purposes of calculating the embodied energy of a material but when comparing the embodied energy of one material against another, a comparison on a mass basis is not valid. What must be considered is the functional unit – the amount of material needed to achieve the same technical performance. To produce house bricks requires 8 MJ/kg whilst it needs 79 MJ/kg to produce polyurethane foam. However, polyurethane foam is much less dense than brick and has a far lower thermal conductivity so adding 50 mm (2 kg/m²) of polyurethane foam to a 225 mm brick wall (382 kg/m²) reduces the U value from 1.7 W/m²K to 0.4.

In the 1970s the energy required to heat a building during its life was 10-20 times the energy embodied in the construction materials. However, improvements in building insulation and boiler performance etc. have led to a reduction in the amount of energy needed to heat a building whilst at the same time there has been an increase in the embodied energy of the materials used. Therefore, the energy needed to heat the building is now only one to three times that embodied in the fabric of the building. (“Building Materials and CO₂: Western European emission reduction strategies”, D.J. Gielen. Dutch National Research Programme on Global Air Pollution and Climate Change Netherlands Energy Research Foundation; ECN

project number 7.7018). To reduce the overall environmental impact of a building there is a need to reduce the energy embodied in construction materials.

Facade systems are used in a wide variety of buildings such as housing, industrial units, schools, airports and hospitals, their primary use being to protect and insulate the internal structure. Internal partitions are used to divide space, carry utilities and provide thermal and acoustic insulation. The current materials used, such as aluminium, steel, brick and concrete, are energy intensive in their raw material production, forming, installation and disposal and therefore have high embodied energy.

An alternative material is FRP, which already plays a significant role in new, efficient construction applications and benefits from light weight, good formability and simple manufacturing technologies, thereby enabling low material content structures, low transport costs and innovative design. However, the resin and glass fibre used in their manufacture have non-renewable petro-chemical and mineral origins which are energy intensive in their synthesis, and the cost of FRP systems can be higher than those based on traditional materials. Biocomposites can overcome the drawbacks of conventional FRP, whilst maintaining the aforementioned benefits, because they are based on natural fibres and bioresins which have very low embodied energy and are low cost.

Biocomposites have a typical resin and reinforcement structure, as used in FRP, but the sources of the raw materials are bio-based, renewable and sustainable. The resin in this project will be derived from the hemicellulosic part of agricultural wastes (furan resin) and from waste cashew nut shells (bio-epoxy resin). Furfuryl alcohol, the key raw material for the production of furan resins, has a Global Warming Potential (in terms of kg-CO₂-eq) of 0.60 compared to unsaturated polyester resin at 7.5. The reinforcement fibres will be derived from flax and jute plants which can grow in poor soil and have a long history of industrial application.

Flax fibres have mechanical properties comparable to those of glass fibres, whilst having approximately half the density. Recent research has shown that flax and other bast fibres have significantly lower environmental impact than glass, in particular in the areas of climate change, ozone depletion, toxicity and eutrophication (Green Guide to Composites, BRE and NetComposites 2004, ISBN 1 86081 733 5). The energy required to produce hemp and flax fibre suitable for composite applications is lower than that needed to produce glass & carbon fibres. The energy required does depend on the form in which the fibres are used (UD tows, random mat, woven fabric). Reliable figures for natural fibres are difficult to obtain as there are a number of different assumptions which need to be made with regards to yields, fertiliser use etc. Values ranging from 15-52 MJ/kg are reported, which is still lower than glass (55 MJ/kg) and much less than carbon fibre (130 MJ/kg). Jute provides similar environmental credentials at a lower cost and reduced mechanical performance but with better moisture resistance.

Biocomposites are already used in a number of commercial applications, most notably in automotive interior parts. Unfortunately biocomposites have some shortcomings which may limit their use in certain applications. They may not be as strong or as stiff as conventional materials, they are combustible and they can be degraded by the action of water, sunlight or microbes. However, much of the same can be said of wood which has been used as a construction material since prehistory and mankind has developed strategies for overcoming the shortcomings of timber.

The BioBuild project consortium was established to develop biocomposite materials and construction products with a life span of at least 40 years, by protecting the natural fibres with novel treatments and coatings and improving the overall biocomposite properties.

Scientific & Technical Objectives

The overall aim of this project was to create new biocomposite construction systems which could replace the high embodied energy materials currently in use, significantly improving the environmental impact and sustainability of the European building industry. Within this broad aim three primary objectives were set:

- To develop large, low embodied energy flat or shaped, biocomposite panels which can be used as external or internal cladding for new or re-developed buildings.
- To develop low embodied energy continuous biocomposite profiles which can be used in external facade or internal support structures.
- To integrate the elements into a cohesive and efficient construction system and prove the technology by means of full-size demonstration installations.

To achieve these primary objectives, the project was broken down into a coherent series of smaller tasks, each with related technical objectives:

- Gather and analyse relevant current and draft standards, legislative requirements and European targets and use them to set parameters for the project case studies (Milestone 1).
- After some initial work the feasibility of a combined fibre and resin system will be evaluated (Milestone 2)
- At an early stage an Environmental quick-scan of proposed technologies will be carried out in order to inform and direct the choices of materials and processes. (Milestone 3)
- The integration of the proposed materials and parts (sheets, profiles, panels) will be reviewed at an early stage to inform the design and decision making process (Milestone 4)
- Optimise biobased resin systems for long-term durability and fibre compatibility and optimise flax and jute fibres and continuous yarn, mat and textile formats in order to replace glass fibre in composite manufacture (Milestone 6).
- Combine biocomposites with coatings, sandwich materials and adhesives to generate construction materials with improved functionality (Milestone 5).
- Manufacture new composite parts and optimise processing and process control using a wide range of established composite manufacturing methods
- Assess the mechanical properties, the fire performance, the weathering and environmental impact of the developed composite materials (Milestone 7).
- Build full-size but partial assemblies for internal and external applications to optimise the integration of the design, materials, performance and functionality. These will be used for testing, demonstration of the functionality and industry feedback (Milestone 8).
- Carry out tests to current standards and certify the products where possible. The objective is to create materials and systems which achieve standards comparable with current technology (Milestone 9).
- Manufacture large tools and parts to construct full-size demonstrators to be used as testing installations and for demonstration. The ultimate objective is to combine all the new materials into a representative building project (Milestone 10).
- Carry out continuous, comprehensive environmental evaluation and monitoring which will inform the decision making process for the materials and processing. An eco-efficiency impact evaluation will be made and will feed out to the LCA community as well as support the project (Milestone 11).
- Connect with industry, policy makers, authorities and associations to keep realistic and practical goals and to disseminate within the European construction industry and the end-users within the industry (Milestone 12).

4.1.3. Main Scientific & Technical Results

WP1 – Performance and Standards Requirements

Task 1.1: Gather Appropriate Standards

European and national standards and regulations relevant for biocomposites in the building industry were researched and collated by 3XN, LNEC, Arup, TNO and SHR. Guidance about the general performance of biocomposite materials in the context of building industry applications and input about was provided by NetComposites. This task was run in parallel to WP5 which relates to the design of the case studies. The outcome was to select the following types of building elements as case studies:

- External wall panels (EWP)
- External cladding kits (a rainscreen cladding system) – the ECK
- Internal partition kits (IPK)
- Suspended ceiling kits (SCK)

The relevant harmonised European Standards (EN) or Guidelines for European Technical Approvals (ETAG) relevant to the chosen case studies were considered. The primary aim of the project was to develop more sustainable building products, so assessments of environmental, health and cost issues were required. The work therefore covered a review of relevant CEN & ISO Standards in this area.

The results were compiled into a comprehensive document that specified all of the relevant performance requirements, standards and associated tests to follow in the development of the case studies mentioned above.

Task 1.2: Identify the Key Materials and Processes

The base materials to be used in the project were selected, along with a limited selection of benchmark materials against which they would be assessed. These benchmark materials were materials conventionally used in similar applications.

The materials to be used were specified. This included suitable types of reinforcement: flax and jute fabrics supplied by NetComposites, (Figure 1), biobased resins (bio-polyester & polyfurfuryl alcohol) from TFC (and DSM prior to their exit) and core materials, primarily cork supplied by Amorim (Figure 2). The project identified suitable treatments to be developed to enhance durability and other key performance requirements, such as fire performance. The selection of treatments was led by KUL, IVW & SHR, with some input from Cimteclab before they exited the project. Suitable manufacturing methods were identified for all of the proposed materials. This was led by the manufacturing partners (Acciona and Exel, with additional input from IVW & NetComposites).

Task 1.3: Specify Desirable Case Studies

There was a broad overlap between this task and Work Package 5, as it was necessary to identify the case studies and do initial concept designs in order to specify them. 3XN & Arup led this activity in consultation with the other partners. In selecting and developing the case studies, and identifying appropriate performance requirements to specify, existing products made from conventional materials were chosen as benchmarks. The capabilities and expertise of the partners was also considered, resulting in a decision that a biobased window frame was not a worthwhile case study and a suspended ceiling kit was selected instead.



Figure 1. Biotex Flax from Composites Evolution



Figure 2. Resin bonded cork crumb panel from Amorim Cork Composites to be used as a core material

Task 1.4 Draw up Target Properties and Characteristics for the System Components

This involved quantifying appropriate performance requirements derived from the Standards, Building Regulations and Directives gathered in task 1.1. All partners in the consortium were consulted to identify and understand the materials properties and materials processing factors linked with the different performance requirements to be specified. This information was used to influence the design of the case studies and identify the relevant parameters associated with the manufacture of the parts. The output from this task was a detailed specification defining quantified performance requirements. An extensive deliverable was compiled by 3XN and at the end of the project it was agreed that this document could be made public.

WP2: Reinforcement and Matrix Development

The global objective for WP2 was the modification of the resins and fibres in order to improve the combined properties. A key aim is improving the moisture resistance properties and the durability of bio-composites through a selection of fibre treatments. Simultaneously, an increase in moisture resistance and fire retardance and a decrease in porosity and degradation are targeted through a development of the bio-resins. A third target is the optimization of the fibre-matrix interface towards improved composite performance.

Task 2.1: Fibre Treatment to Reduce Direct and Indirect Moisture Uptake

The work started by measuring the baseline properties of the untreated fibres. A range of treatments were investigated. Various strategies were applied by SHR, KU Leuven and

IVW. The strategy behind all of the treatments was threefold. On the one hand, fibre treatments were aimed to make the fibres more hydrophobic by nature. This strategy was primarily followed by SHR (acetylation treatments) and yielded promising results for both flax and jute fibres. On the other hand, fibre treatments with the possibility to increase the interphase strength between the natural fibres and the furan or bio-polyester resins were looked at by IVW and KU Leuven. In the first part of the period, the latter two institutes also searched for fibre treatments to compatibilise the natural fibres with bio-epoxy resins from Cimteclab. This work was abandoned due to the bankruptcy of this partner and the results of the QuickScan which demonstrated that the proposed bio-epoxy composite did not produce much reduction in embodied energy

Other treatments studied by KU Leuven were, mercerization techniques, APS coatings and plasma treatment. IVW focussed primarily on the use of bio-derived cashew nut shell liquid varieties to improve the interphase strength of the different composite types.

Task 2.2: Fibre Treatment to Improve Durability, Fire Retardance and Biodegradation Resistance

This included the appliance of fibre treatments to improve durability, fire retardance and biodegradation resistance. Again various (different) strategies were adopted and investigated by KU Leuven, IVW and SHR. KU Leuven focussed on the durability increase by strengthening the internal structure of the flax fibres. Research strategies were developed and attempted to increase the internal interphase strength of flax fibres by treating the fibres with specific cross-linking chemical agents. The idea behind this technique is that hydrophilic molecules that are inherently exposed within the reinforcing flax fibres are prevented from interacting with water molecules in the atmosphere by covalently binding them to chemical precursors. Therefore, the resistance of the flax fibres towards external environments is increased, swelling is reduced, damage is retarded and as a result durability is increased.

An approximation of the effect of different chemical treatments on the interfacial shear strength has been clarified by performing transverse three-point bending tests on composite specimens. The effect of 3-aminopropyl-tri-ethoxysilane (APS) in small and medium concentrations on the interfacial properties has been explored, both in pure form and in combination with a mild alkali treatment (4 wt%). In addition to this, the effect of heavy alkali treatment (18 wt%) on the fibre properties was also established. Finally, a treatment with dimethylol-di-hydroxyethyleneurea (DMDHEU), an industrial process already readily established as an anti-wrinkling agent, was examined. Regarding the heavy alkali treatment, longitudinal tensile tests on technical fibres indicate a decrease in Young's modulus by 17% and a decrease in longitudinal tensile strength of 23% are obtained. As the deterioration of the fibre mechanical properties was too severe, this chemical treatment was discarded.

The remaining treatment combinations were examined based on their effect on the transverse 3-point bending strength, as depicted in table 15. From this table, it becomes clear that both a mild alkali treatment and treatment with DMDHEU lead to an improvement in the transverse 3-point bending strength. This was expected as alkalization treatment presumably removes most of the waxy essences that cover the surfaces of raw flax fibres. This ensures that hydroxyl groups become present at the surface, which increases the amount of reaction sites with the epoxy matrix. As a second effect, the fibres tend to become rougher, which also increases the interfacial strength due to mechanical interlocking. APS generally weakens the positive effect of the alkalization treatment. The combined effect of the positive treatments (NaOH and DMDHEU) is still to be explored.

IVW conducted work on the treatment of flax fabric yielding water-resistant “green” coatings or graftings on the fibers’ surface using bio-derived phenalkamines (PhAlk) and water glass (WG) of mineral origin. Water glass, as a very cheap highly alkaline polysilicate precursor was applied as mercerisation agent yielding improved fire resistance. It is also well known that mercerisation of natural fibres usually results in their improved mechanical properties.

Liquid phenalkamines derived from cardanol (distillation product of cashew nutshell liquid) bear high-reactive amino groups, which are able to react with carboxylic and/or methylol groups of the natural fibres. The super-hydrophobic character of the long aliphatic chain in the structure of phenalkamine was employed to improve hydrophobicity of the fibers and to enhance their compatibility with the (bio)epoxy matrix (especially containing cardanol based components). In addition, improved durability and some bioactivity of PhAlk-treated fibres were expected. Combined WG and PhAlk in sequential combinations were also prepared.

For the treated fabrics, a significant change of their chemical structure due to the chemical reaction between functional groups of fibers and WG and PhAlk was confirmed by FTIR spectroscopy. Moreover, microscopic investigations demonstrate that fiber surface topography changes due to the modification. At the same time, after combined treatment, a second Tg was observed indicating the formation of an organic-inorganic hybrid polymer network. It was found from DSC data that WG modification increases glass transition temperature (Tg) of fibers. On the other hand, WG treatment decreased thermal stability of treated fibers, but improved char-yield, whereas PhAlk showed no significant effect on thermal properties. It was found that PhAlk-type has significant influence on the water resistance. Higher reaction temperature also resulted in lower water uptake values.

IVW and SHR also focussed on the fire retardance of the composites by investigating the effect of applying fibre treatments. Amongst others, formulations of phosphates and aluminium-tri-hydrates were looked at. Most of the formulations succeeded in elevating the fire behaviour of treated flax fibre composites, although not so successfully as the investigated coatings from work package 3.

Although a number of treatments were identified which gave some improvement in fibre properties, it has also been proven that it is inadequate to test fibre properties alone as behaviour in the composite can be different. For example, IVW showed that the fibres could be made hydrophobic by cardanol treatment but when these were used in a laminate the composite still exhibited water swell. Further, some treatments made the fabric rigid and this limits further processing.

The sequence in which treatments are applied is very important. The effectiveness of a treatment also depends on the resin used.

Alkali treatment is good at removing waxes etc. from the surface of the fibres and so increase adhesion to polar resins but it is important that the fibres are properly washed to remove all alkali as long treatments weaken the fibres. An alkali wash followed by treatment with furfuryl alcohol gave a very large increase in transverse three point bend strength in a flax-PFA laminate but in the polyester resin laminates there was no measured effect of the alkali wash.

Plasma treatment of the fibres was not effective at raising the strength of the bond to the resin. This was unexpected. It may be possible that since the resins and fibres are polar the plasma treatment is unnecessary.

Of the various treatments examined for reducing moisture uptake it was found that acetylation was the most effective, particularly when it was applied to jute fibres. Acetylation was deemed most suitable for scaling up.

Water glass coating was the best treatment for reducing the ignitability of the fibres but to achieve the desired performance a very thick coating had to be deposited on the fibres thus making the fabric unsuitable for pre-pregging.

Task 2.3: Resin and composite benchmarking

Broad screening work on the development and characterization of the biobased resins was performed. Moulding trials were carried out by NetComposites, IVW & KUL to create a series of test plaques from non-bio (e.g. traditional epoxy and polyester resins), part-bio (e.g. partially biobased epoxy and polyester resins) and full-bio resins (polyfurfuryl alcohol), combined with glass fibres or natural fibres. Unidirectional composites were made first, in order to create benchmark data on the most fundamental composite properties. Laminates were then made from woven fabrics & tested.

These plaques provided valuable early data on mechanical, thermal and acoustic properties which was fed into WP5. They also allowed a quick assessment of some processing by the environmental experts TNO.

Task 2.4: Resin Property Development

Task 2.4 dealt with the development of resin properties. Cimteclab & DSM were supposed to contribute to this task but their input was limited as both organisations exited the consortium shortly after the end of the first year. The majority of the work therefore fell to TFC. It included the development of PFA varieties with improved fire performance, water resistance and facilitated demoulding. To improve the fire retardance of the PFA base resin, insoluble inorganic polyphosphates were added to the resin. Up to 15 wt% could be mixed in the resin system without significant variations in the curing cycle. To decrease the moisture absorption of the furan base resin, cashew nut shell liquid was added to co-react with the oligomeric furans. Cashew nut shell liquid was added at up to 10 wt% without significant alteration of the curing behaviour of the PFA resin. It was shown that this blend increased the hydrophobicity of the resin, therefore reducing the moisture absorption. Finally, a variant was made with an addition of micronised thermoplastic poly-methyl-methacrylate particles. It was shown that up to 5 wt% of particles could be introduced without significantly changing the curing characteristic of the neat resin. This gave increased shielding of natural fibres against moisture and UV in external environments.

WP3: Integration of Coating, Joining and Sandwich Technologies

This Work Package has as specific objectives the development of:

- In-mould coating, developments of current gel-coat (resin based) systems
- Post-moulding coatings such as paint, nano-coatings, films or laminates
- Joining technologies such as adhesives or mechanical assembly methods
- Sandwich structures with bio foam or cork, for mechanical, thermal and acoustic improvements

Task 3.1: In-mould Coatings

This task set out to identify if an in-mould coating was necessary, or even applicable, to the composites structures that the BioBuild project intended to develop. These types of coatings were intended to be integrated in the manufacturing process as a method to improve surface

quality of the part, to provide a barrier against degradation caused by UV exposure, reduce water uptake, offer flame retardance, wear protection, and be a decorative element.

Since gelcoat application is an additional manufacturing operation it became necessary to verify if a Biobuild composite structure would benefit of having such type of extra layer thus leading to an early test phase that proved to be vital to incorporate these elements. Test plaques were prepared by SHR and NetComposites. Both weathering (SHR) and fire performance tests (LNEC & SHR) showed the need for a coating to protect uncoated composites. Deliverable 3.1 described the results of accelerated weathering tests proving the need for a coating. An example of the degradation which can occur on an unprotected panel is shown in Figure 3.



Figure 3. Jute-biopolyester sample as moulded (left) and after 12w accelerated weathering (right) to illustrate the need for a weather resistant coating on the biocomposites.

Deliverable 3.1 also described the results of ignitability tests and demonstrated the need for a fire protective coating too. It was established that no bio-based in mould coating could be developed or purchased for use in conjunction with the biocomposites developed in the project. There was also no one coating which could provide both adequate fire and weather protection. Thus it was concluded that applied coatings would be required and hence work focused on these.

Task 3.2: Applied Coatings

This task had the objective of evaluating the compatibility of market available coatings such as paints, varnishes and films with biocomposite materials and also to evaluate the consequent impact on overall performance. Main testing procedures focused on determination of water uptake, on the impact that sealing the edges of the composites panels has on water absorption, on weathering, and on fire behaviour. The results of this work were reported in Deliverable 3.2.

In summary the results showed that by applying intumescent coatings the fire behaviour of the both the BioPE and PFA laminates can be improved substantially. The results also showed that fire retardant coating in general and thus also fire retardant/protection intumescent coatings were susceptible to water uptake under moist conditions. Therefore additional protection of the intumescent coating will be required for outdoor use.

Task 3.3: Adhesives

The main objective was to verify the bonding strength of glued joints with different glue systems over different substrates that include not only the different resin-fibre (jute, flax, furan bio-polyester) combinations but also their coatings (pre or post applied). This work was conducted by KUL. The study also took into account the possibility of having glued joints between composite materials and metallic structures, making the study of hybrid glued joints an important factor. The results of this work were reported in Deliverable 3.3.

The consortium was not able to provide this task with a target acceptance criterion for failure value. Therefore, when the results were reviewed it was agreed that a two-component epoxy glue system would be most appropriate since this has the best results, often with the location of the failure being in the substrate rather than at the glue line. Work by TNO showed that the embodied energy of the adhesive had negligible effect on the overall embodied energy of the system.

An attempt was made to formulate a variant of the PFA resin as an adhesive. These efforts proved unsuccessful.

Task 3.4: Sandwich Structures

This task was focused on creating suitable sandwich structures. A sandwich allows an improvement in specific mechanical properties. It was decided to start with the identification of the major needs for each of the four demonstrator designs to set out the requirements for the sandwich structure.

The IPK skin was initially conceived as a jute or flax furan prepreg + cork core sandwich configuration with a total thickness of 10 mm. The processing parameters – such as temperature, compression, press-time, degasification cycles, etc. were investigated. Prepreg was produced by NetComposites and was sent to Amorim & IVW for compression moulding trials. It was found that the optimal configuration was comprised of two layers of prepreg on each side of a 12 mm layer of NL20 cork core which after the compression under temperature resulted in a panel with approximately 10 mm total thickness.

Despite the excellent results found during lab scale testing, problems with delamination between skin and core were found when scaling up from lab scale samples to SBI scale panels (Figure 4). In this case the delamination was caused by steam build-up inside the panel itself due to the cure of the furan resin which generated steam at the processing temperature. This effect wasn't problematic in small samples because the quantity of steam generated was much lower and the vapour could easily escape through the edges of the panels.



Figure 4. Result of a preliminary feasibility trial showing the effect of uncontrolled steam production during the cure of polyfurfuryl alcohol laminates with a cork core.

Various efforts were made to mitigate the problem, such as developing the pre-preg to have lower steam production and cure at a lower temperature to slow the rate of steam evolution. However, difficulties persisted and the sandwich concept was abandoned.

Similarly the ECK was due to be a sandwich panel but continued difficulties with delamination and a lack of flatness led IVW to conclude that it was simplest to proceed without a cork core in the material.

Task 3.5: Analysis of Properties

This task had the objective of evaluating the outputs of task 3.1 through 3.4 by means of small scale sample testing. Several partners conducted these tests. The following tests were conducted:

- Dimensional stability and swelling in liquid water (EN317) and humid air (EN318) – KUL, IVW & SHR
- Moisture resistance (EN321) – SHR, IVW & KUL
- Bending strength (MOR) and bending stiffness (MOE) (EN 310) – NetComposites, IVW, KUL, SHR & LNEC
- Durability test (fungi tests) (EN 12038, EN113) - SHR
- Durability in ground contact (ENV807) – SHR
- Acoustic properties - LNEC
- VOC emission - LNEC

WP4: Processing of Biocomposite Panels and Profiles

Summary of Progress

The overall aim of WP4 was to develop a series of panels and profiles by using different processing techniques and combining the materials developed in WP2 and WP3. The processing techniques used in this WP were hand lay-up, vacuum infusion, pre-pregging, vacuum bagging, compression moulding, continuous compression moulding, semi-continuous compression moulding, and pultrusion. Shaped large-scale profiles were produced by using semi-continuous compression moulding and pultrusion. Pre-pregs were cured using vacuum bagging and static, continuous and semi-continuous compression moulding.

Task 4.1: Hand Lay-up/Infused/Vacuum Bagged Panels

Hand lay-up was performed by Fiber-Tech with bio unsaturated polyester resin and flax. Flat plaques were made to provide samples for testing in WP6. A small scale section of the EWP was mocked up (Figure 5).

Pre-pregs were made by NetComposites using flax and jute fabrics and the PFA resin. NetComposites were able to control fibre weight fraction, volatile content and flow value in response to other partners' processing limitations.

Static compression moulding was used, because it is the most important technology for the manufacturing of natural fibre materials. It is also a long established process whose advantages and disadvantages are well known. The process was adapted to use natural fibre pre-pregs.



Figure 5. The first version of a small scale EWP. The later design used a loose fill insulation and the through thickness ribs were removed to reduce thermal bridging.

Pre-preg was supplied to other partners for compression moulding (primarily Amorim & IVW). NetComposites also conducted compression moulding but additionally produced panels by vacuum bagging. Since the cure of PFA liberates steam it requires careful control to prevent the resin from foaming during vacuum bagging. NetComposites established procedures which allowed dense rigid panels to be made without foaming.

For the production of the SCK, Acciona investigated vacuum infusion as alternative to pultrusion. It was performed with flax textile and bio UP resin. Small surface defects occurred which were avoided by adapting process parameters. The main disadvantage was that it was not possible to a fire retardant, because the fillers would block the resin flow through the textile. Therefore an alternative for the SCK is the combination of hand lay-up with vacuum bagging.

Task 4.2: Continuous Processing

The aim of this task was to develop a continuous high pressure laminating process according to the existing facilities at ACC. It had originally been expected that this would be used to produce large flat panels, such as those required by the IPK.

The task started with several difficulties. The supplied pre-preg material was made to a specification which was known to work well for static compression moulding, but in a continuous process, there was no opportunity for “breathing” or degassing the material. Moreover, the continuous double belt press at ACC required modifications to make it suitable. Currently is it designed for non-continuous feed and continuous output. It was not possible to adapt the input of the equipment due to the lack of space. Before a suitable

compromise could be developed Amorim embarked on a restructuring and they decided to decommission the press and relocate it in a different factory.

Task 4.3: Semi-Continuous Processing

Semi-continuous processing was performed using a semi-continuous compression moulding machine (CCMM), see Figure 6. NetComposites tailored the pre-preg to suit this apparatus. The process parameters were in compliance with the parameters investigated in the static compression moulding process. The production of sandwich panels with cork was stopped as steam formation caused delamination in some parts of the panels.

The flat panel geometry was not ideal for a rainproof external cladding kit. A new CCMM tool was planned with an improved geometry to prevent seepage behind the panel but this was stopped as the principle could be proved with the original geometry. Therefore, the ECK was built up with completely flat panels with no overlap.

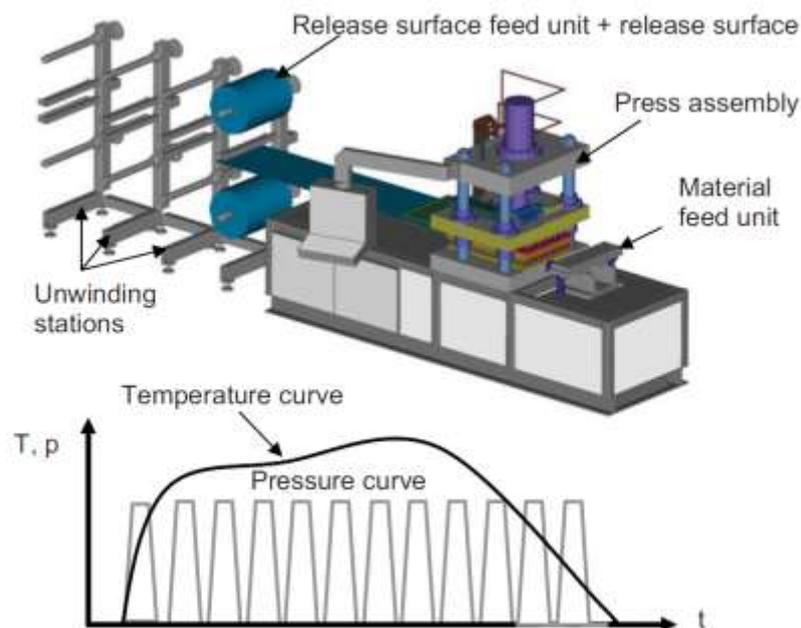


Figure 6. The semi-continuous compression moulding process

Task 4.4: Optimized Bio-Pultrusion

Pultrusion was performed by Acciona and Exel Composites. The aim was to pultrude natural fibres and biopolymer together.

Acciona did some work with three different furan resins and bio UP. The viscosity of furan resin with low water content was too high for the process ($> 1000 \text{ mPa}\cdot\text{s}$), whereas the water content of furan with lower viscosity is too high ($\sim 20\%$). Pultrusion with UP resin and natural fibres is very slow compared to standard processes with glass fibre.

The main drawbacks come from the natural fibre side. In pultrusion dry natural fibres gave higher friction than glass fibres which produced fibre buckling, fibre rupture, and fibre blockage near and in the mould. This issue was solved by adding zinc stearate but the output rate was low compared to a glass pultrusion.

It had been hoped that pultrusion would be viable for the production of the SCK demonstrator. However the lamella were too stiff to be bent to give the desired aesthetic. Consideration was given to using glass-polyester resin pultrusions as brackets and connecting rods to support the demonstrators. Such products are on the market, although their uptake has been slow. It was expected that the biobased polyester resin could be used for this work and allow the manufacture of a partially biobased glass reinforced pultrusion. Some initial trials were conducted but there were problems in the batch consistency polyester resin supplied so it was not possible to produce large quantities of exhibition standard pultrusion.

Task 4.5: Process Monitoring

The manufacturing processes were permanently monitored by all processing partners in order to minimise the energy used and to maintain the correct balance between fibre degradation, cure quality and process speed. The results were sent to TNO for inclusion in the LCA.

Task 4.6: Analysis of Properties

Most of the processing partners tested the mechanical, physical and/or chemical properties of the produced parts. This was done in order to check the process parameters and to improve the process. The mechanical tests usually included tensile, three point bending and impact resistance, whereas the physical performance is tested microscopically, by fire tests and water uptake. Also cure tests were carried out to examine the quality of the output from the process. Furthermore, this task involved the preparation of samples for testing at LNEC.

WP5: Construction System Integration

Summary of Progress

The four building systems developed through the project were:

- The External Wall Panel (EWP)
- The External Cladding Kit (ECK)
- The Internal Partition Wall (IPK)
- The Suspended Ceiling Kit (SCK)

The design process was influenced by and is consequential to the activities carried out in WP2-4 regarding materials properties and manufacturing. The designs were intended to impress and convince a wide audience of the potential of using bio-composites materials at the building scale. Aesthetic, physical and structural performance for the systems were considered before finalising the design.

Task 5.1: Designing External and Internal Panel and Profile Systems

The External Wall Panel (EWP), is a unitized façade panel incorporating insulation and window elements, with the purpose of separating the outdoor climate from the indoor climate. From the structural point of view the system works with an external structural bio-composite skin that transfers the design loads to a wooden frame (mullions and transoms). The internal skin has no structural function but has been designed to resist to impact loads from the interior of the building and ensures a nice architectural finish. The internal structure of the panel is designed to limit the local buckling and excessive deflection by including stiffening ribs. Technical solutions were adopted to solve the connections to the floor slab.

Requirements such as fire, acoustic performance and thermal insulation influenced the design process of the EWP and defined the thickness of the panel. The formal-design concluded with a three dimensional complex configuration allowing both an improved stiffness of the panel (the folds add to the stiffness) and the window elements are shaded by the composite shell at the top side. The final design is shown in Figure 7.

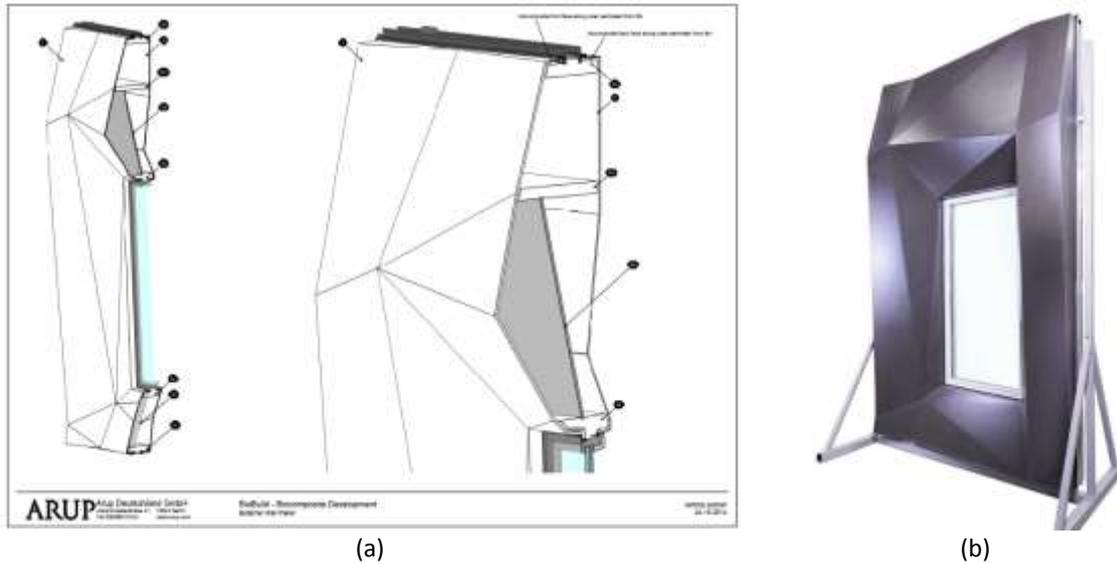


Figure 7. Detailed drawings (a) for the External Wall Panel and its final appearance (b).

The External Cladding Kit (ECK), is a rain-screen system comprised of panels, which protect the wall (insulation, structure, etc.) behind it. The ECK is also an important architectural element being the outermost layer of the building façade. The design process of the ECK focused on increasing the span of the panels between supports by incorporating shaped stiffening elements on the back of the flat outermost bio-composite plates (the so called open-hat profiles). A large span allows for cost savings in installation (see Figure 8)

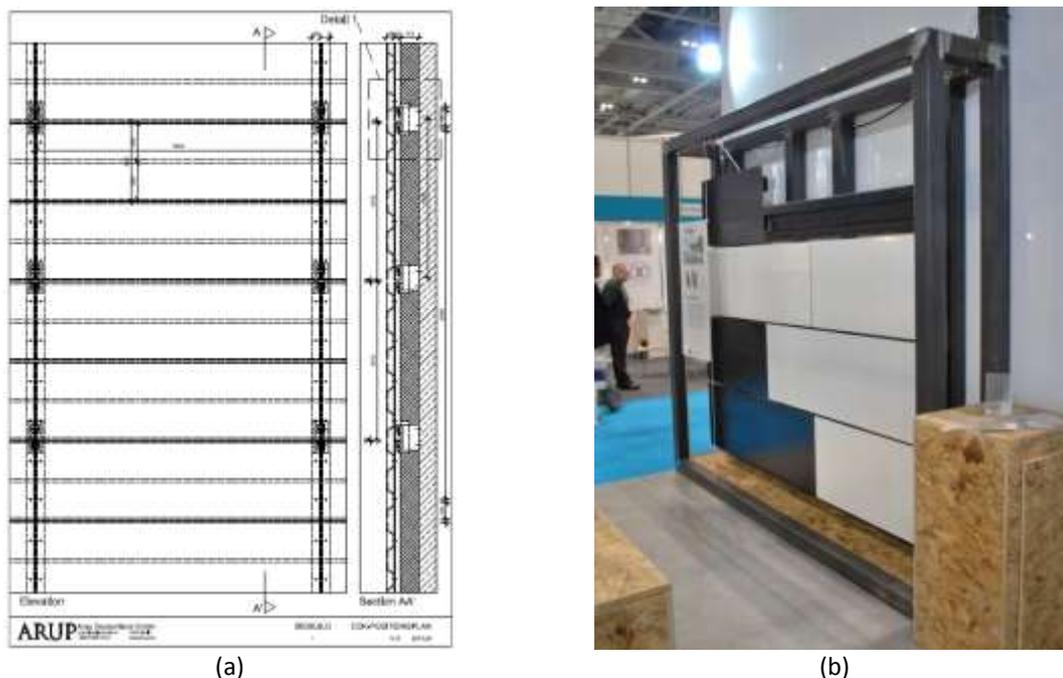
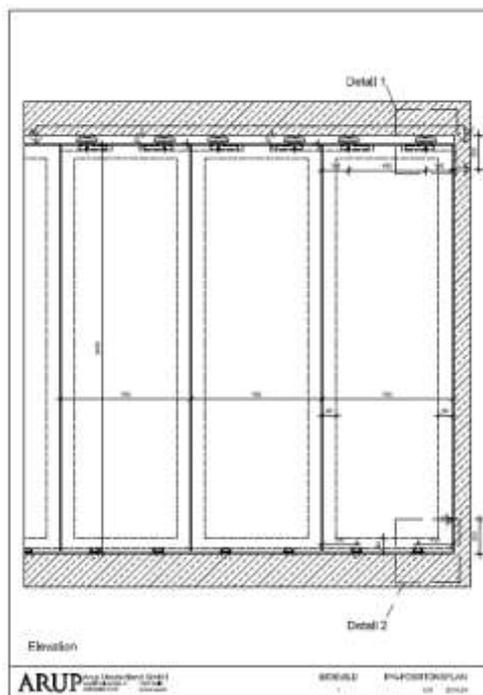


Figure 8. Detailed drawings (a) for the External Cladding Kit and its final appearance (b).

The Internal Partition System (IPK) provides appropriate visual and acoustic performance to be used in both residential and office buildings (Figure 9). The system has been conceived as a sliding partition to ease the installation procedures and increase the system flexibility within the buildings and it moves thanks to castors along a metal top and bottom rail. The panel is composed of two flat bio-composite plates fixed to a wooden frame by an adhesive bond. The bio-composite plates provide both stiffness to the system to avoid excessive deflection and resistance to impact. They also provide an appropriate weight to the partition to meet the acoustic requirements. The total weight of the panels can be “tuned” depending on the specific threshold value for the sound insulation (in dB) and be adaptable to a wide range of internal spaces.



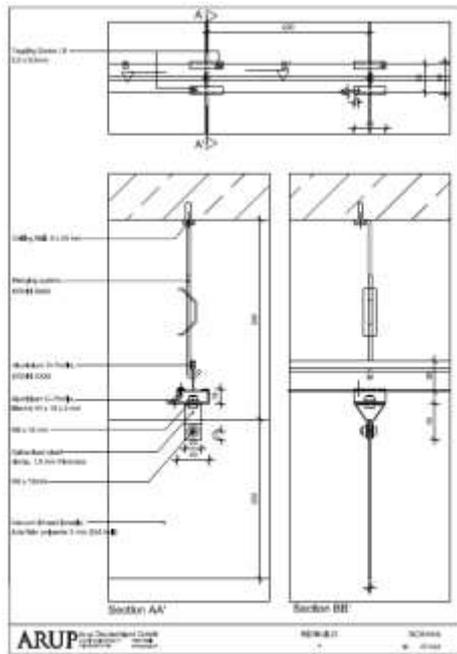
(a)



(b)

Figure 9. Detailed drawings (a) for the Internal Partition Kit and its final appearance (b).

The Suspended Ceiling Kit (SCK), is an open, lamella-based element attached to a structural grid (Figure 10). The SCK acts as an architectural element with the purpose of hiding technical installations in the gap between the lamellae and the building floor plate. The design process has been influenced by a number of parameters, including acoustic performance, fire performance and architectural expression. The lamellae are connected and placed in position by a composite pultruded substructure and a metal clamping system. The lamellae are manufactured as freely shaped components that can be installed directly in the final configuration and are not meant to withstand any structural load.



(a) (b)
 Figure 10. Detailed drawings (a) for the Suspended Ceiling Kit and its final appearance (b).

Task 5.2: Joining Technologies

Joining technologies were explored by Arup with the intention of developing a design which works with existing commercially available systems, the main reasons being:

- Reduce the time needed to design and test a custom made solution
- Reduce the cost of the systems by using available joining technologies

In many cases traditional metallic mechanical fixings were used. Adhesives and sealants were also used. The QuickScan showed that the choice of adhesive and sealant had little impact on the overall embodied energy of the part.

Task 5.3: Small-scale Demonstration Unit(s)

During Period 2 Arup coordinated the activities to produce small scale assemblies to assess the quality of the manufacturing process and potential criticisms with respect to the conceived design. Within the consortium it was decided to build some of the systems and then conduct an SBI test (fire performance test performed within WP6) - reducing the number of components to be produced overall.

WP6 Evaluation of Biocomposite System Performance

Task 6.1 Manufacture and Testing of Lab-Scale Systems

WP6 started with the definition of the test samples. The tests required are adapted to every specific Biobuild demonstrator product, but, in general, the following tests are considered:

- a) Reaction to fire tests (Ignitability test, Single Burning Item test (EN ISO 11925-2 and EN 13823))

- b) Determination of flexural properties at ambient temperature (EN ISO 14125 and ISO 178)
- c) Determination of tensile properties at ambient and at elevated temperatures (EN ISO 527-1,4)
- d) Apparent interlaminar shear strength (ILSS) (ISO 14130);
- e) Determination of dynamic mechanical properties (storage modulus, loss modulus and tan delta) during a linear temperature scan under heating conditions (ISO 6721);
- f) Charpy impact properties or Izod impact strength or tensile impact strength (EN ISO 179-1, EN ISO 180 and ISO 8256);
- g) Temperature of deflection under load (ISO 75-3);
- h) Water vapour transmission properties (permeability) (EN 12086);
- i) Determination of water absorption properties under controlled conditions at ambient and elevated temperatures (EN ISO 62);
- j) Volatile Organic Compounds (VOCs) emissions from Building materials (ISO 16000-3,6 and EN 717-1);
- k) Dimensional stability at ambient and elevated temperature (EN 438-2, Sections 17 and 18);
- l) Determination of moisture resistance under cyclic test conditions (EN 321 and EN 310);
- m) Durability against fungi (Basidiomycetes and other fungi) (DD 15083-1; DD 15083-2);
- n) Assessment of the effectiveness of fungistatic compounds in plastics formulations (ISO 16869);
- o) Biological resistance – plastics (EN ISO 846).

This was a long list so the tests were prioritised to react to time pressures to ensure that the basic properties of the Biobuild products were properly assessed. The preliminary assessment of the results obtained up to month 24 was reported in deliverable D6.1. This highlighted some technical problems, namely:

- Problems of delamination were found on the Biobuild panels comprising a cork core;
- Problems with the reaction to fire performance of Biobuild panels were found. Due to the natural organic nature of the composites, fire performance needed to be improved either by introducing environment friendly fire retardants or applying protective finishing coatings.

The initial ignitability tests (small ignition source) on the basic performance of the materials showed, especially, that:

- Furan resin does not ignite easily;
- Furan/flax prepreps may ignite and sustain a slow propagation of combustion;
- Biopolyester resins ignite (flame edge attack) and sustain the development and propagation of flame resulting in total combustion of the material.
- Biopolyester resins require the use of fire retardants and/or intumescent coatings.
- Edges must be protected (in the end product/kit). Practical/cost effective solutions must be studied.

It was not possible to avoid delamination between cork core layers and outer PFA skins in the sandwich panels. Therefore, the designs of the panels were changed so that they do not include cork anymore and the manufacturing method was improved. Single Burning Item tests were then conducted on the new designs of panels.

Task 6.2 Manufacture Full-size Test Rigs

In this task, new test rigs were built upon receipt of the full sized test samples. The rigs were designed to support the panels as they would be supported in a building environment. They also included all the metrology equipment needed to measure the response of the components under test.

Task 6.3 Definitive Testing of Full-Scale Demonstration Installation Test-Rigs

In this task, the full sized test samples (or where appropriate, test coupons cut from the large scale panels) were subjected to a range of tests used to assess the performance of the BioBuild products according to the relevant Guideline for European Technical Approval (ETAG) or European Standard (EN) and thus to compare with current products for the same uses.

The main conclusions were:

1. From the assessment of chemical and mechanical properties, it was concluded that the obtained results confirm that natural fibre biocomposites have a potential to replace glass reinforced composites in many applications that do not require very high load bearing capabilities.
2. From the assessment of moisture resistance, it was concluded that composites Biopolyester-flax and Furan-flax increase their length at high humidity,
3. From the assessment of water vapour permeability, it was concluded that Biopolyester-flax (EWP) is impermeable, Furan-flax (ECK) is very little permeable ($S_d=78$ m) and Furan-jute (IPK) has some permeability ($S_d=9$ m).
4. From the assessment of water absorption, it was concluded that all the studied biobased composites absorb water at room temperature but it seems that Biopolyester-flax (EWP) is more resistant to water penetration.
5. From the assessment of durability, it was concluded that biobased composites need a protective coating and that intumescent coating systems showed inadequate durability for outdoor exposure.
6. From reaction to fire assessment, it was concluded that:
 - Furan products have better fire performance than biopolyester products, but use of additional either surface protection or fire retardants is required;
 - Class B may be obtained with some intumescent coating systems, but not in all the BioBuild case studies;
 - Tested intumescent systems showed poor weathering resistance (outdoor use);
 - Intumescent coating systems require thick multi-layer expensive solutions;
 - Use of adequate (environment friendly) fire retardants may be the best approach to reach class B.
7. In the evaluation to standards and specifications of BioBuild products, it was concluded that they have good mechanical strength, weak durability performance for outdoor use (unless with protective coating) and fair reaction to fire performance.

Figures 11 & 12 illustrate the SBI test conducted on panels, made from the same material but without and with an intumescent coating.



Figure 11. Uncoated furan-flax (cork core) sandwich panel (right: damaged surface after end of test)



Figure 12. Furan-flax sandwich panel (as in Figure 11) coated with intumescent coating system (left) subjected to an SBI test (centre) showing surface intumescence after end of test (right).

2.2.7. WP7: Demonstration Installation

The global objective for WP7 was to demonstrate the developed materials and systems as full size installations. This was to allow a full test of the design, materials, assemblies, installations and logistics and to produce demonstrators for dissemination purposes.

In the first stage, the consortium partners agreed on the allocation of partner's roles. This decided who would be responsible for the different steps needed to manufacture each of the four demonstrators proposed within BIOBUILD. The partners agreed on the final configuration of each demonstrator in regard to materials composition, fibre, core material, resin type etc. Thirdly the partners involved on design/manufacturing tasks selected the most appropriate manufacturing method for each demonstrator taking into account all the design/production constraints.

Task 7.1. - Manufacture and Install an External Cladding Kit

For the External Cladding Panel (ECK), the front face was a 5 mm thick panel with several layers of flax-furan pre-preg. The back face used the open hat (omega) profile, 3 mm thick. Both front face and open hat were made by IVW using pre-preg from NetComposites in a semi-continuous compression moulding machine (see WP4). It was decided to remove cork from the core to simplify production and to improve flatness and surface finish. IVW also bonded the open hat profile to the front face and added the metallic fasteners. A number of the panels were exhibited with their natural colour and several were painted white by Fiber-Tech.

Task 7.2. - Manufacture and Install an External Wall Panel

The EWP was prefabricated in the workshop ready for installation on site. It was made by hand lay-up of a biobased polyester resin reinforced with woven flax textiles. The hand lay-up was done in a plywood and fibreglass mould made from an MDF pattern. Two moulds were made – one for the outer skin and one for the inner skin. A gelcoat was used for both skins, but the inner skin was additionally painted to achieve the highest quality finish. The interior of the panel contained a loose fill insulation and the connection between the inner and outer skins was made by a plywood frame. The glazing unit was also workshop installed prior to shipping. On site the EWP was simply lifted by crane into its final position and it was fixed to the frame using a metallic fixing.

Task 7.3. - Manufacture and Install Internal Partitions

The IPK is a sandwich material with jute-PFA composite skins and a cork core with a wooden or pultruded profile frame for rigidity and support. The skins were produced by NetComposites using pre-preg which was vacuum bagged on a rigid flat surface in an oven to produce the panels. These panels were then bonded to the frame by SHR who also applied the metallic fixings and runners. One panel was painted by Fiber-Tech to change its aesthetic.

Task 7.4. - Manufacture and Install Suspended Ceiling Kit

The suspended ceiling was made from vertical lamella of biocomposite. Sheets were made by infusing a planar preform of three layers of jute fabric with a biopolyester resin. They were then CNC machine to the final design specifications. Acciona performed all the tasks necessary to achieve this result.

Task 7.5. - Combine the New Technologies in a Single Demonstration Unit

All the full scale developed elements were presented at EcoBuild 2015. The structures which were produced are shown in Figures 7-10 and Figure 17.

WP8 – Environmental & Economic Analysis

Task 8.1 Environmental Benchmarking

A report was prepared on environmental benchmarking (D8.1) which covered:

- the whole methodology (goal & scope) description for all WP8 analyses, in line with the ILCD Handbook for Life Cycle Assessments and the ISO norm for building products (EN ISO 15804);
- a description of the case studies and selection of the reference materials (in a workshop with 3XN and Arup) to which the BioBuild products will be compared;

- the benchmarking results for embodied energy, land use, water use and costs for the BioBuild products as well as the reference products;
- a scenario investigation of the potential of the BioBuild products in the market;
- an overview of the potential sensitivities in the calculations, which should be subject to further research during the project.

BioBuild products are expected to have much higher water and land use than the other materials, which was in line with the expectations. This is more an observation than a conclusion, because there is no target for BioBuild with respect to water and land use. During the BioBuild product development the consequences of choices on resins and fibres for water and land-use were taken into account, to have the possibility to reduce water and land-use of the intended product to be developed.

Task 8.2 Health Evaluation

This task started by establishing the methodology for the health evaluation. The BASF method was used. In this the risk phrases for each substance or mixture used in the work are scored and a weighted average determined. In addition, publically available data for deaths and injuries was recorded for the processes used in the proposed manufacturing methods to arrive at a measure of the impact of the BioBuild demonstrators on human health.

The agricultural phase that generates the raw materials for BioBuild products contributes over half the all health risks of the product. The other phases of the life cycle (production of resins and fibres, production of panels, installation and maintenance and end-of life) have a relatively small contribution to the risks. Increasing the efficiency of the production processes (conversion of agricultural products) or use of by-products will decrease the health risks associated with BioBuild products. This was explained in D 8.2. The non-biobased components used to produce BioBuild products (such as chemicals for fibre treatment) contribute relatively little to the health risks.

This approach to assess Health Risks over the life cycle of products is a rather innovative assessment, which proved to be appropriate given the data availability. It is a useful approach in development processes, as the assessment reveals options to decrease health risk either by shifting to other product resources, or to other production processes.

Task 8.3 Prioritising Environmental and Cost improvement to support technical development (“the quick scan”)

Many quickscans were performed: on the basic fibers, the fiber preforms, the resins, the fiber treatments and the BioBuild product costs. The fiber preforms and the resins are the most important part of the embodied energy and the environmental impact, so attention was focused on these.

A comparison was made of different additives with the embodied energy compared against the embodied energy of the resins on a volume basis. This revealed which additives have the potential to decrease the embodied energy content of the resins, and which additives increase the embodied energy. Coatings contribute relatively little to the embodied energy. However, depending on the type and amount used over the life cycle, the contribution is not to be neglected. This conclusion also applies on functional paints (paints with fire retardants). The embodied energy of adhesives contributes relatively little to the embodied energy of the full product. Therefore, it was recommended to select the adhesive with the best technical performance.

A quick scan model was developed together with Arup, to directly support the design process. Data has been generated for this model, both for the biocomposite designs as well as for reference product designs.

Task 8.4 Methodology development for new impact categories

The methodology development for new impact categories for assessments of biobased products required a fundamental policy and literature study. Gaps were identified and with research in this project.

Task 8.5 Final Eco-efficiency impact evaluation

The data gathered for the quick scans was updated according to the designs for the demonstrator unit as presented at EcoBuild in London. In addition data was collected for a theoretical design that is optimised on energy efficiency. The purpose of this optimised design was to demonstrate the future sustainability potential of further developed BioBuild products.

A full environmental profile was calculated, in addition to the life cycle costs and the life cycle risks for health incidences. The results were reported in D8.5. The main results of the final evaluation were the comparison of Embodied Energy, Environmental Impact, Costs and Health risk between the BioBuild demonstrator unit, the BioBuild optimised design and state of the art benchmark products for the four applications (Figures 13-16). For some product application, the BioBuild optimised design has the potential to have lower embodied energy - up to 50% compared to the reference product – according to the project goals against similar or lower costs. For other product applications these goals were not met. The BioBuild product will need further technical development to meet technical requirements (such as fire performance) recommendations are made how to further develop towards increased energy efficiency.

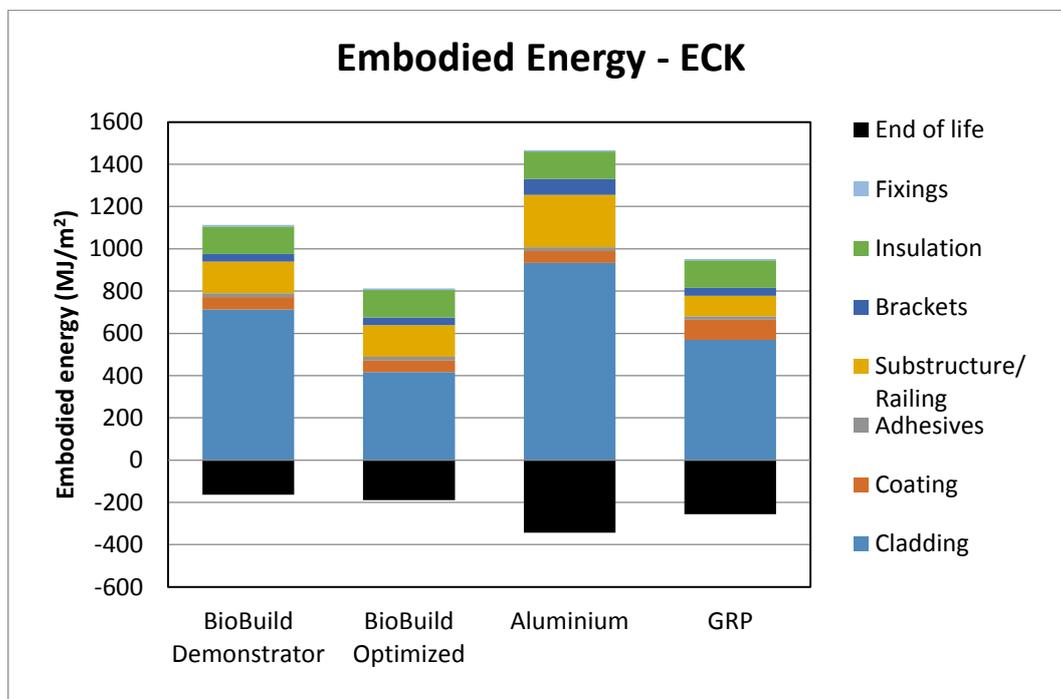


Figure 13. Embodied energy (non-renewable energy) of the ECK variants, shown on a component level. End-of-life impacts of all components are shown in black, separated from score of the components themselves.

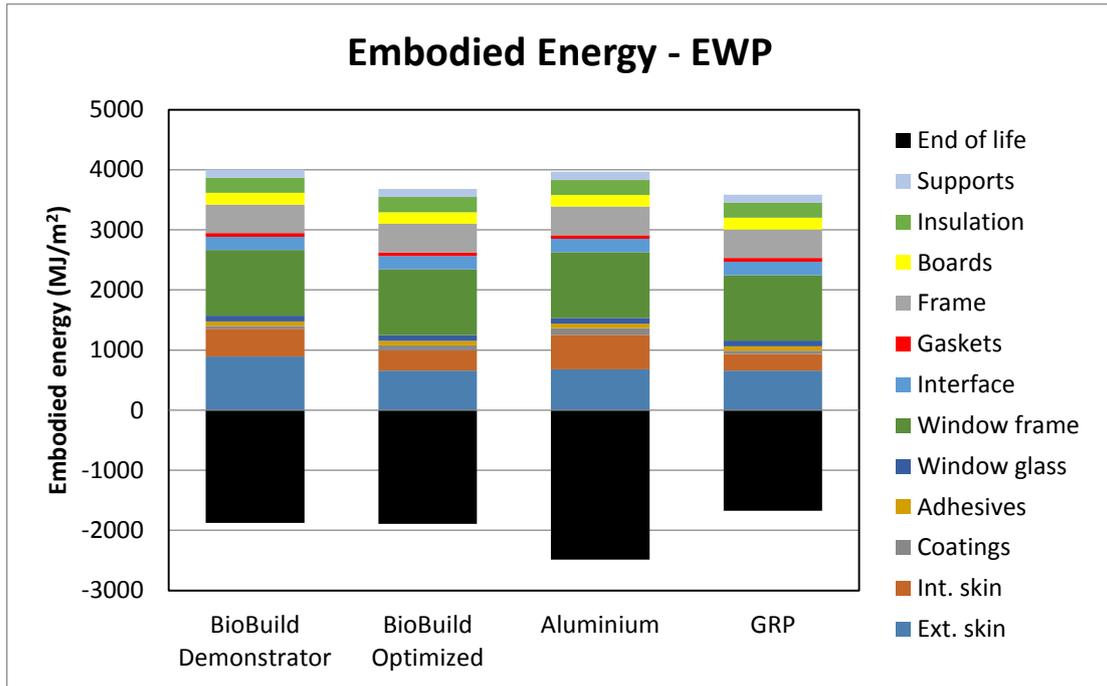


Figure 14. Embodied energy (non-renewable energy) of the EWP variants, shown on a component level. End-of-life impacts of all components are shown in black, separated from score of the components themselves.

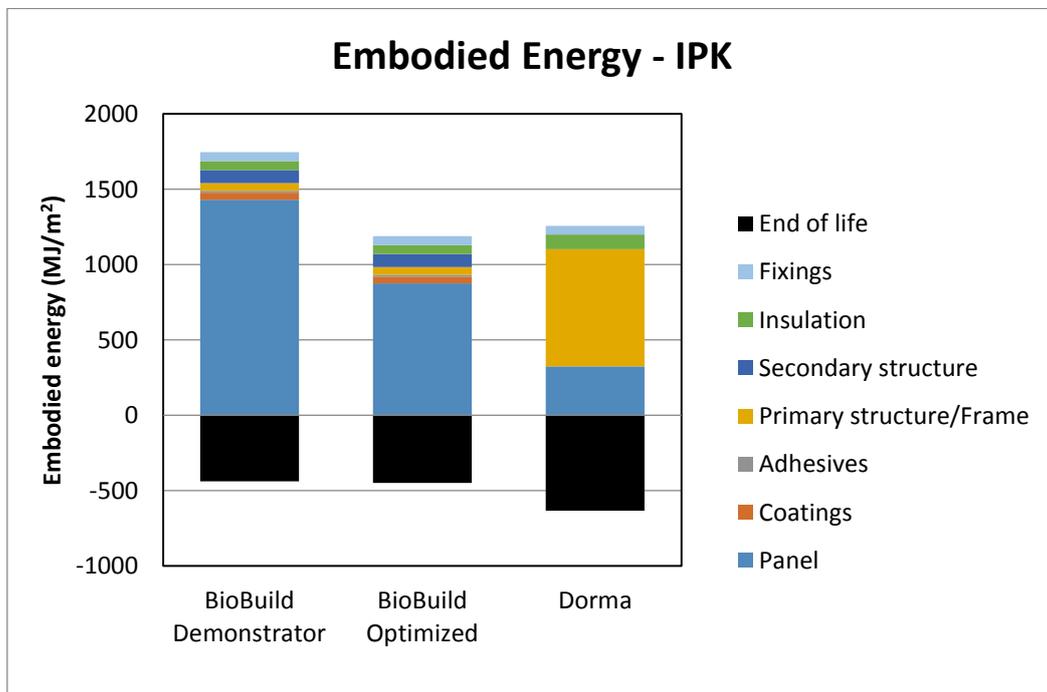


Figure 15. Embodied energy (non-renewable energy) of the IPK variants, shown on a component level. End-of-life impacts of all components are shown in black, separated from score of the components themselves.

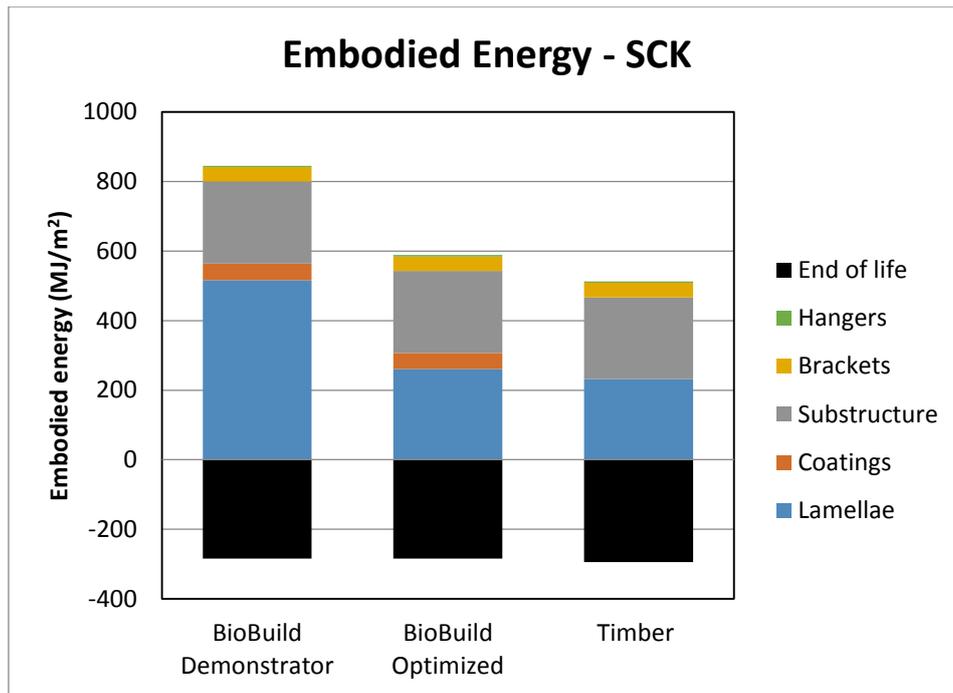


Figure 16. Embodied energy (non-renewable energy) of the SCK variants, shown on a component level. End-of-life impacts of all components are shown in black, separated from score of the components themselves.

WP9: Dissemination and Exploitation

Task 9.1 Project Dissemination

The dissemination activities are shown in the table attached to this report. A full version of this table is also available in D9.1.

The project has presented a significant number of academic papers at international conferences, including four at ICNF, two at ICAE, two at ECCM and two at ICCM. In addition the project has been highlighted at a number of exhibitions, including CompIC, the Composites Engineering Show, JEC and EcoBuild. The project wrote a few press releases in particular those relating to the JEC award and the activities of BioBuild at EcoBuild. Both were picked up by the national media in several countries resulting in the project receiving a lot of coverage.

The project also produced two newsletters which described the activities of the project. The first focused on the designs for the demonstrator parts whilst the second explained the manufacturing methods which the consortium would be using to produce the demonstrators. The newsletters also contained articles on the testing of the materials and the LCA.

EcoBuild was the primary dissemination event in the project. All four demonstrators were assembled on a stand according to a design by GXN & Arup. This enabled the novel biocomposite building parts to be exhibited to a wide range of construction industry professionals (see Figure 17).



Figure 17. The BioBuild stand at EcoBuild.

Task 9.2 Website

The website was set up at the start of the project and is a repository of project related information. It has a private side which contains all the partner presentations given at the quarterly project meetings, the confidential deliverables and other reports. The public side contains the presentations given at the IIG Meetings and the Newsletters. There are also some deliverables on the public side. The website was periodically updated with new content and was given a new look in the final year of the project to improve its visual appeal (see Figure 18).

Task 9.3 Industrial Interest Group and Association Liaison

The project held three IIG Meetings. The first was held in Lisbon (LNEC) in December 2013. The second was held at Wageningen (SHR) in March 2014 and was largely a re-run of the event in Lisbon. The final IIG was held September 2014 in Copenhagen at the Dansk Arkitektur Centre. This was a joint event with LEEMA and SUS-CON.

Task 9.4 Exploitation Planning and Execution

The project held two Exploitation Strategy Seminars. A total of 19 Key Exploitable Results were identified although most of the results are orientated to the processing methods and so whilst some aspects may be inventive and novel any patent would be difficult to enforce. Work is continuing on the fibre treatment technologies and this is generating useful IP which may be worth protecting.

Task 9.5 Workshops Delivered

Originally it was expected that the project results would be disseminated by means of a workshop towards the end of the project. However, it was agreed that displaying the products at EcoBuild would be a very effective method of publicising the results of the project. A presentation was made at EcoBuild which resulted in a number of stand visits and good contacts being made with potential customers for biocomposite products.

Displaying all four demonstrators at EcoBuild was a major undertaking. However, it was a successful venture with hundreds of people visiting the stand to see the parts. The EWP was also awarded the JEC Innovation Award for Sustainable Construction. This helped to raise the profile of the project and generated considerable media interest.



Figure 18. The BioBuild website (www.biobuildproject.eu) from which is intended to inform the public about the project & allow them to download related documents.

4.1.4. Potential Impact & Wider Societal Implications

The results of BioBuild are the knowledge, process techniques and equipment to produce and install biocomposite building components and systems with significantly reduced embodied energy compared to conventional building components. The project has produced four full scale prototype parts in biocomposites:

- External Wall Panel
- External Cladding Kit (rain screen panels)
- Interior Partitions
- Suspended Ceiling

Each of these parts has been produced in full scale using manufacturing processes which are already in common use in the composites industry. Constructing the parts in full scale allows a proper investigation of all aspects of the manufacturing and the supply chain and the successful delivery of the four demonstrators on time proves that the processes have been properly investigated. Thus the parts could be readily reproduced by other manufacturers with experience in these techniques and appropriate plant.

Some of the techniques applied are readily scalable to bulk production (e.g. pre-pregging and semi-continuous compression moulding). The other techniques employed are batch processes, which were selected due to the small quantity of components needed. However, such techniques are ideal for producing bespoke items. Biocomposites remain a niche product and there is demand for bespoke signature pieces.

The partners have undertaken assessments of the embodied energy of the biocomposite components and systems, to assess the reduction in embodied energy compared to incumbent components. It was shown that savings were made in the majority of cases. With improved optimisation then a saving of 50% is readily achievable using existing technologies when compared to state of the art products. Further technical development may allow greater reductions to be achieved.

Biocomposite materials have a lower embodied energy than glass reinforced polymer composites (GRP) and in many applications, GRP represents a low energy solution compared to steel and masonry structures. The wider use of composites, including biocomposites, will thus lead to a reduction in greenhouse gas emissions.

The main drawbacks of biocomposites perceived at the start of the project were, a lack of durability and a concern over combustibility. The project has shown that by using existing coating technologies that improvements can be made which elevate the performance of the biocomposites to that required by the application. It should be stressed that these coatings were not designed or optimised for use on biocomposite substrates and therefore may not represent the most efficient technical solution.

The project identified suitable fillers which give improvements in fire performance without reducing the stiffness of the materials. A filled matrix offers better fire protection than a coating since coatings can be damaged or degraded over time, resulting in a loss of protection.

The project has demonstrated fibre treatments which reduce water uptake and improve adhesion of the resin to the fibre. More work is needed to optimise the more promising treatments and scale up the process to enable high volumes of fibre to be treated.

The biocomposite systems also enable a significant reduction in building costs. The density of biocomposite structures (1.3 g/cm^3) is significantly less than existing materials currently

being used in structural applications, even that of aluminium (2.7 g/cm^3), which means that supporting structures such as foundations, cantilevered floors and frameworks need to have significantly less load-bearing capacity. This in turn means that they can be designed to be lighter, use less material and be cheaper. Initial calculations have shown that a 20% reduction in these supporting structures is realistic.

Progress in the energy efficiency of buildings over the last 40 years has meant that the direct energy costs (e.g. through-life heating) have been significantly reduced, and in fact many national and local authorities have now set targets for zero direct energy public buildings, such as schools and hospitals) by 2020. This is particularly relevant to the thermal performance of walls, such as the curtain walling and facades developed in this project. The biocomposite systems developed have at least the equivalent thermal insulation performance of existing systems. Biocomposite materials are in general poor thermal conductors and so do not contribute to thermal bridging. The use of pultruded composite profiles as brackets and connecting systems has been investigated in this project, and these too reduce thermal bridging.

The target for BioBuild was a 50% reduction in the embodied energy of the systems developed. This target was reached in the case of the ECK. The comparator was an aluminium cladding system but the BioBuild solution was also 20% lower than a GRP product. In the UK the market for wall cladding systems is 48 million m^2 per annum (AMA Research). This does include facing bricks, metal panels and composite products. One leading cladding manufacturer, Steni, produces 25 million m^2 of GRP composite cladding panel globally each year.

If such a quantity of cladding panel was produced in biocomposite rather than GRP then the energy saving would be 4,500 TJ/yr (a TJ is one terajoule, which is a million megajoules). If the biocomposite replaced aluminium then the energy saving would be 15,500 TJ/yr. This is the output of a medium sized power station. Thus it is obvious that greater adoption of biocomposites would lead to a measureable reduction in CO₂ emissions. It would also allow the closure of older more polluting power stations, or reduce the build of new power stations. This could reduce the need to build wind turbines; for which there can be strong local opposition. A typical gas fired power station emits 141 kg CO₂/GJ (source: US EPA), thus the use of BioBuild ECK reduces GHG emissions by 635 kT.

The impact on climate change from the other BioBuild components may not be as great as for the ECK but they make a significant contribution. It is clear from the results that biocomposites in general do reduce energy use resulting in a reduction in greenhouse gas emissions. The apparent poor performance of the SCK in BioBuild needs to be judged against its comparator – timber. Wood is a biocomposite material: it consists of cellulose fibres in a matrix of lignin and hemicellulose. Thus a manufactured biocomposite cannot match a naturally occurring biocomposite in terms of energy use. However, the crops used to make biocomposites are fast growing and by manufacturing a composite there is greater freedom of form than with wood.

Wood has been used for many years as a building material. However, it does have some shortcomings – it is anisotropic, it changes dimension in response to humidity changes, it is susceptible to biological attack and it is combustible. Despite these issues, wood has been widely used as a construction material for at least 8000 years. In that time several design and scientific solutions have been found to overcome the shortcomings of the material.

A key aim of BioBuild was to develop technical solutions for biocomposites to overcome the same shortcomings. Not all of the technical problems were completely solved in the 42 months of the project. Some of the approaches tried did not yield the expected results but others were more promising. KUL have published their initial work on the results of fibre

treatments. The aims of the treatments were to improve fibre-resin adhesion, thereby increasing the mechanical performance of the composite and reduce the water swell by better encapsulating the hydrophilic fibres in a hydrophobic resin. By publishing data the information is disseminated to the scientific community and other workers can build on that conducted by KUL. A negative result can be just as useful as a positive result. The approaches adopted were informed by experiences with wood and cotton fibres. It was therefore expected that the approaches taken would yield positive results. It was therefore counter-intuitive when some were found to be ineffective. Some though did work extremely well but need more work to optimise them before they can be published, which may be delayed until; after the intellectual property has been protected.

Fibre treatments to improve the fire retardance did not give an adequate level of performance without rendering the fibres unsuitable for composite manufacture. Again, negative results are useful as the experience can be disseminated and other workers will know that this line of work is unlikely to yield useful results. BioBuild did demonstrate that by adding fire retardant fillers to the resin matrix and/or by applying intumescent coatings then significant improvements can be made to the material. EuroClass B can be achieved. Not all intumescent coatings give the same performance. Some coatings adhere better than others. The knowledge as to the grades and quantities of fire retardant additive is being treated as a trade secret by the material producers in the project. Similarly the IP around the choice of coating and its method of application is not being disclosed.

The lesson from the project is that biocomposites can achieve exploitable levels of fire performance. Thus whilst the details are being kept secret by the partners to protect their market the knowledge that the target can be achieved will allow other producers to maintain their efforts until they reach a suitable target. Fire retardance is an essential requirement for many applications. BioBuild can now demonstrate that biocomposites will meet some targets so the perception that biocomposites have no fire retardance can be changed. This will encourage other end users to consider biocomposites for their applications.

In general the weathering resistance of intumescent coatings is poor and the project was unable to find a combination of intumescent and weatherproof coat to achieve both. This work will have to continue. External applications may not need fire retardance but materials used for external applications do need to be weather resistant. It was beyond the scope of the project to develop a biobased weatherproof coating but it was demonstrated that existing technical solutions are compatible with biocomposites. Thus weather resistance need not be a barrier to uptake. Edge sealing was shown to be critical for biocomposites as water tends to wick long the fibres. Design solutions which protect the panel edges would also be of benefit. In this project Arup & GXN have developed new design codes which can be exploited for biocomposites.

BioBuild has shown that a range of traditional composite manufacturing techniques can be used to produce biocomposites. No significant evolution of the techniques is required. Thus the method of manufacture does not present a barrier to the uptake of the materials. The impact is therefore limited only by the material cost and technical performance and not by any barriers in terms of capital investment in equipment. Companies working in GRP will be able to add biocomposites to their capabilities thus increasing the range of work which they can do, upskilling their workforce and reducing their reliance on individual sectors.

The project investigated several manufacturing methods and not all methods investigated were employed to produce the demonstrators. More research work is needed to develop certain processes (in particular, pultrusion). When this work is done the range of manufacturing processes which can be used will be broadened so the quantity of applications for which biocomposites can be considered will be increased, thus improving the impact.

Working with biocomposites is safer than working with GRP and with timber. The number of fatalities and injuries associated with each stage of the manufacture has been calculated from publically available sources of data. The main contributor to the risk to health as in the production of biocomposites occur as a result of injuries sustained in agriculture. In the production of GRP health outcomes such as occupational asthma and dermatitis have to be included in the list. Increased use of biocomposites will therefore have a beneficial impact on workers' health compared to the use of GRP. This will result in an improved quality of life for the workers and reduced demand for health services.

Producing crops for biobased materials is potentially in conflict with food production. However, the polyfurfuryl alcohol resin is produced from an agricultural waste (sugar cane bagasse). Production of the furfural adds value to the crop for no increase in cost. Far more bagasse is produced annually than is needed for resin production or for all of the other industrial uses of furfural so the majority of bagasse is burnt. This does only liberate the carbon dioxide fixed by the plant in its lifetime but production of furfural and its conversion into a resin does represent carbon sequestration and a corresponding reduction in the use of fossil resources.

The crops used for fibres are not food crops. Flax plants do produce seeds which are edible but the best fibres are obtained if the plants are harvested before the seeds are mature. The land used for growing flax, hemp & jute could therefore also be used for food production. However, crop rotation is an important part of any agricultural cycle. Monocropping can be damaging to soil and result in pathogens reaching critical levels so the inclusion of a different crop is essential, particularly species which are tolerant to a range of soil types. To date selective breeding of flax has either focused on the yield of seeds or the quality of fibres for clothing applications. A market for structural fibres may benefit from new varieties, and perhaps a compromise between fibre and seed yields. A market demand for new (or rediscovered) varieties of natural fibre yielding plants exists so there is a need for agricultural research and highly skilled jobs to be created.

The knowledge and technologies developed in BioBuild are immediately transferable to other sectors. BioBuild focused on buildings but the technologies would be suitable for other applications such as street furniture, (fences, benches, road signs, utility poles etc.) interior furniture, sports equipment, and components in transport applications (side wall panels, seat backs, fascias etc.). Many of these applications will exploit the aesthetic or lightweight nature of the biocomposite materials. There are already examples of biocomposite materials being used for automotive panels, garden furniture, decking and interior furniture items.

At the end of life BioBuild parts can be incinerated for energy recovery. The project has also shown rapid degradation of the material in composting situations. This can be seen as a drawback if durability in a soil contact application is what is required but many components do not get used in soil contact situations so the ability to compost the material is a significant advantage. Incineration will liberate carbon dioxide but the quantity liberated will (in the case of PFA parts) be equivalent to that absorbed by the plant during its growth. If done in a suitable facility, the energy can be recovered; as was assumed in the LCA.

To summarise; BioBuild has developed a lot of knowledge regarding the production of biocomposite components. This knowledge covers the manufacturing methods and the materials used, including fibres, resins, functional additives and/or coatings. BioBuild has also generated reliable test data which demonstrates the applicability and viability of biocomposite parts. Biocomposites exhibit a lower embodied energy than glass fibre composite materials, which often themselves represent a low embodied energy solution compared to traditional materials such as concrete, brick and steel. There is thus a very strong case for the use of biocomposites.

The impact of the project will be to stimulate the uptake of biocomposite materials, not only in the construction sector, but in other application areas too. Significant reductions in greenhouse gas emissions will be a direct consequence of such activities and it is not unreasonable to estimate an annual reduction of a million tonnes of CO₂ emissions through the use of biocomposite materials such as the parts developed in BioBuild.

4.1.5. Website & contact details

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