USE OF ADVANCED AND GREEN CONSTRUCTION MATERIALS BY SMALL AND MEDIUM-SIZED ENTERPRISES

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The use of advanced and green materials by the construction industry can significantly improve sustainability by reducing demand on scarce resources, reducing greenhouse gas emissions, improving safety, facilitating resilience of structures and encouraging the use of modern construction practices. Examples of such material include laminated veneer lumber, glulam, rammed earth, high strength concrete, lightweight concrete and adobe brick. To evaluate the use of such materials, an exploratory survey was conducted on-line in Australia and New Zealand into their use by small and medium enterprises (SMEs) that were undertaking either design or construction. The purpose of this survey was to better understand the use of such materials by the selected firms, understand why they were used or not used, and assess their likelihood of use in the future. Thirty firms responded to the survey. Each firm was asked to respond in detail to the use of five advanced and green materials, selected from a total number of sixteen. The extent to which these materials were used varied by individual firms and their role in the industry. It was found that there were seven leading issues (or factors) with respect to the use of such materials. The range of factors tended to depend on whether or not the firm had used the selected material. Experience appeared to be the leading issue restricting the uptake of individual materials. Other factors included cost of material and the availability of standards or codes of practice. While it is recognised that further work is required to validate the results of this research and extend it beyond Australia and New Zealand, this survey has given good insight into the use of these materials by SME firms in the construction industry.

Keywords: green buildings, material usage, small and medium enterprises, sustainability, technology transfer.

INTRODUCTION

Advanced and green materials in the construction industry can significantly improve sustainability by reducing demand on scarce resources, reducing greenhouse gas emissions, improving safety, facilitating sustainability and resilience of structures and encouraging the use of modern construction practices. While there have been a number of applications of these materials, their uptake at a more general level in civil engineering and building projects, and particular the small and medium enterprise (SME) building and construction sector, has not always been as rapid as it might be.

A number of such materials have considerable promise in terms of innovation in engineering design, construction and asset management. Polymer composites, for

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example, are used in a number of construction applications, such as non-critical structures. There are also a number of applications of other construction materials, such as advanced concrete products and timber based composite materials like glulam.

The SME construction sector can be quite innovative, such as with the adoption of proven products and improved processes (Thorpe *et al*. 2009). There are, however, factors that can impact on the adoption of new materials by firms in this sector, such as price, which is driven by the competitive tendering process, and was found to be the main factor in a study on the adoption of pozzolans as substitutes for cement in Wales (O'Farrell and Miller 2003).

To better understand the adoption process with respect to advanced and green materials, exploratory research was undertaken to evaluate issues for SMEs in the use of advanced and green engineering materials (AGEMs), which require considerable investment and resources in research, design and innovation to develop. SMEs play a large part in the construction market and therefore their adoption of new materials can be crucial to the success of advanced and green engineering material products.

The objectives of this research have been to:

- undertake a survey of SMEs to identify their perceived issues in the use of AGEMs
- evaluate the issues for SMEs in the use of AGEMs
- undertake exploratory research to support further studies into the issues with the use of AGEM for material manufacturers and the construction industry, and particularly its SME firms.

The main terms, and the issues (or factors) in the use of advanced and green materials in the construction industry, are discussed in more detail below.

ISSUES IN THE USE OF ADVANCED AND GREEN MATERIALS

Description of Advanced and Green Materials

Advanced materials are an improvement on conventional materials. They are developed to enhance strengths, or mitigate weaknesses of conventional materials. Polymer composites, advanced concrete products and glulam have previously been listed. Other examples of such materials include post-tensioned timber, which combines timber's flexibility, aesthetic and environmentally friendly properties, with the ductile properties of steel to improve the ductility and strength of timber (Symons 2014); and ductile self-compacting concrete (DSCC), which minimises the need for skilled labour as levelling and compaction occurs under self-weight (Nuruddin *et al*. 2014). A New Zealand company is manufacturing an advanced heavy timber material, cross-laminated timber (CLT), which has strong demand in Europe and elsewhere (Symons 2014).

The definition of green materials is contested and seldom completely understood, with greenwashing leading to reports that Americans believe only 12% of products that claim to be green actually are, through to consumers tending to rank equally environmentally friendly products differently due to the centrality of the green component (Gershoff and Frels 2015). This research used the definition that green (or sustainable) materials can provide a more energy efficient alternative to conventional materials. They may be classified into one or more of six categories such as green process, improved sustainability, recycled content, recyclability, low toxicity and biodegradability (RSMeans 2002: 232-234). The nature of green can be challenging for practitioners due to the wide variance of materials conforming in one form or another, to one or more categories, which adds an extra layer of complexity to the evaluation of alternatives.

Use of Advanced and Green Materials by SMEs

Small and medium-sized enterprises (SME), which are distinguished from larger firms by the number of staff employed and legal forms of business, comprise a significant number of the business enterprises in modern countries. In New Zealand, for example, SMEs firms have up to 49 employees, with firms of up to 19 employees accounting for 97% of enterprises (Ministry of Business, Innovation and Employment, 2014). SME firms in Australia may have up to 199 employees, and comprise over 99% of actively trading businesses (SME Association of Australia 2015). Their legal forms of business can include sole proprietorship, partnership, or corporation, each of which has a different structure, may be assessed for taxation differently, and may have different approaches to risk management.

While advanced and green materials are developed to extend the boundaries of conventional materials and help in the provision of an environment that can be enjoyed by future generations, the research, design and innovation involved in developing them can take sizable resources and investment, and therefore they can be relatively costly compared with traditional materials. Their perception can also impact adoption, particularly by the SME sector, which because of the smaller size of firms, has less capacity to take risks than better financed larger firms.

Factors related to materials include material properties, and the perception, environmental impact and selection of materials available. In addition, the use of the term *"green"* may lead to perceptions of something that is low-technology, uncontrolled and unprofitable to SMEs. Some manufacturers may be reluctant to advertise the use of green processes for fear of prejudice (Spiegel and Meadows 1999).

There may also be relatively few standards and guidelines for advanced and green materials, with those that are available being performance rather than prescriptive (Spiegel and Meadows 1999). The lack of standards has been highlighted more recently by the Queensland Department of Transport and Main Roads in the case of engineered fibre composites, in which it was observed that there was a lack of an Australian standard for that product. Fragmentation and the use of Intellectual Property as a tool to closely guard information, but also limit transparency surrounding manufacturing, can limit the openness of information published in papers. Ultimately, such a lack of standards poses a professional indemnity risk for designers (Pritchard 2014).

Green materials may also suffer from requirements to both use the standards of the conventional materials they are replacing and meet the requirements of sustainable design standards such as BREEAM (BRE Global Limited 2014) to demonstrate the sustainability aspects of a material. Thus while construction using green materials is required to be built and managed to a budget and provide economic benefit, it should also implement sustainable development requirements (Brundtland 1987) by maintaining the balance between the economic, social and environmental aspects of sustainability.

Overall, while there are likely to be a number of positive features for the use by the SME construction sector of advanced and green materials, there are also a number of barriers to their adoption by this sector, including perception of the materials and their use, and both design and construction risks associated with the requirement for more standards. The next section discusses additional factors that may impact on the use of such materials by the SME construction sector.

INVESTIGATION OF THE MATERIAL USAGE DECISION

Factors affecting the decision by SMEs to adopt advanced and green materials

The adoption by an organisation of an advanced or green material is an innovative step. An innovation may be defined as an idea, practice, or object that is perceived as new (Rogers 2003: 12). In the decision to adopt an innovation, the potential user of the innovation gains knowledge of the innovation, forms an attitude about it, makes a decision whether to accept or reject it, implements the new idea, and confirms the decision (Rogers, 2003: 168-170). There are rewards for early adopters of an innovation, and also negative risks, such as potential financial loss. This situation is particularly relevant for SMEs, which tend to be more exposed to such risks as they are generally younger (Abdullah and Manan 2011) than larger mature firms and are likely to be experiencing higher growth than them, particularly in an active industry like construction, in which there tends to be a strong demand for materials. Such materials are required to be profitable to the firm, in order that the firm can pay interest on funds borrowed or pay dividends to equity investors, and thus grow.

In addition to perception, the limited availability of standards and the matters associated with growth, a number of other factors (or issues) have been identified, through literature or hypothesized by the authors, which have the potential to impact on the use of advanced and green materials by the SME sector. A discussion of these additional factors is below.

Experience

The construction industry tends to rely on previous experiences to guide future decisions. As SMEs have less access to expert opinion than larger organisations, advanced and green materials carry more risk to SMEs with less experience. This risk increases the risk premium used in their evaluation (Brooks 2010).

Identification and Evaluation of Materials

The identification of the most suitable materials for a particular application may be quite complex and costly as a result of the number of alternatives available. Evaluation methods will include financial assessment and may also include other considerations such as ease of use of the material, its acceptance by clients, its availability and ethical considerations, including the evaluation of externalities, which refer to situations when the effect of production or consumption of goods and services imposes costs or benefits on others which are not reflected in the prices charged for the goods and services being provided (OECD 2003). They include positive externalities, such as improved air quality from using green material; and negative externalities, such as greenhouse gases created in the production of Portland cement. Externalities can be difficult to evaluate and quantify.

Material Cost

SMEs are likely to have less access to capital than larger organisations, thus making them quite sensitive to material cost. Advanced and green materials tend to be more expensive by face value. For example, conventional 30 MPa concrete tends to cost less than 30 MPa lightweight concrete (Simons 2012). This premium in the cost of such materials covers externalities, or compensates for research and development or specialist knowledge and labour required. Externalities can include improved future sustainability. For example, in timber products, there may be a premium paid for maintaining forests through planting and other resource management (Mankiw 2009). Other sources of cost include investigation and evaluation of new materials; and the difficulty of evaluating future benefits of new materials, which can make it challenging to justify their use given their increased cost.

Inventory management

Inventory management is closely linked with working capital and the management of current assets. Firms require working capital, which is the net of current assets and liabilities, to operate. A lack of working capital will lead to insolvency. Thus maintaining positive working capital is an issue to firms of any size (Brooks 2010).

Availability and properties of materials

Availability of materials is also a likely factor in the decision to adopt advanced and green materials. It varies with the material. For example, concrete is very widely used, and timber and wood are renewable resources when managed sustainably. The availability of earthen materials, for example, would be expected to be locality dependent. The properties of materials, and knowledge of these properties, can also impact on the material usage decision. For example, research on earthen materials tends to lack depth and consistency compared with research of other engineering and construction materials.

Materials investigated for this research

While there is a large selection of advanced and green materials available, it was decided to limit those used for this research to a representative group of such materials primarily used in the building structure. The materials used for this research were:

- Advanced concrete materials - ductile self-compacting concrete (Naik *et al*. 2008); high strength concrete; lightweight concrete; fibre reinforced concrete (Sivakumar and Santhanam 2007); cement replacement materials, such as pozzolans and geopolymer cement.
- Earthen Materials (Miccoli, Muller, and Fontana 2014) - adobe brick, rammed earth; cob (a mixture of earth, water and plant materials).
- Timber - glued-laminated lumber (Glulam); laminated timber lumber (LVL); cross-laminated timber (CLT); hybrid timber with post-tensioning reinforcing (Symons 2014); glued-laminated bamboo (Glubam) (Xiao *et al*. 2014); hybrid timber with fibre reinforced polymers.
- Other - green roof and pervious concrete.

Each of these materials has quite different properties and uses.

RESEARCH DESIGN AND IMPLEMENTATION

In order to further investigate the use of advanced and green materials in SME firms in the construction industry in Australia and New Zealand, a survey was conducted in mid-2014. This survey was approved by the Human Research Ethics Committee of the University, and is discussed in further detail below.

Survey questions

The survey questions were formulated to: collect generic firm details; evaluate issues that the firm had with advanced and green materials; identify such materials previously used and unused by the firms; and assess whether their use would continue (for used advanced and green materials, or commence (for unused materials), with or without perceived issues being addressed. Participants were asked to select materials from the list of 16 materials listed above, or could nominate other materials.

The questions were split into four sections, as follows:

12. Business profile - type of firm, staff numbers, areas of the construction industry and regions in which the firm operates, use of AGEMs.
13. The three most common AGEMs used by the firm, including use of the material, main issues in its use, whether firm will continue using it.
14. Two AGEMS not used by the firm (selected by the firm) - issues preventing use (selected from a list), questions about material and possible future use.
15. General issues with AGEMs - issues (selected from a list) ranked on a five point Likert (strongly disagree to strongly agree) scale, how firms identifies potential materials for use, how firms evaluates alternate materials.

The issues (or factors) to which responses were requested at a general level were standards or codes, experience, identification of alternative materials, evaluation methods, inventory management, cost of material, material properties, perception and growth of business. For individual materials not used by the firm, the factors were standards or codes, experience, evaluation methods, inventory management, availability, cost of material, material properties and perception. Respondents could add additional materials and issues to those asked. While responses to most questions were specific, open questions of how the firm identified potential materials for use and evaluated alternate materials sought more detailed answers.

Selection of firms

A number of SME firms in the construction industry in the three disciplines of architecture, engineering and construction in Australia and New Zealand were invited to participate in the survey. The list of participants invited was collected from the 16 regions (up to 10 firms from each region per discipline) of New Zealand, and 6 states (up to 20 firms from each state per discipline) of Australia. The firms invited to participate were identified from the Yellow Pages telephone business directories of New Zealand and Australia. This process resulted in an email list of 749 firms.

Administration of the survey

The survey was administered using an online data collection tool, using email, Facebook posts and a web link. An initial email containing the survey was followed up, if there was no response initially, with a second email showing the link to the Facebook page. In the third week of the survey, a further email was sent to firms yet to respond with a web link.

There were 30 firms that responded to the survey. While this number was not high, it did permit analysis of the sample of firms that responded to the survey, but was less satisfactory for analysis of results by discipline or country (19 responses were received from New Zealand and 11 responses from Australia), or for detailed trends to be examined for each material. The relatively high proportion of responses from architects (50 per cent of responses, compared with 20 per cent of engineers and 30 per cent of contractors) could potentially introduce bias into the sample. The breakdown of responses by discipline and country is shown in Table 1.

Table 1: Breakdown of number of firms responding by discipline and country

Country	Architect	Engineer	Contractor	Total
New Zealand	11	2	6	19
Australia	4	4	3	11
TOTAL	15	6	9	30

While 30 responses is not ideal and cannot be claimed to represent an industry of many thousands of firms, it is contended that it can provide some indication of how results of the survey can be perceived by industry. The basis for this statement is that according to Hamburg (1970), the sample size n for a given estimation of the mean is given by the formula (z^2*variance/e^2), where *"z"* is the number of standard deviations from the mean for a desired confidence level and e is the magnitude of the error. Transforming this formula to calculate *"e"* given *"n"* shows that a sample size of 30 would, for a variance of 1.0 (considered on the high side for most 1 to 5 Likert Scale results) and a z value of 2.0 (about 95 per cent of a normal distribution), result in an error in the mean of +/- 0.365 from the point of view of the overall population, which is well within the limits of one gradation in a five point Likert Scale. The use of a more qualitative interpretation of most responses to the survey is also considered to aid its wider applicability.

MAIN FINDINGS

Issues in the use of advanced and green materials

The majority of firms approached in this exploratory review (90 per cent) indicated that they used advanced or green materials. Their main use was occasionally (50 per cent of firms). The inclusion of focus groups and in-depth interviews in further research will help to determine whether a bias towards firms that have previously used advanced and green construction materials responded to the survey was present.

With respect to issues (or factors) in the use of these materials at a general level, seven factors out of the nine to which responses were requested were considered significant. They received a mean ranking from the survey of more than three (3) on a 1 to 5 Likert scale, and were experience, perception, cost of material, standards or codes, evaluation methods, identification of alternatives and material properties. Growth of business and inventory management were considerably less significant in the decision by firms to use these materials.

The main ways in which firms identified potential materials for use were research, reading (for example, trade literature), client and peer discussions, and investigation of design and performance of the material. In evaluating alternative materials, there was a stronger focus on in-depth research, assessing technical specifications and testing.

Materials commonly adopted by SMEs

There were six advanced and green materials commonly adopted by at least 10 per cent of the SME respondents. They were:

- Laminated veneer lumber (LVL), used in roofs, floors, walls and inbuilt furniture. The main factors in use were cost of material, material properties and availability.
- Glulam, used in roof, floors and walls. The main factors in its use were cost of material, availability and evaluation methods.
- Rammed earth, used in walls and retaining walls. The main factors in its use were cost of material, experience, perception and material properties.
- High strength concrete, used in floors, road pavement and foundations. The factors in its use were cost of material and experience.
- Lightweight concrete, used in walls and floors. The factors in its use were cost of material, experience, availability and material properties and availability.
- Adobe brick, used in walls. The main factors in its use were material properties, experience and evaluation methods.

Overall, the main factors in the use of these materials were cost of material, material properties, experience and availability. Evaluation methods and standards and codes were also listed as factors by respondents. With the exceptions of high strength concrete and adobe brick (both of which are expected to continue to be used by the majority of respondents), all materials are expected to be used in the future.

Materials not commonly adopted by SMEs

Six advanced and green materials were commonly not adopted by SMEs. They were:

- Post-tensioned timber
- Cement replacement materials
- Cob
- Cross laminated timber (CLT)
- Ductile self-compacting concrete (DSCC)
- Rammed earth.

The main issues in the non-use of these materials were experience, standards or codes, availability, evaluation methods and cost of material. High strength concrete was likely to be used in the future by all respondents if the issues were addressed. There was doubt about the future use of cob, ductile self-compacting concrete and rammed earth.

DISCUSSION AND CONCLUSION

Of the 30 firms responding to the survey, 90 per cent had used advanced or green materials. There were seven main factors, which are a combination of organisational factors and factors specific to each material that affected the decision whether to use these materials.

It was found that the main four factors relating to AGEMs commonly used by the SMEs in the sample of 30 were cost of materials, material properties, availability and experience. For AGEMs not commonly adopted by SMEs, the main factors were experience, standards or codes, availability, evaluation methods and cost of material.

Experience and cost of materials were common to all three sets of factors, and can therefore be considered significant in any decision with respect to the firms in the decision whether to use a particular advanced or green material. Material properties were significant at the general level and for materials commonly adopted by SMEs Standards and codes were significant at both the general level and for AGEMs not previously adopted by SMEs. It is therefore considered that properties of materials, and the availability of standards and codes, both of which may be considered related to the material, are important considerations in the new material selection process.

It follows that the primary factors in any decision by the SMEs surveyed to use an advanced or green material were experience and matters related to the material itself. These findings tend to be supported by the innovation decision process discussed by Rogers (2003) and other literature. For example, the study by Thorpe *et al.* (2009) into innovation in small residential builders found that most innovations tended to be those developed or researched by the firms themselves. As discussed previously, Pritchard (2014) noted that a lack of standards and other factors related to materials and the construction industry impeded the use of advanced materials like fibre composites in the road industry, and also imposed a risk on their use in design.

Of the materials that the respondents were asked to consider, the most commonly used materials laminated veneer lumber, glulam, lightweight and high strength concrete, rammed earth and adobe brick. These materials had different applications in the construction industry. Only post-tensioned timber, cement replacement materials, cob, ductile self-compacting concrete, and timber with fibre reinforced polymer were not used. Most of these materials would be used if current issues were addressed. Therefore, there was reasonable usage among the respondents of these materials. The range of factors in their evaluation by the firms depended on whether the material had been used before, with tangible factors (such as cost of material) predominating over intangible factors (such as experience) for materials that been used by firms. Intangible factors tended to be dominant for materials that had not been used by them. Price was an issue noted in the study by the previously cited study O'Farrell and Miller (2003) into the use of pozzolans in Wales.

The main materials used tended to be fairly well-known to the industry. This consideration, along with the strong focus on experience and factors related to particular materials, may reflect the lower risk taking approach of SME firms compared with larger and better resourced firms, which would result in their being later adopters of product innovations. This caution is underscored by the verbal responses to the identification and evaluation of potential new materials, which indicated a cautious approach to their use. One possible option with respect to encouraging more use of such materials by SME firms could be improving their awareness and understanding of them through dissemination (for example, through industry organisations and education).

Because of the small sample size of respondents to this research, its results can be viewed as indicative only of the use of advanced and green materials in SME firms in the construction industry. A logical extension to this research is to validate it, possibly through using one or more focus groups, a Delphi survey, in-depth interviews, or similar approaches. Doing so would present the research questions to a different group, and may also overcome bias towards architectural firms in the sample. It could also address another potential source of bias in the survey, which is that firms with little or no previous use in these materials may choose to ignore the survey. Other improvements to future research might include the addition of other materials, such as advanced plastics and metals, in-depth elicitation of reasons by firms for using selected materials, and extension of this research beyond Australia and New Zealand.

Overall, this research has shown that, within the group of firms undertaking this survey in the SME construction sector in Australia and New Zealand, there is good use of particular advanced and green building materials, but less use of others. As AGEMs have the potential to contribute substantially to sustainable construction practices, it is desirable that their use be encouraged. Steps to improve their use that have been provisionally identified in this research include the development of detailed standards and codes, an improved pricing structure, and developing knowledge and use of them though knowledge dissemination and the provision of opportunities for firms to gain experience with them.

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