Upscaling non-residential bio-based circular construction in the United Kingdom

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Abstract. Non-residential circular construction projects using bio-based materials have been realised in the United Kingdom. Case studies include the Adnams Distribution Centre, the University of East Anglia's Enterprise Centre and the British Science Museum's hempcrete storage facility. The bio-based buildings utilise the natural properties of bio-based materials to insulate and regulate internal environments, particularly with reducing fluctuations in temperature and relative humidity, which can be harmful to sensitive stored products and artefacts. Projects have been successful on both on environmental and physical performance levels; however, they have not led to a subsequent proliferation of non-residential large-scale circular projects within the UK using emerging bio-based materials. This study examines why and uses analysis based upon exclusive interviews with key figures associated with three case studies. Challenges faced include the ability to upscale production by manufacturers of bio-based materials, problems surrounding initial costs, gaining accreditation for materials, the vested interests present in the construction industry and levels of knowledge among clients and construction professionals. Potential upscaling solutions identified include long-term financial savings on running costs and high staff productivity, policies regarding grants, incentives and planning applications and local economic regeneration.

1. Introduction

A circular economy strives to eliminate waste product and reuse or recycle source materials upon completion of first use. This is in contrast to the linear economy model which ultimately involves waste product requiring disposal and new, increased demand for source material. The construction industry needs to play a significant role in reducing the use of virgin material, reducing the energy required in processing resources and furthermore a reduction in waste resulting from non-recyclable product [1]. Circular economy, in the context of the construction industry, represents the aim to construct in a sustainable manner, with renewable natural resources being re-used following the design life of a project; however, the application of circular principles to the built environment is currently not considered mainstream [2]. Bio-based materials are suitable for circular construction; they are renewable when sustainably and responsibly managed, and can be recycled, resulting in minimal waste and reduced demand for resource material [3]. Bio-based materials are used for thermal performance, sound insulation, thermal mass, indoor air quality and the prevention or reduction of condensation [4].

Large non-residential buildings using emerging, non-traditional bio-based materials have been realised in the United Kingdom (UK). However, despite on-budget delivery and success from environmental, operational and building physics perspectives, the realised projects have not resulted in a significant increase in large-scale projects, with circular construction procurement still being considered an emerging field [5]. The aim of this study is to evaluate the numerous challenges regarding the upscaling of circular bio-based construction and identify potential opportunities and approaches to promote upscaling. Interviews were conducted with senior professionals who had first-hand experiences in the

conceptualisation and implementation of large-scale non-residential circular buildings using emerging bio-based technologies . This paper formulates issues into three core categories; finance, knowledge and policy.

1.1 Finance

There is a perception that green building inevitably comes with an increase in capital cost [6] in an industry driven by finance [5]. Environmentally certified natural products can attract premiums in price [7]. Stakeholders and decision-makers involved with project funding typically focus upon initial costs and managing budgets [8]. Bio-based materials need to be a profitable option for construction industry professionals to have confidence in their use [9].

1.2 Knowledge

The advantages of using bio-based materials in a construction project include hygroscopic properties (absorption of moisture from the air), a renewable supply chain and biogenic carbon sequestration within plant-based material [10]. Hygroscopic materials adsorb and desorb moisture, a property known as 'moisture buffering' [11], which attenuates peaks and troughs in humidity, leading to improved indoor environmental quality and potential for improved energy performance [10], [12]. Bio-based materials can sequester more carbon than is embodied in construction, therefore having a negative carbon footprint [13]. However, knowledge of beneficial properties of emerging bio-based materials may not be extensively known by construction industry professionals [9].

1.3 Policy

Policy-makers have a key role to play to promote sustainability in construction. Sustainable construction has been addressed at national and international levels; government policies have required planning applications to meet carbon targets [8], [14]. A tax on carbon in the construction industry is one option for punitive legislation [15] to promote circularity in construction and has been adopted in numerous countries, though the aim of reducing carbon emissions inevitably impacts upon the operational costs of the construction industry [6]. Bio-based subsidy measures are also in operation [16], but they can be focused upon energy and bio-fuels, with subsidy for bio-based materials limited to research and development [17]. There can also be adverse effects upon construction industry supply chains due to political events [18].

2. Methodology

Buildings can typically be considered a prototype [19] and this can be considered even more so with large-scale projects using emerging bio-based materials; projects are unique and cannot be considered numerous or mainstream. It was therefore decided to choose a select group of senior professionals for their extensive, first-hand experience in the realisation or development of pioneering bio-based construction projects (as summarised in table 1). Interviewees were selected so that insights could be gained from the perspectives of a private sector client, a public sector client, an academic and a policy-maker involved with case study projects in the United Kingdom. The core categories of finance, knowledge and policy formed the basis of adaptable questioning tailored to the interviewees' perspective. Interviews were recorded and transcribed by the authors. Analysis arising from responses to questions extending from the three core categories of finance, knowledge and policy is subsequently presented. Personal involvement on the realisation of a particular bio-based project commenced the interview process. Questions then progressed in a flexible manner on to wider views concerning the present climate of emerging bio-based materials within the UK and wider construction industry and thoughts on upscaling circular bio-based construction.

Table 1. UK Case study experience of interviewees.

Interviewee	Case study experience
A	Adnams Distribution Centre, Suffolk
B	Enterprise Centre, UEA, Norfolk
C	Enterprise Centre, UEA, Norfolk
D	British Science Museum, Wiltshire

2.1 Case Studies and materials

The case study buildings, shown in figure 2, are the Adnams Brewery Distribution Centre near Southwold, Suffolk (private sector); the British Science Museum Hempcrete storage facility in Wroughton airfield, Wiltshire and the University of East Anglia's (UEA) Enterprise Centre in Norwich, Norfolk (both public sector). The buildings were selected as prominent examples of buildings designed to be circular (disassembly, reassembly, expansion and modification capabilities) and use of innovative non-traditional bio-based materials, locally sourced wherever possible.

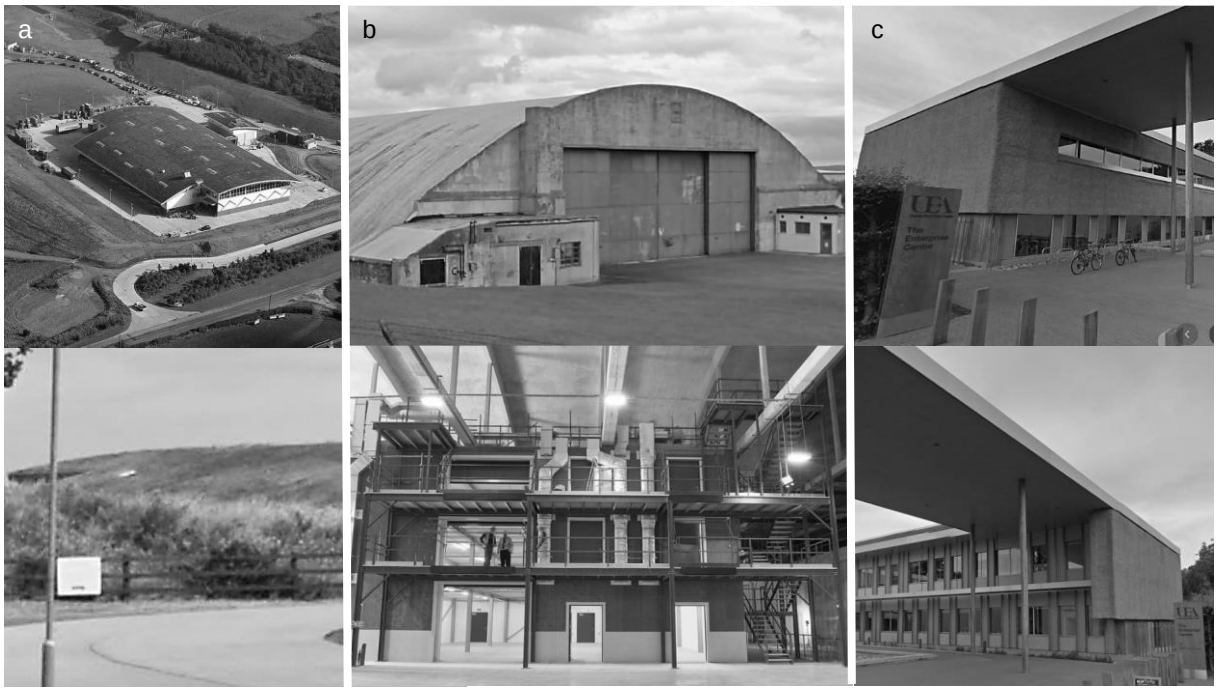

Figure 2. Bio-based case studies in the United Kingdom. a) The Adnams distribution centre, Southwold, Suffolk; aerial view (top) [20] and view from the road. b) British Science Museum hempcrete storage building, Wroughton airfield, Wiltshire; world war two concrete hangar (top) and the hempcrete storage construction within a hangar [21]. c) University of East Anglia Enterprise Centre, Norwich, Norfolk.

Built in 2006, the Adnams Distribution Centre has hemp-lime block walls, the largest green roof in the UK and structural glulam beams (the longest in the UK at up to 41.6 m long and 2 m deep). Sequestered within the bio-based elements is an estimated 150 tonnes of CO_2 [22]. Hemp-lime was used to regulate the internal environment and maintain suitable temperatures for storing produce prior to national distribution. The British Science Museum's storage building was constructed inside an existing concrete hangar dating from the 1930s and features prefabricated dried hemp-lime walls within timber panels connected to a structural steel frame along with cross-laminated timber floors and wood fibreboard

ceilings [21]. The purpose of hemp-lime was to reduce fluctuations in relative humidity (RH) and protect valuable historic artefacts. Hemp is a hygroscopic fast-growing plant and can be considered readily available in Europe and highly renewable [23]. Hemp-lime (also known as hempcrete) consists of shives from the core of hemp plant stems mixed with a binder made from air lime with pozzolanic, cementitious or hydraulic lime additions [24]. Hemp-lime can be sprayed or rendered in-situ while wet, or dried and pre-cast as compressed blocks, as used in the Adnams project [22], or in panels as used in the Science Museum store. Constructed on the UEA campus and opened in 2015, the Enterprise Centre has a glulam structural frame with studs and joists sourced from local timber, cellulose fibre insulation made from recycled waste paper, sprayed recycled paper ceilings and cladding solutions including locally sourced thatch and straw. Straw is known for excellent thermal insulation properties [25] and bales possess a negative carbon effect with each kg of straw able to sequester 1.35 kg of CO_2 [26].

3. Results

Interviewee responses are arranged into the three core categories of finance, knowledge and policy.

3.1 Finance

An established barrier for bio-based construction is the initial higher cost; however, responses showed there are financial savings to be made over the course of the design life of a building due to lower operational running costs. Extending economic viability throughout the supply chain is also an important factor. Non-food crops for bio-based construction needs to be grown locally and be part of a coordinated program to boost regional economies, using local businesses, trades and crafts. Contractual and risk issues may result in circular or bio-based elements being value-engineered out of projects. A major economic issue for emerging bio-based materials and technologies is upscaling production and whether materials can be supplied in the quantities required for large-scale construction. An important step towards upscaling is gaining certification and accreditation, but there are potentially large costs involved. Data and certification resulting from research is important for the confidence of clients, contractors and insurers to work with bio-based materials. The construction industry can be described as conservative and risk-averse. Large, powerful companies working in conventional materials may be financially motivated to maintain the status quo.

> *There was considerable discussion around initial cost, and we estimated it was 20-25% more expensive than doing a conventional build. But it's a long term perspective; a typical warehouse of equivalent size would be running heating in winter and cooling in summer, but we have none of those expenses - we're saving six figures a year in energy costs. Construction companies at the time, and I suspect it's true today, will look to value-engineer environmental and sustainability aspects out of the project.* (Interviewee A)

> *In the civil service, we were looking at ways to make non-food crops profitable. An important point was that farmers and people in rural areas could make a profit. We are very good in the UK at doing research, but we need to jump from the research to making the product; scaling up is a big problem. You can't promote a product if there isn't enough of it to be sold. We wanted to build data on bio-based materials. People could not get insurance for their materials, that's why the government gave finance for testing. The construction industry is conservative; the plastics, concrete and steel industries all have big lobbying groups. Biobased industries do not; they are disparate and small. It is hard for new innovators to push through with new products, even though we've put lots of finance into the research.* (Interviewee B)

> *The process is driven by cost and not by environmental, aesthetic or human factors. The whole cost consultancy community is telling me we can't do timber-framed and modular pre-fabricated business unit designs on a comparable budget to concrete and steel. We need to get there on price, otherwise we're never going to prove this can be done commercially. We have issues around material supply chains in the UK; we buy globally from the open market based on price. We need to drive local economies, drive jobs in local businesses, use local suppliers wherever possible and address the carbon impact of the transportation of materials. We did encounter problems with contractors not having confidence in the materials, and the inevitable happens which is they try and cost risk into every aspect, which makes many sustainability outputs almost unachievable.* (Interviewee C)

> *A hempcrete building costs about 10% more to build than the cost of a normal museum storage building of that size. But costs were mostly in the design rather than the materials. The solution was considered to be more important; a slightly elevated cost was accepted. The hempcrete building costs two-thirds less to run than an equivalent, traditionally built store on-site.*
> (Interviewee D)

3.2 Knowledge

In addition to sustainability and environmental considerations, bio-based materials chosen for realised projects were there to perform a function; the regulation of the internal environment, reducing fluctuations in temperature and Relative Humidity (RH). Interviewees were happy with the performance of materials and from a building physics perspective, the bio-based materials can be judged to be a success. An opportunity for the uptake and promotion of bio-based materials is the concept of wellness and creation of a natural and appealing environment in which to work and live, resulting in low levels of turnover and staff absences, and high levels of health, well-being, morale and productivity. The bio-based projects also considered circular construction and engineered-in the capability to expand, modify or even relocate. There have been problems with Life Cycle Assessments (LCA) arising from where materials originate globally and the carbon involved in transportation. Case studies of bio-based material use and university research involvement are deemed to be effective methods of dissemination to construction industry professionals. Databases of information on bio-based materials have been established, but these need to be promoted, maintained and merged to form a central body of knowledge. The question of who should be knowledgeable; client or construction industry professionals, and thus influencing the bio-based circular agenda in design, is a subject of debate. The case studies have not led to an increase in industrial scale bio-based construction. Interviewees broadly agree that rather than progress being made, the industrial scale bio-based agenda in the UK has, if anything, slipped backwards over the course of the past five years. Challenges can be faced within client companies, with people promoting the use of bio-based materials potentially conflicting with reluctant colleagues who are perhaps lacking knowledge of the benefits of using bio-based materials or are primarily concerned with initial costs. It is clear that a bio-based project requires an advocate at a senior level within client organisations.

> *We have been successful in maintaining an ambient temperature optimal for our product of between 13°C – 16°C. The material is performing as we hoped it would perform. I think it was very beneficial that we were seen to be bringing sustainable values to life and the project gave members of staff a sense of pride. We made sufficient space at one end of the building to extend in the future with the same technologies; in essence, it's the first part of a modular building. We worked with the University of Bath on the properties of the hemp-lime blocks, glulam beams and*

sedum roof. The (bio-based) drive has to come from architects, structural engineers, the supply chain into companies - rather than from the companies. At the time, professionals were relishing the opportunity, because it was such a landmark project. Whether you would get the same response today, I don't know; a later sustainable university project had challenges we did not have. Every project needs a champion in the boardroom, who has credibility and can argue the long term case. Without someone who can paint the picture, finance directors won't do it. (Interviewee A)

Things such as growing crops locally, not using pesticides, knowing where the material comes from are all very important. When Brussels gave finance for biofuels, the unintended consequences were people buying biofuels from South America, and the cutting-down of forests. The circular economy has been hijacked by waste in some ways; it's easier, because you can say that you're using waste material from the food industry; but knowing where it's come from is much more important. Rather than keep setting up new bio-based data directories, we should put existing directories together and keeping directories current. (Interviewee B)

You're not just delivering energy and carbon savings, you're also creating a better workplace and people are more productive according to their wellness. We would monitor the carbon miles associated with materials that went into the building. We had been working with the UK Building Research Establishment (BRE) and felt there was a fairly good knowledge base, but there is still not enough case study material around. We need informed clients, and then that needs to run right through a project. I think the attitude at the time of the project was that this is the future. But at the moment, there's no impetus in this country, the sector is not moving as fast as it should be. The project hasn't triggered a flow of projects like it afterwards, which it should have done. The UK has a problem with technology translation; it does world class research, but then doesn't implement it. We are not as well connected into various movements in Europe as we were. You need to be an ambitious leader and never take 'no' for an answer. (Interviewee C)

Museums are interested in RH because that damages objects far more than temperatures. We attended a university lecture and heard about hempcrete; it seemed reasonable to have a very hygroscopic material as part of a low energy solution controlling RH. There was opposition; museums are very conservative. We must have been very persuasive! The hempcrete store is modular, so it could be disassembled; if we needed to move it out of the hangar to another, it would be feasible. Currently, we are in the process of building a massive store on site. We wanted to build it out of hempcrete, but couldn't find a contractor in the UK who would take it on. They're afraid of it, they don't know how it works, there isn't enough information and we just couldn't find anybody comfortable with doing a building of that size - so we've gone backwards in a way. (Interviewee D)

3.3 Policy

The construction industry, and innovative bio-based material use within it, has not necessarily been at the top of governmental agendas in looking at societal needs and the issues of energy and climate change.

Major topical issues of the day can form an obstacle or promote the restructuring of governmental policy - and client - priorities. Legislation at the national level to guide and direct change can be punitive; banning, taxing or penalising, or positive; incentives and subsidies. All interviewees were of the opinion that government legislation was needed to drive a bio-based, circular agenda in the construction industry. There are pros and cons attached to both approaches. Banning products has been effective at changing behaviour and practice in other industries. There may be a role for punitive, and educative, legislative measures in the construction industry. Positive legislation was broadly welcomed; however, there are risks associated with positive legislation. One opportunity for sustainably-sourced bio-based materials is the potential for building design to be sympathetic with the surrounding natural environment, especially in green-belt areas of natural beauty with strict planning restrictions.

> *We have had the aftershocks of the financial crisis of ten years ago, and we see another crisis now with Covid-19. Finance is tighter; are people prepared to invest in innovative technologies? I'm always in favour of positive legislation. Trying to level the playing field between bio-based materials and conventional materials would be the right route; rather than put industries out of business by pricing them out of the market, I think price-in the new technologies. Bio-materials also eased planning permission issues because it was something different, good and sustainable.* (Interviewee A)

> *There was a big push to go for industries like nuclear, solar and wind, which were worked on a lot, while bio-mass was demoted. Policies were tried that were green around the edges, with a lot done on renewable and clean energy. However, climate change was always the poor cousin of energy. With electricity, we were trying to encourage renewable energy, but a lot of finance was put on nuclear power. We are going to have to grow more crops in the UK to be bio-based because it doesn't make sense to bring it from somewhere else; the further away the biomass is, the more expensive. We need legislation; banning worked with pesticides, incinerators with noxious emissions and lead in petrol. People didn't want to change, so we had to ban. You have to be very careful about policy. Giving finance for a particular thing, all of a sudden there is a focus on that; everybody wants to do it and people with no skills jump on the bandwagon.* (Interviewee B)

> *You need institutions who are procuring projects, whether private or public sector, to understand the impact of using non bio-based materials and high carbon emission materials. I think we need quite strict legislation to drive this through the supply chain; otherwise, it won't happen.* (Interviewee C)

> *It has to be legislated; the only way we will stop driving petrol cars is if we're no longer allowed to. Big commercial builders are never going to move to bio-based materials until they are made to move.* (Interviewee D)

4. Discussion

It is clear from the interviews that emerging bio-based materials and circular construction face barriers to breaking through into mainstream construction practice; however, opportunities can be identified.

4.1 Finance

There are major issues within client organisations concerning the initial cost of materials and whether they would be available in the required quantity. A major consideration is whether client organisations are financially and structurally able to think long term with regards to recovering initial outlays by reducing energy costs and having high levels of staff attendance, retention and productivity. Measured financial incentives such as interest free loans at governmental level may be a route to enable client organisations to plan for projects over a much longer time-scale, allowing greater initial expenditure on emerging bio-based technologies and circular design, and subsequently long term energy and personnel-related savings facilitating repayment. Loans would also assist innovators and material developers to test, certify and market their product. There are clear long term financial benefits to circular construction, especially if adaptability and modification is considered in the design process to accommodate future company needs and expansion. However, these may not be enough to satisfy the balance sheets of client companies structurally having to think and work on shorter time frames.

4.2 Knowledge

Gathering data from experimentation carried out on newly developed materials, and knowledge of where the constituents within the material have globally originated will aid the growth of data and assist in achieving product accreditation. Dissemination of data and certifications to professionals will aid the promotion of the products' use and reassure clients of properties and performance. Even with incentives to plan long-term, client organisations still require leadership from senior personnel who are informed and enthused about using bio-based materials and designing innovative structures which are designed for adaptability and can be modified to reflect the future changing requirements of the business. More case studies are required to demonstrate the benefits and feasibility of bio-based construction and cases need to be accessible, not solely flagship and premium high-end projects. High levels of wellness among occupants, with high productivity, low turnover, low absenteeism and high-density use and occupation are measures of a successfully realised building compatible with circular construction principals. Personnel data from case studies should be gathered and assessed; if it is found that bio-based buildings are conducive to high levels of staff performance and productivity, this information requires dissemination along with the long term financial savings.

4.3 Policy

Policy can be identified as being key to upscaling bio-based construction. Conventional materials such as concrete and steel would realistically continue to be required to meet the construction needs of society. Therefore, punitive measures for an industry already in a difficult position as a result of years of austerity and the Covid-19 virus, would surely be inappropriate and would not gain wider support. This study submits that a long-term, measured program of positive legislation should promote bio-based circular construction. A clear way forward is to grow more non-food crops such as hemp within the country where a construction project is taking place. Subsidies to increase growth would be required to stimulate supply and create regeneration, boosting regional economies and local employment, businesses and supply chains. Countries must become more self-sufficient with growing crops for non-food purposes and landowners and farmers can be financially incentivised towards non-food crop growth. This should be accompanied by appropriate regulation and protection of virgin forest and areas of natural beauty. Local planning authorities should be encouraged to look favourably upon planning applications which are designed for adaptable, modular construction, future expansion and blend into the environment with the use of bio-based cladding and green roofs; this may be a solution for greenbelt development. If one punitive measure may be considered, it is that of placing conditions upon the granting of planning applications that a degree of circularity in design must be demonstrated.

5. Conclusions

The upscaling of circular bio-based construction with sustainably managed resources would impact significantly upon reducing the carbon footprint of the construction industry. Semi-structured interviews conducted with senior professionals with experience in bio-based construction identified barriers to upscaling in the form of initial costs, opposition to bio-based projects within client companies, absence of knowledge, limited case studies, absence of accreditation and material availability.

Policy both at national and regional levels can be viewed as crucial to drive the growth of bio-based circular construction. Though caution should be exercised, positive legislation can encourage bio-based material use. Potential solutions and recommended courses of action for policy-makers and circular construction practitioners can be found in promoting long-term economic cases to client organisations with low running costs, promoting the wellness agenda with high staff productivity, regenerating local economies with farms locally growing non-food crops, boosting local businesses, skills and labour with transforming crops into products and emphasising sustainability as a requirement in planning applications. Every successfully realised project would increase case studies and increased university research experimental data would facilitate accreditation and certification of emerging materials.

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