Technical Issues and Algae Building Technology

Journal:	*Building Research & Information*
Manuscript ID	Draft
Manuscript Type:	Research Paper
Keywords:	alternative technology, biomass, climate change, solar power
Other keywords:	

Abstract:

Mitigating the impact of the predicted three degree UN Panel on Climate Change increase in global temperature by 2100 is a significant challenge. The built envi-ronment contributing, circa 40% of all greenhouse gas emissions, has a significant role in delivering reductions. One option is to develop and adopt innovative tech-nologies, such as algae building technology (ABT), which uses façade panels to gen-erate solar thermal energy and produce biomass, which is converted to biofuel.

With innovation, there are new standards and guidelines to be developed for all stakeholders. There are technical issues to consider in design, construction and building operation and maintenance. The whole building lifecycle involves many practitioners from real estate developers, planners, architects, structural, civil, electrical and mechanical engineers, building surveyors, contractors, facility and property managers and Valuers.

This study adopted a semi structured interview methodology to ascertain opinions from 23 leading practitioners in Australia about technical issues related to the de-sign, construction, operation and maintenance of ABT buildings.

The findings show critical issues need to be addressed in respect of education and provision of guidelines in the design, regulation, construction and operational phases of the building lifecycle in order to secure the successful uptake of the technology.

Introduction

A major environmental impact of humans is the emission of greenhouse gases (GHG) which contribute to the greenhouse effect, whereby, global temperatures increase and the Earth warms (UN 2017). Buildings, and the energy used therein, contribute around 40% of total GHG emissions and it follows that reducing building-related GHG emissions could mitigate global warming significantly. One option is to increase energy efficiency while another alternative is to use renewable energy. Renewable energy and, bio-energy in particular offers great potential, and it is predicted to dominate energy production in the 21st century (Rosillo-Calle & Woods, 2012).

In 1839, Alexandre Becquerel discovered the photovoltaic (PV) effect however, it took another 102 years before Russell Ohl invented the solar cell in 1941, and energy generated by PV started to become more efficient and less prohibitively expensive. Further developments in battery storage, smart electricity grid management in the latter part of the 20th Century and early 21st Century greatly reduced costs, eventually transitioning PV to a viable replacement to fossil fuels ((Chen et al, 2011). Financially, in the late 1950s, PV cost over AS$2700 per watt in 2016 money, however over six decades of innovation solar energy costs dropped to AS$1.14 per watt by 2016 (Wilkinson et al, 2016). A pattern of largely unpredictable technology shifts can render previously non feasible technologies attractive (Davila et al, 2012) as shown with solar energy. It follows that such innovation and improvement could be delivered for other renewable energy technologies such as bio-energy.

By 2014 worldwide biomass energy production stood at 88 GW (Rosillo-Calle & Woods, 2012); and as such bio-energy is no longer a transition energy source. Algae is a source of bio-energy which can be used In buildings and in 2013 the engineering firm Arup designed a building adopting this technology in Hamburg, Germany (Arup 2013). The building envelope, or façade, is one of the most important external elements for building functionality, that helps to define the aesthetics of the building. The

PBRs form the façade which has a vital role regarding energy performance. The maximum growing temperature for the algae species used in Hamburg may limit panel use to cooler regions of Australia as air temperatures can exceed 40°C in much of the country. However it is possible to use other algae species, which can tolerate higher temperatures.

The majority of the existing built environment stock largely predates concerns about environmental impacts and climate change over the last 30 years (Kelly, 2009). It was estimated in 2009 (Kelly, 2009) that 87% of the buildings we will have by 2050 exist already and; therefore, the imperative for delivering sustainability resides in adaptation of existing stock. This is acknowledged and this study focussed on new building and retrofit issues.

This paper explains how Algae Building Technology (ABT) works and explores the technical issues of ABT in New South Wales (NSW) perceived by practitioners in design, regulation, engineering, construction, valuation, property management, planning, facility management and building operation. The aims of this paper are to:

a. identify built environment stakeholder perceptions of the technical issues associated with Algae Building Technology, and;
b. to evaluate the extent and importance of those issues with respect to buildings in Sydney, Australia.

Algae Building Technology explained

The BIQ building in Hamburg Germany, with a gross floor area of approximately 1600m², designed by Arup and constructed in 2013 adopts Algae Building Technology (ABT). Hamburg, Germany has a cool temperature climate. The BIQ has 15 apartments, with 50-120 metres squared space, on four floors (Buildup, 2015). Two forms of energy are produced for residents use. Algae is grown in triple glazed storey height façade panels called integrated photo-bioreactors (PBRs) totalling 200m², in 120 panels fixed on two façades (see Plate 1). The PBR façade panels can be moved horizontally across balconies to create a thermally controlled microclimate around the residential building, as well as reducing unwanted external sounds transmission and dynamic shading (Arup, 2013). The external walls of the BIQ are passive haus low energy design. Construction costs were approximately five million euros, which was higher than conventional apartment construction (Buildup, 2015).

Plate 1 BIQ Hamburg, Germany – about here

.

Biomass production

Microalgae absorb sunlight and the PBRs provide dynamic shading, with the amount of sunlight absorbed and shading, dependent on the algae density. With more sunlight, algae grow faster providing more shading for the building (Arup, 2013). The flat PBRs on the Hamburg building are highly efficient for algal growth; and designed to require minimal maintenance (Arup, 2013). The PBRs have four glass layers: a pair of double-glazing units creating a cavity, filled with argon gas to minimise heat loss.

The microalgae are cultivated in the PBRs. Sunlight and constant turbulence delivered by a mix of air and carbon dioxide (CO^2) to maintain appropriate pH levels, causes the microalgae to grow producing heat and a food source; phosphorous (Wilkinson et al, 2016). The biomass and heat generated are transported to an energy management centre where the biomass is harvested and heat is recovered by a heat exchanger.

The heat produced by solar thermal energy has 38% efficiency compared to 60-65% in a conventional solar thermal source. Further the biomass has 10% efficiency compared to 12-15% with conventional PV installation (Buildup, 2015) . Algae sequesters CO^2 and the 200m^2 PBR façade removes up to six tonnes annually by using flue gas delivered in the gas burner to produce biomass**.** The excess heat from the PBR façade panels pre-heats domestic hot water and warms interiors using radiators or hydronic heating. The heat production around 40ºC (150KWh/m^2/yr) is reintroduced to the system via a heat exchanger in the heating network or stored in below ground geothermal boreholes. The boreholes store heat from 16-35^{o}C depending on the season. When higher temperatures are needed for heating and/or hot water, a heat pump forces the water back into the system. A unit is operated to provide the CO^2 nutrient (flue gas) required by the microalgae in the bioreactor façade and, to cover the supply of hot water at 70ºC or heating in the energy network (Buildup, 2015) .

The biomass grown totals around 30KWh/m^2/yr., and is harvested every 3 – 4 weeks through an algae separator and collected (Buildup, 2015). Although it could be possible to convert biomass onsite, around 80% of the biomass harvested in Hamburg is converted into methane at an offsite outdoor biogas plant. It is then returned to the apartment building for electricity and heat generation (Buildup, 2015).

PBR water temperature is controlled by the speed of fluid flowing through the panels, i.e., lower flow rates give more time for sunlight to warm the water passing through. The amount of heat extracted via heat exchangers in the central plant affects the PBR water temperature. Maximum temperature within the PBRs is kept around 40^{o}C, because higher temperatures harm, or even kill, the microalgae. This relatively low maximum PBR temperature limits the practical use of the extracted heat to mainly a pre-heating function for other building systems. In a warmer climate such as Australia, this might vary.

Total energy system conversion efficiency is 27% relative to the full available solar radiation incident on an unobstructed building roof (Arup, 2013). When sited optimally to capture total available solar radiation, PV systems have an efficiency of 12-15% and solar thermal systems 60-65%. The BIQ total energy conversion of the algae system is lower than conventional solar hot water panels therefore. However the bio-responsive façade delivers energy directly to several building services systems, and delivers supplementary energy benefits such as shading during the summer and the biomass for conversion to biofuel. Therefore, on a total cost benefit analysis of tangible and intangible costs and benefits overall outcomes might be positive, however this is currently unknown.

Take up and acceptance of any new innovative technology such as ABT requires an understanding and view of the systems' benefits for owners, users, and built environment professionals such as planners, surveyors, project managers, contractors, quantity surveyors, certifiers property managers and facility managers (Arup, 2013). This paper identifies the views and perceptions of this influential stakeholder group. The drivers and barriers to ABT are summarised in table 1.

Drivers and barriers to ABT

The environmental drivers for ABT are; innovation, carbon abatement, bio building technology, greater rating in environmental tools such as BREEAM, Green Star or LEED. Whereas the environmental barrier is potential contamination (Subhadra, 2011). Adoption of ABT would lead to lower operational GHG emissions and; if adopted on a larger scale, there is potential to contribute to mitigation of the Urban Heat Island effect (Subhadra, 2011) and; for reduced loading on existing energy infrastructure. Another driver is the possibility to retail the biomass to pharmaceutical companies, where high value algae species are used, or for potential food production, with potential sales revenue offsetting energy costs. Another driver could be to gain innovation points in building-rating tool which can generate higher capital and rental values in some markets (AECOM, 2017).

With new technologies there is a risk that the innovation does not perform as predicted and this needs to be managed, as currently renewables such as solar, PV and wind produce more energy than algae (Wilkinson et al, 2016). However Australian algae production rates may be higher than Germany because there is more sunlight, over longer periods of time. The BIQ building which is shut down due to lack of winter sunlight (Wilkinson et al, 2016), would not be a problem in Australia, although overheating may be an issue.

New technologies compared to established technologies are expensive, because economies of scale are yet to be realised. There are fears about odours, contamination and leaks because some algae species contain hepatotoxins and neurotoxins, which are harmful to humans (Bell and Codd, 1994). Any damage or leakage in the panels or pipes could cause leakage and unpleasant odours.

Table 1 Drivers and Barriers to ABT – about here

Technical issues and Algae Building Technology

Technical issues are associated across the whole building lifecycle from design, regulation and compliance, construction, building operation and maintenance. For example, the structure of a building needs to be sufficiently strong to support the facade and transmit all dead and live loads safely (BCA, 2018). Whilst some issues relate to the building structure and fabric, others relate to the PBRs and associated building services. Often following occupation, alterations and adaptations are undertaken to buildings and the drivers for this can be technological or regulatory, as well as environmental (Wilkinson & Remoy, 2015. Wilkinson et al, 2016). At other times technical alterations can be unforeseen and a result of impact damage or malfunction (Chong and Low, 2006). General maintenance is required to ensure the façade and PBRs continue to function at optimum levels (Chanter & Swallow, 2008). Alterations to facades are less common due to excessive costs and tend to occur when existing facades are heavily worn or aesthetically outdated and unattractive (Wilkinson & Remoy, 2015). Good access to the façade and components is required for planned and unplanned maintenance (Chanter & Swallow, 2008).

Other technical issues are associated with the amount of algae biomass produced in the PBRs as the amount and intensity of sunlight is directly related to amounts of biomass produced and harvested (Chen et al, 2011). At times, of fluctuating temperature and light intensity, it may become necessary to shade or drain the PBRs to prevent algae dying in the panels. This requires a monitoring system is installed as part of the Building Management System (BMS) to ensure Facility Managers are alerted when conditions become untenable.

Another aspect to consider is that new technologies that are not yet proven, can be labelled 'green wash' and negative associations are created, this is due to risk aversion of the stakeholders (Bowen, 2014. Ottman, 2017). There is a danger that ABT because of its' novelty, because it is not proven in use with known lifecycles, is perceived as 'green wash' by industry (Lstiburek, 2008). Green wash is said to occur when environmental or green buildings do not perform as claimed. The plant room, where the biomass is harvested will require planned maintenance and calibration of the equipment. Maintenance issues, would be similar to other building services where water or liquid to transported in pipework (Allen and Iano, 2013).

Factors that need to be considered in PBR design include temperature, lighting, rates of dilution, water quality and pH level, CO_2 sequestration and removal of oxygen (Kunjapur and Eldridge, 2010). The effects of algae culture density and the geometry of the PBR panel on daylight penetration was examined by Decker et al (2016) who concluded remote control of the PBRs would reduce the chance of algae dying and PBR failure occurring. Another consideration is the interaction between the façade and the PBR, Pruvost et al (2014) concluded that optimum design enhances microalgae production rates, energy savings and thermal regulation of the building. The quality of the PBR glazing can affect production rates (Vasumathi et al, 2012). Where flat PBR panels are used across window or door openings on a façade, there is an issue of levels of daylight penetration and illuminance to be considered with some studies finding enhanced luminance (Kim, 2013) and other studies focused on tubular bioreactor design finding that daylight penetration is reduced (Elnokaly and Keeling, 2016). The design of the PBR panel affect production rates and the geometry will affect the existence of dead culture zones, where the algae dies off (Iqbal et al 1993). Iqbal et al (1993) concluded V shaped flat sided PBRs could produce high mixing rates and minimise dead zones. In summary, the micro-algae growth issues can be categorised as biological, chemical, physical, operational and health and safety.

Health and safety also relates to the design and construction of the façade and panel. Issues are the live and dead loadings; where live loads include wind and, in some regions, seismic activity or snow. The building will have to meet minimum requirements in respect of fire safety too. Dead loads are the weight of the panel and the method of fixing to the façade. For the PBR, design must ensure that leakage does not occur and the sealants do not react with the microalgae. The panel should accommodate any building settlement and movement without failure of the seals or connections to the façade (Kim, 2013). The materials used in construction should be sufficiently durable to have an expected lifecycle comparable to conventional façade designs. Finally the design should protect the

PBR from accidental, or impact, damage as leakage of the microalgae could be hazardous to human health and/or cause odours and contamination (Kim, 2013).

Research Design

This is qualitative research with the characteristics of an inductive, holistic and naturalistic approach advocated by Silverman (2010). The study sought to ascertain the views and opinions of the research population who were professional practitioners and stakeholders in the built environment (Robson & McGarten, 2016. Naoum, 2003: 38-43). The researchers wanted to gain an in-depth overview of the technical issues perceived by various built environment stakeholders with respect to algae building technology. Time, finance and physical distance allowed the use of data collection via semi-structured interviews. The research design comprised semi structured interviews with 23 key stakeholders in planning, design, construction, valuation and property and facility management (see table 2).

Table 2 – Stakeholder Professional Discipline – about here

The participants were highly experienced professionals who are highly qualified in respect of professional and vocational qualifications. The majority are members of professional bodies including; the Royal Institute of British Architects (RIBA), the Royal Institution of Chartered Surveyors (RICS), the Planning Institute of Australia (PIA), the Australian Institute of Property (API), the Chartered Institute of Building Services Engineers (CIBSE) and the Association of Project Management (APM). Participants professional practice experience ranged from 6 to 40 years, with the median term being 29 years. This experience was gained in Australia and internationally. Most participants had worked overseas, particularly in Asia, the Middle East and the UK. Significantly, most participants had senior management roles in their workplaces, as well as direct experience of dealing with complex projects and sustainability technologies. In summary, the participants had the requisite knowledge and skills and levels of experience to reflect on ABT and the technical issues associated with implementation of this technology in Sydney.

The semi-structured interview questions were designed using best practice methods (Moser and Kalton, 2002; Robson, 2002) and comprised seven sections and lasted approximately one hour. Questions were generated through a combination of information derived from the desk-top study, direct consultation with research panels and expert advice. Given the novel nature of the technology, an information sheet was sent to the interviewees to give them some understanding and background on which to base a reasonable interview.

The semi-structured interview allowed the researcher and interviewee to explore the issues particular to that professional area covered by the interviewee. For example, technical aspects featured more with the construction professionals, building surveyors and engineers. The semi-structured interview asked about participant's background and experience to gain an understanding of the participant's strengths and practical experience with sustainable technologies both in Australia and overseas.

Interviews were conducted in NSW and Victoria from January to April 2016. The data was analysed using a content analysis approach (Silverman, 2010) where similarities and differences between the various stakeholders were identified and grouped.

Key observations and discussion

This part of the paper describes the technical issues that arose during the semi structured interviews and is set out in four distinct sections; technical issues design, technical issues regulations, technical issues construction and technical issues operation.

Technical issues - design

The design of ABT solutions in public and residential buildings is subject to a variety of climatic, economic, infrastructural and efficiency related factors. The production of the biomass has a direct relationship with the climatic conditions within which the ABT system functions. Exposure to sunlight, as well as issues pertaining to overheating and the associated damage caused to the microalgae, are directly related with this factor. As there was only one full-scale built project in Hamburg, Germany as a demonstrator for this technology (which has a very different climatic condition compared to NSW), a major concern according to all the engineering interviewees, as well as the architect and building surveyor interviewees, was the lack of evidence to prove and validate the biomass production rates in NSW. Maintenance issues resulting from a higher biomass production due to heavy exposure to sunlight would necessitate investigations in new design systems which will enable easier cleaning and maintaining optimum temperature conditions, including investigating the impact of using glazing with a lower friction coefficient to reduce algae biofilm formation, use of robotic scrubbers and computer monitoring of the panels. These issues were brought to light particularly by the Window manufacturer, Bio- engineer and property manager interviewees.

Life span, durability and reliability was deemed a vital factor for the PBR system especially from the property and facility manager interviewees as well as the engineering panel interviewees. This is due to the sheer number of components which include the panels, piping, valves, flow of fluid and temperature maintenance (engineering interviewees). Each component has to work in unison in order to ensure optimum algae growth and bio-mass production rates (bio engineer interviewee). Issues surrounding adequate measures to ensure that no leaks happen in the system, as well as a general consensus that the life span of such panels should be between 20-25 years were agreed upon (all interviewees). Besides this, technical issues surrounding the need for re-calibration of controls during situations where weather conditions change unexpectedly were seen as issues which need to be solved at the building level (façade engineer and bio engineer interviewees). Development of automated control systems and AI based interventions can be seen as possible mitigation measures to such concerns (architect and engineering interviewees).

Comparisons pertaining to the performance and costs of existing renewable technologies vs ABT became a concern for all the participants. The fact that ABT is a new technology which has not been exposed to large scale uptake as yet, also results in its being perceived as expensive, compared to proven technologies such as solar panels (sustainability, property manager and valuer interviewees). A balance between cost and efficiency concerned all participants and particularly the quantity surveyor, property manager and engineering interviewees. Besides this, the fact that the uptake of the technology, real-world deployment and testing of the ABT system is very limited, results in a lack of Blueprint and design guidelines which can be followed during various stages of design development of a project (engineering and building surveyor interviewees). To bridge this gap, spreading awareness about the technology, educating professionals to design, build and manage ABT, as well as creating rigorous design guidelines needs to be become the norm (all interviewees).

Green Leases, as a collaborative goal-setting and upgrade of buildings in order to improve their performance was discussed as a potential boost for the uptake of ABT (property manager). Both building owners and tenants can benefit from controlling carbon emissions, water and energy consumption. However, weather related changes and thus the significant variability in the performance of the algae technologies was seen as a deterrent, if meeting performance standards was the objective of the Green Leases model (property manager interviewee).

Technical issues regulations

Various issues in regulating the use of ABT within Australia were raised. Power of vested interests, which concerns political interference in the approval of new innovative systems owing to political soft-handed approach towards the Australian coal and gas industry was one such issue which surfaced (Carbon Manager, Microalgae expert, Property Manager interviewees). Lobbying and large scale donations by the non-renewable energy sectors results in a lack of investment and support for renewable forms of energy production such as ABT and Solar (Carbon Manager, Microalgae expert interviewees). In addition, an expensive and time-consuming alternate solutions approach was seen as the only option for ABT to meet building compliance and certification (Building Surveyor, Sustainability Consultant, Sustainability Manager interviewees). The Alternate Solution approach entails the production of calculated and professionally reported proof of performance to be submitted by the designers to certifying authorities (Building Surveyor interviewee). In this context an opportunity for trying, testing and evaluating experimental ABT set-ups by owners/developers while they simultaneously disseminate the results to the broader community is seen as an alternative to laboratory based professional reporting approaches. Laboratory based models alone are unlikely to give all stakeholders the confidence needed to adopt the technology.

The possibility that the market could be incentivised to develop renewable on-site energy technology, including biomass, by making it a requirement of certain types of development surfaced via our professional interviews (Carbon Manager, Building Surveyor, Sustainability Consultant, Sustainability Manager interviewees). These could be in the form of necessitating the partial self-sufficiency of large residential developments on existing brownfield sites, which would otherwise use existing infrastructure. Regarding maintenance, commissioning, and operation, directives and guidelines in respect of Health and Safety would also be required to ensure the safety of building operators, occupants, and the public by (Carbon Manager, Building Surveyor, Sustainability Consultant, Sustainability Manager interviewees). It was also suggested there may be requirements for certification of installations from Health and Safety officers. Grassroot level promotion and education was seen as necessary to increase the acceptance of the technology (all interviewees). Deploying ABT on public buildings as a push provided by the Government, could help to change the perception of people towards such new technologies (Carbon Manager, Sustainability Consultant, Sustainability Manager interviewees).

Technical issues construction

The issue of feasibility of adaptation of buildings was brought up by all participants. The drivers of adaptation can be technological, economic, social, environmental, locational or regulatory (Wilkinson, 2014). Over time, building utility declines, often due the factors noted above, this is known as obsolescence, and the drivers can be unpredictable in many instances. This unpredictability, coupled with the fact that Façade alterations are less common owing to high costs, could result in very slow rates of deploying ABT (Façade engineer, Building Surveyor, Property Manager and Valuer interviewees). On the other hand, the possibility of working with components that are modular, easy to relocate and disassemble is seen as an interesting construction and design proposition (Façade engineer, Building Surveyor, Property Manager and Valuer interviewees).

The modular approach could result in active retrofitting scenarios, although this would need legal permissions, if the retrofit would lead to overhanging of the boundary line of the building, as well as consideration of the structural load carrying capacity of the building (Façade engineer, Building Surveyor and Property Manager interviewees). Retrofitted algae facades add dead loads to an existing structure and are also affected by live loads, such as wind. The facades would need to be tested for their dead and live load carrying capacity before engaging in any retrofit and, if needed, provide for additional structural capacity, which will result in increased costs (Façade engineer, Quantity Surveyor interviewees). Interviewees noted Australia has a lack of sufficiently educated professionals in the design, build and maintenance of algae buildings. This could mean that manufacturing of facade components may occur overseas and that lead-in times for construction projects can be impacted (Architect, Façade engineer, Quantity Surveyor interviewees). According to the Building Surveyor and Façade Engineer, the lack of knowledge is compounded by a lack of any blueprint or design guidelines for complex ABT systems, for it to perform efficiently without causing any health and safety hazards.

Technical issues operation

Participants highlighted a number of issues associated with the operational phase of the building lifecycle (Sustainability Consultant and Property Manager interviewee). Operational technical issues are associated with the amount of algae biomass produced in the PBRs and knowing the optimum amount and intensity of sunlight that is related to optimum biomass production. Furthermore, knowing when to harvest the biomass is an issue Facility Managers will need to learn about. Participants, especially those with building maintenance and engineering backgrounds were concerned about frequency and amount of cleaning of the PBR glazing panels would be required (Eco-concierge, Sustainability Consultant and Property Manager interviewees). They noted that the pipes with valves will require regular cleaning and periodic replacement (Eco-concierge, Engineers, Sustainability Consultant and Property Manager interviewees), however currently the frequency of cleaning or replacement is unknown (Wilkinson et al, 2016). Algae is known by industry specialists to adhere to surfaces and is colloquially known as 'slime' (Wilkinson et al, 2016) and therefore an effective cleaning program is imperative.

All participants stated that maintenance training and education of the tradespeople and professionals is needed. Maintenance may be onerous, and therefore more expensive than other technologies, and few have experience with such technology. A structural issue noted by some participants (Facade engineer and Building Surveying interviewees), is the weight of the algae façade requiring support for dead and live loads and whether more expensive structures would be required, thereby pushing buildings costs higher.

The issue of alterations and adaptation arose, with participants noting this can be unpredictable. They were unsure about the flexibility of the ABT system to accommodate alterations, as well as the potential cost implications (Wilkinson & Remoy, 2015). The absence of a 'blueprint' means algae panel information and design guidelines are needed for all stages of the development process (all interviewees).

A number of interviewees stated that there is a danger of algae buildings being perceived as 'green wash' (Carbon Manager, Sustainability Managers, Sustainability Consultant and Eco Concierge interviewees), and it would be essential not to make any unsubstantiated or misleading claims about the environmental benefits of the technology. There is a danger that algae technology, because of its' novelty, is perceived as 'green wash' by industry. Reliability of the installations was raised and algae technology would need to approach the reliability of static systems, performing consistently to succeed (Engineering and Property Manager interviewees). Almost all participants summed up the technological issues as 'complex'. This is because the technology is new and unknown; no one has direct experience of the technology on which to draw. Table 3 summarises the technical issues identified by the participants.

Table 3 Perceived Technical ABT Issues about here

The issues raised by the professional practitioners during the various stages of the building lifecycle (from Design to Operation) related to technical aspects are summarised in table 4 below. The professionals identifying the issues and the degree of importance perceived by the issue are also highlighted.

Table 4 about here

Table 4 highlights that there was considerable consistency amongst all participants where the need for education and the complexity of the ABT systems was concerned, as both ranked high in all four categories related to the building lifecycle. This is not surprising given the novel nature of this technology, and the fact that no building adopting this technology exists in the southern hemisphere, let alone Australia in order to confirm other convincing perspects of energy production, biomass yield and cost vs benefit analysis based researches (Slegers, P., Beveren, P., Wijffels, R., Straten, G, & Boxtel, A., 2013; Medipally, S. K., Yusoff, F. M., Banerjee, S. & Shariff, M. 2015; Borowitzka, M.A. & Moheimani, N.R.,2013). All participants were intrigued with the technology and how it might work in Australia. Naturally each professional initially, and primarily, considered how adoption of the technology would manifest itself in their respective fields of practice. As each professional has different roles at different stages of the building lifecycle this approach enabled the researchers to gain a deeper understanding of each stage, and the key technical aspects to focus on.

Conclusions

Fossil fuels provided energy for the industrial revolution to the end of the 20th century, with the role of greenhouse gas emissions and climate change impacts predicted, many predict that the 21st century has to be dominated by the renewables and biofuels (Borowitzka et al, 2013). Adoption of biofuel energy in the built environment is in its early stages, with only one building occupied in 2013; the BIQ building in Hamburg Germany. It is imperative that greater understanding of the potential of renewables as a building sited energy source for buildings is achieved. To date no such data exists and no study of the technical issues associated with ABT has been conducted. The aims of this paper were to:

a. identify built environment stakeholder perceptions of the technical issues associated with Algae Building Technology, and;

b. to evaluate the extent and importance of those issues with respect to buildings in Sydney Australia.

These aims have been fulfilled and a variety of professionally qualified and experienced key built environment stakeholder views in Australia about ABT are now known. All research has limitations, and this study is limited to the view of 23 experienced and qualified people, who have no direct experience of ABT but do have extensive experience of sustainability and innovation in the built environment, as well as design, construction, maintenance and building operation. It is their collective knowledge and experience that has enabled both research aims to be fulfilled, as far as possible at this point in time. It is knowledge that enables the first step in ABT in Australia to be taken.

Further, it was possible to analyse the extent and importance of the ten technical issues raised (see tables 3 and 4) in respect of Sydney buildings. Overall conclusions and recommendations from the research are reported. The participants feedback in relation to the factors surrounding technical issues in design, construction, regulation and operation showed clearly, the directions which need to be taken for the successful development and adoption of Algae Building Technologies in Australia. A clear need to invest into research and development, as well as testing and evaluation of efficient panels and photo bio-reactors which are suited for the Australian climate was identified. This is primarily due to the fact that various aspects ranging from maintenance, efficient cleaning, ease of deployment, weight of the panel, as well as costs of construction, are all directly linked with the design and engineering of the panel/PBR system. Apart from this physical development, the need to invest in efficient monitoring and decision making software for automating the processes of maintaining sunlight exposure and constant turbulence delivered by a mix of air and carbon dioxide to maintain appropriate pH levels. This, in combination with re-engineered panel systems can greatly enhance the perceived barriers for the uptake of ABT in Australia.

It was recognised also that solving design and engineering issues is not the only solution for ensuring a healthy uptake of ABT. Both social and legal acceptance needs to be built in; bottom-up and concurrently. This involves developing education programmes for both the general public, as well as, for people who would undertake design, installation, operation and maintenance of ABT. Such modes of imparting knowledge can be extremely helpful for demystifying concerns around the operation and benefits of ABT, while at the same time building the much needed technically sound community for maintaining and engineering future ABT installations.

It is essential that opportunities to experiment and test ABT within Australia are encouraged. This will allow for evidence based testing on the amount of algae production within different climatic conditions within Australia and will actively aid the piloting and testing of different algae species and panel typologies. Once tried, tested and evaluated, the creation of blueprints and design guidelines, specific to the climatic conditions within Australia, as well as appropriate ways to develop automation processes to cater to such climatic conditions can be developed successfully and circulated to all stakeholders. Overall, a clear set of drivers and technical challenges were extracted from the conducted interviews and workshops. Critical acknowledgement of these challenges and creatively finding design, construction, legal and social solutions to these issues will ensure that this innovative technology will be viable.

References

Allen, E. and Iano, J., 2013. *Fundamentals of building construction: materials and methods*. John Wiley & Sons.

Arup, 2013. World's first microalgae façade goes 'live' retrieved on 4 February 2016 from http://www.arup.com/News/2013_04_April/25_April_World_first_microalgae_facade_goes_live.aspx

Bell, S. G., and Codd, G. A., 1994. Cyanobacterial toxins and human health. Medicial Microbiology.

Borowitzka, M.A. & Moheimani, N.R.,2013, 'Algae for Biofuels and Energy', Springer, Australia, DOI: 10.1007/978-94-007-5479-9

Bowen, F., 2014. *After greenwashing: Symbolic corporate environmentalism and society*. Cambridge University Press.

Buildup, 2015. The BIQ House: first algae-powered building in the world. Retrieved on 21st September 2016 from;

http://www.buildup.eu/en/practices/cases/biq-house-first-algae-powered-building-world

Chanter, B. and Swallow, P., 2008. *Building maintenance management*. John Wiley & Sons.

Chen, C.Y., Yeh, K.L., Aisyah, R., Lee, D.J. and Chang, J.S., 2011. Cultivation, photobioreactor design and harvesting of microalgae for biodiesel production: a critical review. *Bioresource technology*, *102*(1), pp.71-81.

Chong, W.K. and Low, S.P., 2006. Latent building defects: causes and design strategies to prevent them. *Journal of Performance of Constructed Facilities*, *20*(3), pp.213-221.

Davila T, Epstein M, Shelton R. 2012. Making innovation work: How to manage it, measure it, and profit from it. FT press; 2012 Nov 9.

Decker, M., Hahn, G., & Harris, L.M. . 2016. Bio-enabled façade systems-managing complexity of life through emergent technologies. In: Proceedings of the 34the CAADe Conference on Complexity and Simplicity. Oulu, Finland: University of Oulu; 2016.

Elnokaly, A. & Keeling, I. An Empirical Study Investigating the Impact of Micro-algal Technologies and their Application within Intelligent Building Fabrics, in Social and Behavioral Sciences, Proceedings of the Urban Planning and Architecture Design for Sustainable Development conference. Lecce, Italy, 2016.

Iqbal, M., Grey, D., Sarkissian, F.S. & Fowler, M.W. 1993. A flat-sided photobioreactor for continuous culturing microalgae. Aquacult Eng. 12(1993)183–90. DOI: https://doi.org/10.1016/0144-8609(93)90010-9 .

Kim, K.H. 2013. *A feasibility study of an algae façade system. In: Proceedings of international conference on sustainable building Asia* (SB13). Seoul, South Korea; 8-10 July 2013.

Kunjapur, A.M. & Eldigre, R.B. 2010. Photobioreactor design for commercial biofuel production from microalgae, Ind. Eng. Chem. Res. 49(2010) 3516-3526. DOI: 10.1021/ie901459u

Lstiburek, J.W., 2008. Why green can be wash. *ASHRAE Journal*, *50*(11), pp.28-36.

Medipally, S. K., Yusoff, F. M., Banerjee, S. & Shariff, M. 2015, 'Microalgae as Sustainable Renewable Energy Feedstock for Biofuel Production', BioMed Research International, vol. 2015, pp. 1-13

Moser C. A., & Kalton G. 1971 (second edition) Survey Methods In Social Investigation.

Ottman, J., 2017. *The new rules of green marketing: Strategies, tools, and inspiration for sustainable branding*. Routledge.

Patton, M. Q., 2002. Qualitative research and evaluation methods 3 edition Sage. Thousand Oaks, CA. 2002.

Pruvost, J., Gouic, B.L., Legrand, J., 2014. *Symbiotic integration of photobioreactors. In: A Factory Building Façade for Mutual Benefit between Buildings and Microalgae Needs*, 21st International Congress of Chemical and Process Engineering CHISA 2014 Prague 17th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction PRES 2014, Praha, Czech Republik; DOI: 10.13140/2.1.2076.1920.

Robson C. & McCartan K. 2016. Real World Research. John Wiley & Sons.

Rosillo-Calle F, Woods J. The biomass assessment handbook. Earthscan; 2012.

Sarda, R.C., & Vicente, C.A. Case studies on the architectural integration of photobioreactors in building facades. in: F.P. Torgal, C. Buratti, S. Kalaiselvam, C.G. Granqvist, V. Ivanov (Eds.), Nano and biotech-based materials for energy building efficiency, Springer Inc., Switzerland, 2016, pp. 457–484.

Slegers, P., Beveren, P., Wijffels, R., Straten, G, & Boxtel, A., 2013,' Scenario analysis of large scale algae production in tubular photobioreactors', Applied Energy, vol. 105, pp. 395-406

Subhadra B. Algal biorefinery-based industry: an approach to **address** fuel and food insecurity for a carbon smart world. Journal of the Science of Food and Agriculture. 2011 Jan 15;91(1):2-13.

The Guardian Sustainable Business (2016) Solar Power What is holding back growth in clean energy? http://www.theguardian.com/sustainable-business/2016/jan/31/solar-power-what-is-holding-back-growth-clean- energy?CMP=new_1194&CMP 2 Feb 2016

UNEP F. Fiduciary responsibility: Legal and practical aspects of integrating environmental, social and governance issues into institutional investment. NEP FI: Geneva. 2009 Sep.

Vasumathi, K.K., Premalatha, M., & Subramanian, P. 2012. Parameters influencing the design of photobioreactor for the growth of microalgae. Renew. Sust. Energ. Rev. 16(2012) 5443-5450. DOI: https://doi.org/10.1016/j.rser.2012.06.013 .

Wilkinson SJ, Langston C. 2014 Sustainable building adaptation: innovations in decision-making. John Wiley & Sons; 2014 Jan 21.

Wilkinson, S., & Remoy, H. Sustainable Conversion Adaptation: An international comparison of best practices. RICS COBRA Conference UTS Sydney July 8-10 2015. ISBN 978-1-78321-071-8.

Wilkinson, S. J., Stoller, P., Ralph, P., & Hamdorf, B. (2016). The Feasibility of Algae Building Technology in Sydney. City of Sydney Environmental Performance Grant 2015. DOI: 10.13140/RG.2.1.4349.6560.

Yin, R. K., 2011. Applications Of Case Study Research. Sage.

Plate 1 BIQ Hamburg, Germany

(Source Colt International 2013).

Table 1 Drivers and Barriers to ABT

Drivers to ABT	**Barriers to ABT**
1. Innovation 2. Carbon abatement 3. Improved environmental performance 4. Lower GHG emissions 5. Lower running costs 6. Heat transfer and shading 7. Mitigation of Urban Heat Island 8. Reduces load on energy infrastructure in urban settlements 9. Retail opportunity of biomass 10. Higher capital and rental value	1. Risks of poor or non-performance 2. Other renewables produce more energy 3. Costs of new technology 4. Odours may occur if panels leak 5. Human health risks with some algae

(Source: Authors).

Table 2 – Stakeholder Professional Discipline

Professional discipline	Number interviewed
Architect (A)	1
Bio Engineer (Bio-E)	1
Building Services Engineer/professional body (BS Eng)	2
Building Surveyor (Building Control) (BS)	1
Carbon Manager (Carb M)	1
Electrical Engineer (E Eng)	1
Engineer (Eng)	2
Façade Engineer (F Eng)	1
Microalgae expert (M exp)	1
Planner (P)	1
Project Manager (Proj M)	1
Property Manager (Prop M)	1
Quantity Surveyor (QS)	1
Sustainability Manager (Sus M)	4
Sustainable Building System program manager (SBS prog M)	1
Valuer (V)	1
Window manufacturer (Window M)	2

(Source: Authors)

Table 3 Perceived Technical ABT Issues

1. Dealing with climate
2. Lifespan and durability
3. Maintenance
4. Competition with other renewables
5. Structural issues and façade design
6. Blueprints and guidelines needed
7. Performance clauses in Green Leases needed
8. Intentional and accidental damage
9. Education of stakeholders
10. Complexity of system

(Source: Authors).

Table 4: Professional and importance of technical issues identified

Issue	***Professional(s) identifying issue***	***Importance of issue (high/medium/low)***
Design related		
Competition with other renewables	A, Carb M, Bio-E, Sus M	High
Climate	All	High
Lifespan and durability	A, Prop M, Eng, BS Eng, F Eng, Window M	High
Blueprints and guidelines needed	A, P, Prop M, Proj Man, Window M	High
Performance Clauses In Green Leases needed	Prop M, Sus M, Carb M,	High/Medium
Education of stakeholders	All,	High
Complexity	All	High
Construction related		
Blueprints and guidelines needed	BS, Proj M, QS, BS Eng, F Eng, E Eng, Window M	High High
Education of stakeholders	All	High
Complexity	All	
Maintenance related		
Lifespan and durability	Bio E, BS Eng Prop M, V, Window M	High
Maintenance	Bio E, BS Eng, BS, Prop M, V, Window M, M exp	High
Blueprints and guidelines needed	All	High

Education of stakeholders	All	High
Complexity	All	High
Operation related		
Blueprints and guidelines needed	BS, Bio E, Prop M, M exp	High
Performance Clauses In Green Leases needed	BS, Prop M, BS Eng, F Eng, E Eng, Window M	Medium
Education of stakeholders	All	High
Complexity	All	High

(Source: Authors)