The Value of Structural Engineering to Sustainable Construction

Final Report

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The Institution of Structural Engineers

The Value of Structural Engineering to Sustainable Construction

Final Report

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Contents

Tables

Figures

1 Overview

The Institution of Structural Engineers (referred to hence as 'the Institution') commissioned a research project examining three aspects of green building rating schemes and their relation to structure:

- how structural impacts are addressed
- how structural engineers can contribute to assessments through sustainable construction and
- whether the correct incentives are provided to make building structure more sustainable.

This report summarises the research and the findings from this project.

1.1 The project method

The project has been structured around the green building rating schemes, as defined in 1.2.2.

Initially desk-based research was carried out to quantitatively investigate:

- What the ratings schemes measured in terms of structure (section 2)
- How structural engineers can contribute to the sustainability of buildings as a member of a multidisciplinary team (section 2.1)
- How often the scores related to structure were achieved in practice (section 4)
- How much of the environmental impact of a building was attributable to structure (section 5)

From the research carried out it was found that the rating schemes are not adequately addressing the sustainability impacts of a building's structure. Possible explanations were that there was not enough emphasis on the structure in the schemes or because design teams were choosing to target credits in other areas.

To investigate this further it was decided to focus on the effectiveness of the rating schemes and the credits within them. A framework for effectiveness was defined (section1.2.1) and then the rating schemes (section 3) and the individual credits (section 6) were assessed against this framework.

To support this investigation anecdotal evidence on the schemes and the credits was obtained through a survey and further literature review.

The format of the survey was a series of questions, with pre-defined answers to select from, along with frequent opportunities to expand on the topics through open questions and additional comments boxes. This approach allowed a rich data set of both quantifiable and qualitative results to be captured. The survey had a small and targeted circulation, aimed at groups who had an active interest and expertise in the topic area. The international survey gained input from 95 people who were either structural engineers with an interest in sustainability, or sustainability specialists. The respondents came from a variety of regions.

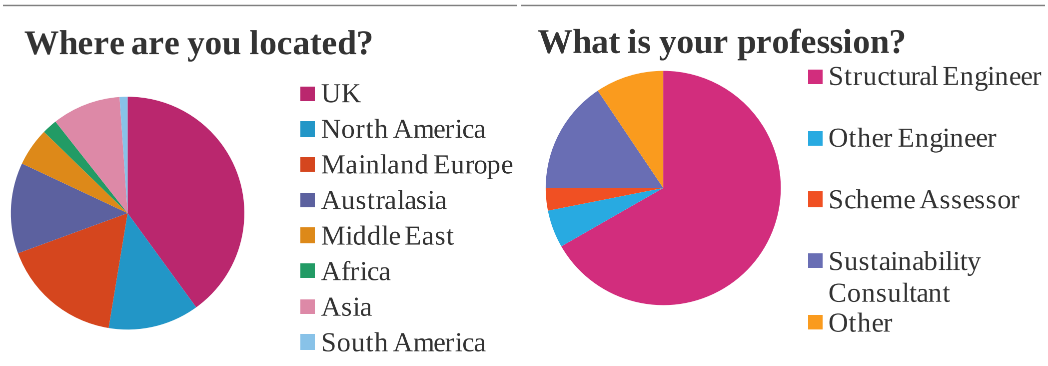

Figure 1: Demographics of survey respondents

Interestingly, even when there was a local building rating scheme available, respondents from around the world commonly chose to provide opinions about LEED and BREEAM. This means that the demographic spread fits the target audience well and that a focus on LEED and BREEAM will be of value to practitioners in many locations.

Finally, based on the detailed review of both the rating schemes and the credits, the attributes of an effective scheme with respect to structure (called aspirational scheme in this report) were identified (section 15).

1.2 Project Scope

The Institution selected the following structural materials for study: steel, concrete, timber, masonry and structural glass. The project scope was to consider 3-5 storey commercial developments on green and brown-field sites. This scope was chosen in order to restrict the breadth of research to align with a six month research and reporting programme. In addition the following areas of scope were defined.

1.2.1 Measuring Value

Value of Green Building Rating Schemes to Clients

Green building rating schemes (referred to as ‘rating schemes’ throughout the report) measure ‘sustainability’ through a broad range of prescribed indicators (called ‘credits’) for a building, e.g. energy efficiency, water use, accessibility, and assign an certification level accordingly. The schemes assess data provided by the project team.

The base assumption of the project is that the rating schemes are of value to clients either because they are a mandatory requirement for developments or because they are voluntary schemes for which there is a significant participation. The ways in which rating schemes may provide value to clients include[1]:

- enabling additional **income** to be realised either through increased rent or property value[2];
- achieving corporate social responsibility (CSR) or other ‘sustainability’ **targets and enhanced reputation;**
- helping to secure **planning permission**;
- providing a **measure** of the sustainability compared to other buildings.

The project considers whether the rating schemes are effective in evaluating the work of structural engineers to increase the sustainability of buildings. This is important because the rating schemes provide a path by which the design team can offer value to clients. The value/effectiveness of the rating schemes themselves is part of the base assumption and beyond the scope of the research. Through concentrating on rating schemes the project's purpose is to enable engineers to increase the sustainability of the built environment.

Value of Green Building Rating Schemes to Structural Engineers

To understand if green building rating schemes are effective in this regard the following aspects were considered with respect to building structure. An effective scheme would:

- Provide incentives for sustainable **actions;**
- Provide a comparable **measure** of the sustainability of buildings;
- Provide a **framework** to define sustainable design practices for professionals;
- Work as a **practical tool** which can be deployed cost-effectively during the procurement of buildings.

1.2.2 The Green Building Rating Schemes

BREEAM[3] and LEED[4] were the main schemes identified for study by the Institution. These were reviewed with reference to a range of other rating schemes likely to influence the work of the Institution's global membership of practising structural engineers . Of the many schemes that could have been considered, a small number were identified in the course of the research in order to cover a broad range of regional contexts and possible approaches to the subject. These were: Green Star (Australia[5] and South Africa[6]), DGNB[7] (Germany); China Evaluation Standard for Green Building[8]; '3 Star', HK BEAM[9] (Hong Kong); Estidama Pearls Building Rating System[10] (PBRS) (Abu Dhabi); Green Mark[11] (Singapore). The studied schemes are shown in Table 1 with the topics covered under each.

Table 1: Topics covered by rating schemes

LEED	BREEAM	Green Star	DGNB
Materials & Resources	Materials	Materials	Ecological Quality
Energy & Atmosphere	Energy	Energy	Sociocultural & functional
Water Efficiency	Water	Water	Technical Quality
Sustainable Sites	Land Use & Ecology	Land Use & Ecology	Process Quality
Indoor Environmental Quality	Health & Wellbeing	Indoor Environment Quality	Economic Quality
Innovation In Design	Waste	Management	Site Quality
Regional Priority	Management	Transport	
	Transport	Emissions	
	Pollution		
China '3 Star'	**HK BEAM**	**Estidama PBRS**	**Green Mark**
Material Saving & Resource Utilization	Materials Aspects	Stewarding Materials	Building Efficiency
Energy Saving & Energy Utilization	Energy Use	Resourceful Energy	Water Efficiency
Water Saving & Water Resource Utilization	Water Use	Precious Water	Environmental Protection
Land Saving & Outdoor Environment	Site Aspects	Natural Systems	Indoor Environmental Quality
Indoor Environment Quality	Indoor Environmental Quality	Livable Buildings	Other Green Features
Operating Management	Innovations and Performance Enhancements	Innovating Practice	
		Integrated Development Process	

Each of these rating schemes takes a different approach to the structure of the building, varying from assessing life-cycle impacts (e.g. DGNB) to specifying actions or material specifications (e.g. Green Star, Green Mark, 3 Star), or a combination of both methods (e.g. BREEAM, LEED).

A number of the schemes were revised during the course of the research and some of the scheme credits presented in this report may not be up to date. They nevertheless served the purpose of providing evidence from experience which the newer credits would not have achieved. The evidence is used to develop the attributes of an aspirational scheme. Where an existing scheme demonstrates these attributes it is to be welcomed.

1.3 Terminology

Within this report the following terms have been adopted:

Green building rating scheme Or Rating scheme	Generic term for BREEAM, LEED, Green Star (Australia and South Africa), DGNB (Germany), China Evaluation Standard for Green Building, '3 Star', HKBEAM (Hong Kong), Estidama Pearls Building Rating Scheme (PBRS Abu Dhabi), Green Mark (Singapore)
Topic	A subject such as re-use of building structure, or local/regional sourcing which may be covered in a number of schemes
Credit	A particular requirement in a scheme which earns scores in the green building rating system
Study Credit	Credits selected for consideration in this project, related to the design and specification of the building structure.
Embodied carbon dioxide	The sum of the CO_2e attributed to a product system or process within a defined life cycle period.
Operational carbon dioxide emissions	The CO_2e released in making the energy to run a building's services.
Climate change	Due to the Green House Effect, average temperatures are rising worldwide, known as 'global warming'. Scientific consensus is that this is causing 'climate change' – permanently shifting weather patterns with likelihood of more extreme events such as storms, heat waves and hurricanes. Most debate stems from whether global warming is due to human activities or natural variation, although most of the scientific community suggest the former, and recommend CO_2 emissions be reduced to avert the worst consequences of climate change.
CO_2	Carbon dioxide is the main pollutant released from the combustion of hydrocarbon fuels, and the most important of the gases that cause the sun's rays to be absorbed by the atmosphere – known as the 'Green House Effect'.
CO_2e	Other gases also cause climate change impacts, but to a greater or lesser extent per unit mass. CO_2-equivalent accounts for these differences and combines all gases released to give a single number for ease of comparison. Unless otherwise stated, CO_2 values quoted in this report are CO_2e.

2 How do the rating schemes measure sustainability of structure?

Each rating scheme studied had different credits, different weightings and different requirements to gain certification. It was agreed that the project should look in detail at credits related to the design and specification of the building structure. The ‘study credits’ identified for detailed consideration are summarised in Figure 2, which shows they cover a broad scope of topics.

BREEAM		LEED		PBRS		HK BEAM	
Mat 1	*Materials Specification (Major Building Elements)*	MR 1.1	*Building Reuse - Maintain Existing Walls, Floors and Roof*	SM-1	*Non-Polluting Materials*	MA 1	*Building Reuse*
Mat 3	*Re-use of Building Façade*	MR 3	*Materials Reuse*	SM-2	*Design for Materials Reduction*	MA2	*Modular and Standardised Design*
Mat 4	*Re-use of Building Structure*	MR 4	*Recycled Content*	SM-3	*Design for Flexibility & Adaptability*	MA3	*Prefabrication*
Mat 5	*Responsible Sourcing of Materials*	MR 5	*Regional Materials*	SM-4	*Design for Disassembly*	MA4	*Adaptability and Deconstruction*
Wst 2	*Recycled Aggregates*	MR 7	*Certified Wood*	SM-6	*Design for Durability*	MA5	*Rapidly Renewable Materials*
GREEN STAR		**DGNB**		SM-7	*Building Reuse*	MA6	*Sustainable Forest Products*
Mat-2	*Building Reuse*	Sb01-05, 10-11	*LCA Credits*	SM-8	*Material Reuse*	MA7	*Recycled Materials*
Mat-5	*Concrete*	Sb06	*Risks to Local Environment*	SM-9	*Regional Materials*	EU3	*Embodied Energy in Building Structural Systems*
Mat-6	*Steel*	Sb 08	*Use of Sustainable Resources / Timber*	SM-10	*Recycled Materials*		
Mat-8	*Sustainable Timber*	SB17	*Multiple Use Adaptation*	SM-12	*Reused or Certified Timber*		
Mat-9	*Design for Disassembly*	SB 42	*Demolition, Dismantling and Recycling*	**CHINA '3 STAR'**			
Mat-10	*Dematerialisation*	**GREEN MARK**		*5.4.3*	*Local Sourcing*	*5.4.10*	*Use of Waste Materials*
Mat-11	*Local Sourcing*	NRB 3-1	*Sustainable Construction - Concrete Aggregate*	*5.4.4*	*Concrete*	*5.4.11*	*Architectural System (Preference Item)*
		NRB 3-1	*Sustainable Construction - Cement Replacement*	*5.4.5*	*High-Performance Materials*	*5.4.12*	*Reused Materials (Preference Item)*
		NRB 3-1	*Sustainable Construction - Concrete Efficiency*	*5.4.7*	*Use of Recyclable Materials*		

Figure 2: Summary of credits applicable to structural materials from selected rating schemes

The indirect effects of structure on the performance of the building, for example through thermal mass & acoustic properties, are not insignificant and are discussed in section 2.1.

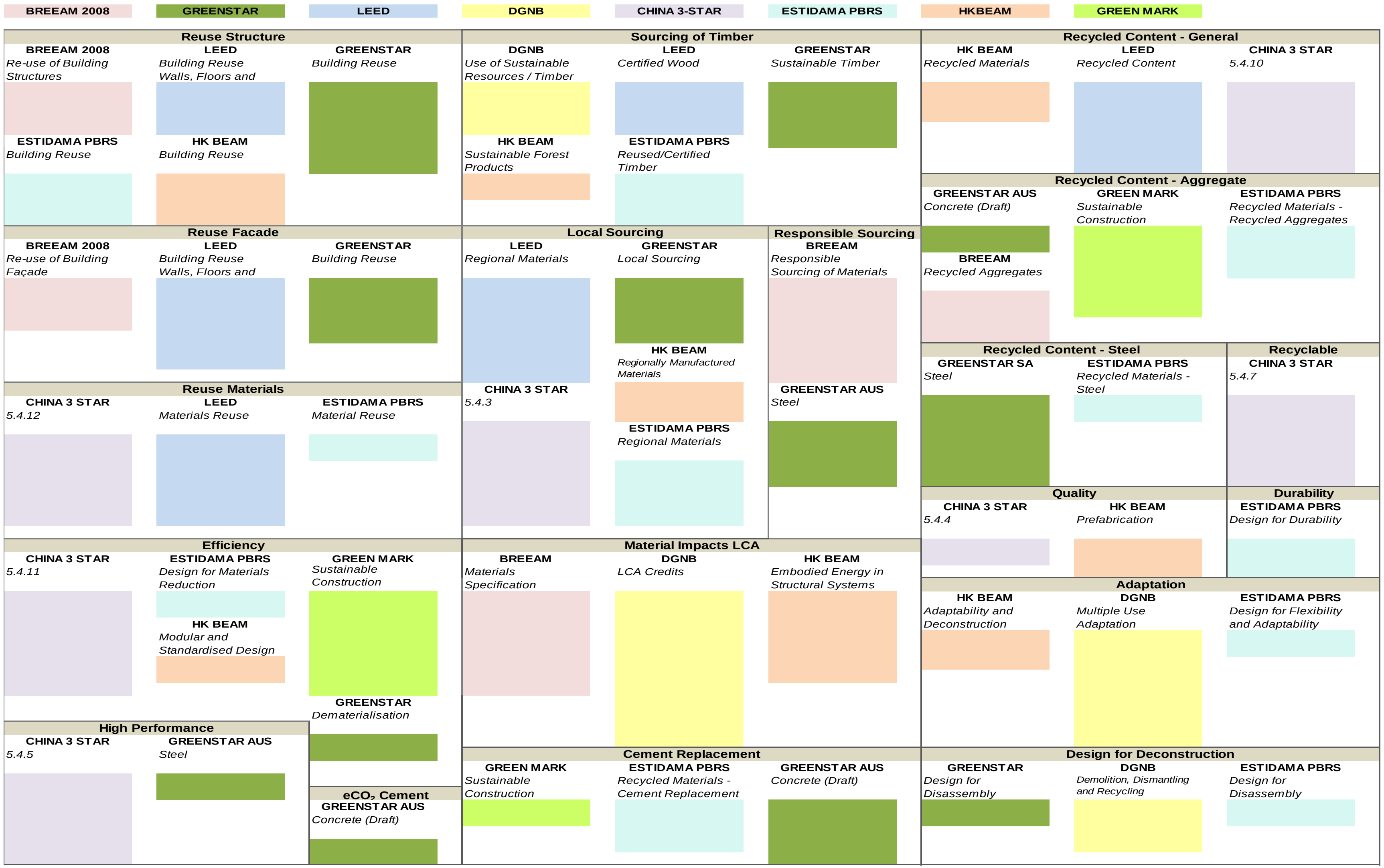

Figure 3:Map of credits relevant to structural engineers across selected rating schemes, grouped by topic.

Figure 3 shows a map of the credits available to structural engineers in the rating systems. Key topics in the rating schemes have been identified and the credits relevant to each of these topics have been grouped together. The size of each coloured block approximately indicates the associated percentage score available. The colours identify the different rating systems. A closer resolution image of each topic area including a detailed description and discussion of the topics can be found in later chapters.

Many of the study credits also include non-structural materials or operational effects, and in some cases the scores have been adjusted to reflect the aspects most directly under the control of the structural engineer.

Three aspects of a rating scheme affect the reality of achieving a given credit:

- difficulty (cost/effort relative to base case design),
- weighting (credits with lower impact on overall score may not be worthwhile) and
- logistics (amount and type of evidence required).

These aspects are not easily assessed through examination of the scheme requirements alone and are better appraised by studying real project experience.

Firstly an overview of experience and opinion regarding the use of rating schemes to appraise structure was drawn from the survey results. This is reported in Section 3.

A quantitative view was achieved through calculating the relative contribution of the structure to a rating scheme score from project data. This is reported in Section 4. Then this result was compared with the contribution of structure to building cost, embodied CO_2 and energy in Section 5.

2.1 The broader influence of the structural engineer

Structural Engineers can play an active role in many aspects of delivering a sustainable building. This can include supporting architectural, acoustic, thermal, lighting and construction performance. Achieving a sustainable building is noted to require a coordinated team, with early input from all parties. This is covered well in many papers about sustainable projects. This section shows that, in an active supporting role, the indirect influence of the structural engineer may support up to 50% of the scores.

As explained in section 2 above, the study identified credits associated with the structural design and specification. However, a broader view can be taken. This was discussed by Potangaroa, Ratchye, & Rees. Their paper [12] explores the role of a structural engineer in supporting good daylight, natural ventilation and exposed fabric energy storage, through the choice of structural form. In addition, the structural engineer can play an enabling role assisting the architect to specify responsibly sourced materials, and ensuring that good practice on site is achieved.

Table 2: LEED Points Rating System and the influence of different building professionals[12]

	Max Points	Structural Engineers	Civil Engineers	Mechanical Engineers	Architects	Modified Structural Engineer
Sustainable Sites	14	0	12	0	6	2
Water Efficiency	5	0	2	3	2	0
Energy and Atmosphere	17	0	0	17	10	14
Materials and Resources	13	12	8	5	11	12
Indoor Environmental Quality	15	4	0	13	9	9
TOTAL POINTS	**64**	**16**	**22**	**38**	**38**	**37**

Table 2 (extracted from the paper) highlights the extent to which structural engineers can influence LEED ratings, based on a superseded version of LEED. The 'Structural Engineers' column covers the credits most directly within a structural engineer's scope of influence, whereas 'Modified Structural Engineer', also contains credits which they can be indirectly influence. This shows that the structural engineer can have an indirect influence on a large number of credits and potentially make a significant contribution to the overall rating. The study found that high scores were achievable with both steel and concrete frames.

These additional or indirect areas of influence cover topics such as construction management, thermal response, lighting, acoustics, architectural finishes, comfort and health. The most commonly quoted indirect influence of the structural engineer is in the use of the fabric energy storage potential of the structure.

2.1.1 Fabric Energy Storage

Fabric energy storage uses the thermal capacity of the building fabric, more commonly called 'thermal mass', to moderate temperatures and improve comfort. This can be combined with natural ventilation strategies.

In temperate climates, for passively assisted winter heating, savings in the region of 5-30% on heating energy can be found, but this varies considerably depending on the building. For summer cooling, the use of thermal mass may make the difference between the need for comfort cooling or not, again with significant energy savings. However, the provision of thermal mass alone will not realise this energy saving potential, and without a fully integrated design, the inclusion of thermal mass can have negligible or adverse effects on the energy use of a building.

The level of benefit from thermal mass will depend on the location, building type and the environmental control strategy. The parameters that can then influence the effectiveness include the area of thermal mass effectively exposed to the room, daily swing in room temperature, and the air-tightness of envelope.

Steel, masonry and concrete frame buildings routinely provide sufficient thermal mass which can be fulfilled by a dense concrete floor slab thickness of around 100mm. Solutions for thermal mass in timber buildings and the use of phase change materials or dense finishes such as clay board, which de-couple the structural mass from the thermal response, are also developing. Hence the choice of material of structural frame is not the most important factor in achieving an optimum thermal response[13].

The building form, the potential to actively expose the surface, and the geometry of the structural system are all within the scope of the structural engineer and can assist with the efficiency of heating, cooling and ventilation. Therefore, the provision of thermal mass within the building structure by the structural engineer may contribute to a more energy efficient building. However it is the role of the building services engineer to exploit this efficiency.

2.1.1.1 Thermal mass in rating schemes

When thermal mass is mobilised in a positive manner, the benefits would be expected to be recognised in energy and thermal comfort credits in rating schemes, although this can be difficult to quantify.

There is widespread acknowledgement of variation between predicted and actual thermal and energy performance of buildings. This has been recorded in the 2010 UKGBC consultation on BREEAM[14] and also in energy studies in America for LEED accredited buildings[15]. Analytical methods currently do not model the subtleties of thermal mass very well and methods vary between countries and rating schemes. To fully quantify the benefit of thermal mass requires a dynamic thermal simulation.

It is very difficult to predict the energy savings and corresponding percentage of rating system points attributable directly to thermal mass. Energy savings may be in the order of 8%[16] but this estimate is sensitive to exact circumstances. It is even more difficult to predict the percentage of these scores that could truly be claimed to be the direct responsibility of the structural engineer. No data was found that explored this connection explicitly.

If used inappropriately thermal mass can have a negative effect and add to energy use or cause over-heating. Lighter weight, thermally dynamic buildings can perform well in hot/humid areas. In temperate zones it may make very little difference. In addition, thermal mass can be decoupled from the structure. This evidence indicates that the provision of thermal mass in the building structure should not be rewarded as an action in itself.

2.1.2 Construction Impacts

Embodied CO_2 studies, for the study building types, which quantify construction and transportation (gate to site) CO_2 emissions typically find that these are 12-21% of total embodied CO_2 [17,67] of an office building. This equates to around 2-4% of the total life-cycle CO_2.

These findings can be compared to Table 5 below which shows that construction and distribution are about 2% of the CO_2 emissions associated with construction overall (including the operation of buildings) in the UK. Similar findings are in the literature[25] regarding energy rather than CO_2. Values quoted for transportation and process energy of erection and demolition give a 1% share of the life-cycle total.

Although CO_2 and energy are only two indicators of sustainability, these findings indicate that credits associated with construction management should receive a lower weighting than those associated with the materials deployed in the building structure.

Waste is another important negative output from the construction phase. In the UK the construction (and demolition) sector was responsible for about 35% of the total waste generated in 2008 as shown in Figure 4. However, structural materials generally have much lower waste rates than fit out materials. All the materials in this study have typical wastage rates of less than 5% by weight[18].

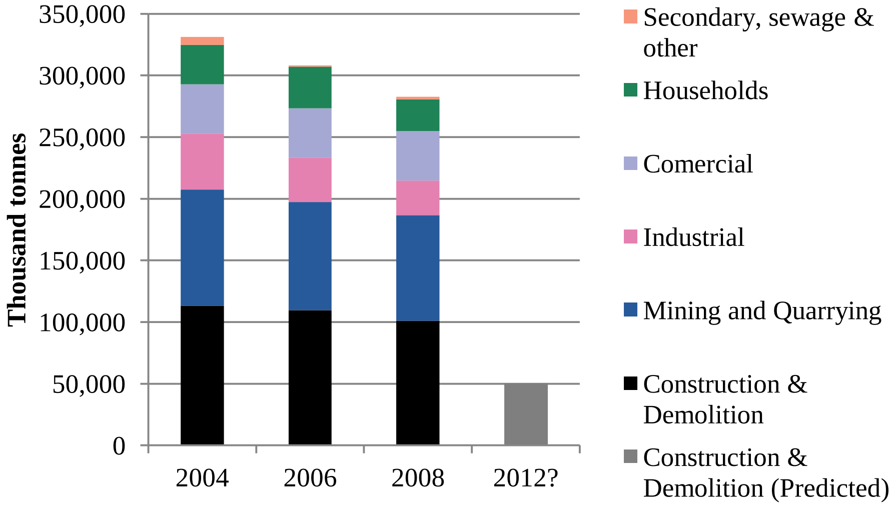

Figure 4: Total UK waste generation, by sector, 2004 to 2008[19, 40]

Therefore while rating schemes should continue to focus on construction impacts, particularly in regions where there is no legislation in this area, this is not an area in which structural engineers will be having the most significant impact. The exceptions are when the structure enables architectural finishes to be reduced or if an existing building is retained and hence demolition waste is reduced. These are covered in separate credits and discussed later in the report (Sections 7 and 13).

Taking the UK as an example, construction features in management and waste credits in BREEAM. The study shown in Figure 12 showed that management credits in BREEAM have a weighting in the scheme of 12% of the total available scores (all aspects, not just construction). However they are very popular credits and are targeted with a frequency higher than this. This means that they achieve an even higher proportion in actual project scores. The reason may be due to the Government target for 2012 set out in BERR's "UK Strategy for Sustainable Construction" from June 2008.

Recommendation 2.1

Credits associated with construction management should receive a lower weighting than those associated with the materials deployed in the building structure.

2.1.3 Other indirect contributions of the structural engineer

In addition to the discussions above, consideration was given to credits in the areas of lighting, acoustics and comfort. As with thermal mass, the interactions between factors were complex, and whilst structural engineers have a role to play in these credits, ultimately the responsibility lies with other professionals.

2.2 Summary

Structural engineers can play an active role in many aspects of delivering a sustainable building. This can include supporting architectural, acoustic, thermal, lighting and construction performance. Achieving a sustainable building is noted to require a coordinated team, with early input from all parties. This is covered in many papers about sustainable projects. The structural engineer can contribute much as part of a multi-disciplinary team in achieving efficient design, good value for the client, and probably additional rating scheme scores in these indirect areas. It has been estimated that, in an active supporting role, the indirect influence of the structural engineer could support up to 50% of the scores.

All rating schemes include some credits which are directly related to the design and specification of the structure itself. These should be the area where Structural engineers can provide the most direct value to clients. The research looks in more depth at these credits in the following sections.

First an overview of survey results regarding the experience of structural engineers with rating schemes is explored in the next Section.

3 How well do the rating schemes enable the structural engineer to provide value to clients?

A limited survey was used to supplement the analysis of project scores with the experience of structural engineers who are interested in this field from around the world.

Overall, the survey showed that although attitudes towards sustainability and the schemes were positive, the schemes were not effective at addressing the impact of structure. Opinions about individual issues were generally consistent. However there was a large variation in responses depending on the exact strategy, material, scheme and region in question.

As defined in section 1, an effective rating scheme would provide:

- incentives for sustainable **actions**
- a comparable **measure** of the sustainability of buildings
- a **framework** to define sustainable design practices for professionals
- a **practical tool** which can cost effectively be deployed during the procurement of buildings

An analysis of the comments in the voluntary text boxes (not in response to direct questions) in the survey provides insights into perceptions of effectiveness. This set of data is small, but it is significant as it represents a spontaneous qualitative reaction to the topic of rating scheme effectiveness. The graphical summary of the open responses in Figure 5 provides an overview of the tone of responses and shows that on the whole participants felt that schemes were unsuccessful in providing either a practical tool or an incentive for structural engineers to provide sustainable solutions to their clients. Respondents were fairly equally split in their opinions on the effectiveness of rating schemes in providing a framework to define sustainable design practices for professionals.

The division of results by scheme cannot be taken as a true relative measure as the numbers of participants were not equal between schemes. The notable result in terms of division by rating scheme is that only LEED respondents using LEED outside North America commented on difficulties in terms of the practicality of applying the requirements. This result is thought to be because the information LEED requires for recycled content and sourcing of materials is not readily accessible in many locations, whereas the US supply chain has aligned itself with the LEED requirements.

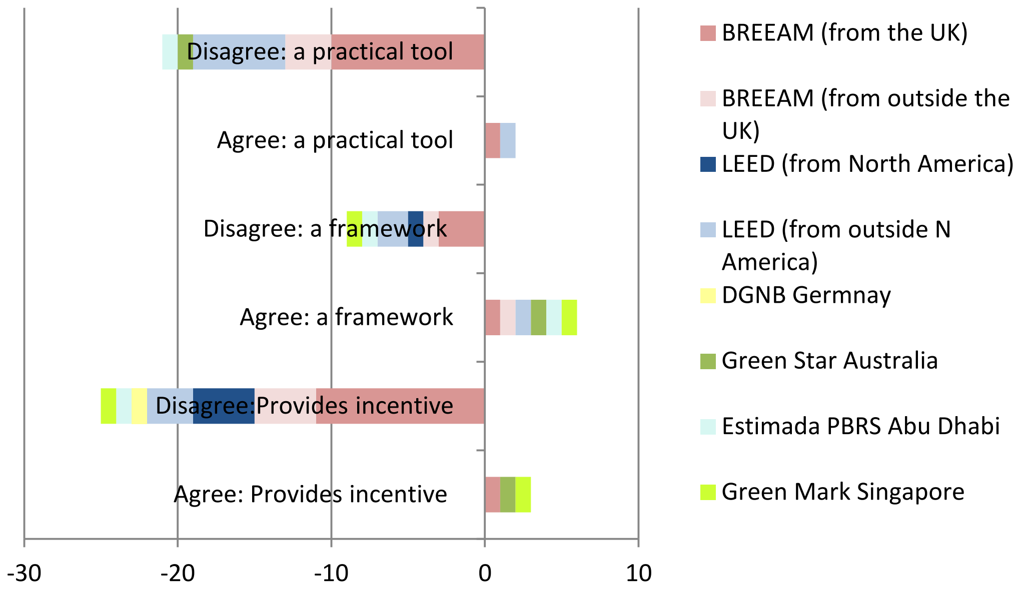

Figure 5: Open text responses grouped against measures of scheme effectiveness

3.1 How well do structural engineers engage with the schemes?

Questions were asked about how common it was for structural engineers to be involved with schemes, how clear the requirements from the schemes were, and whether schemes recognized sustainable structural solutions.

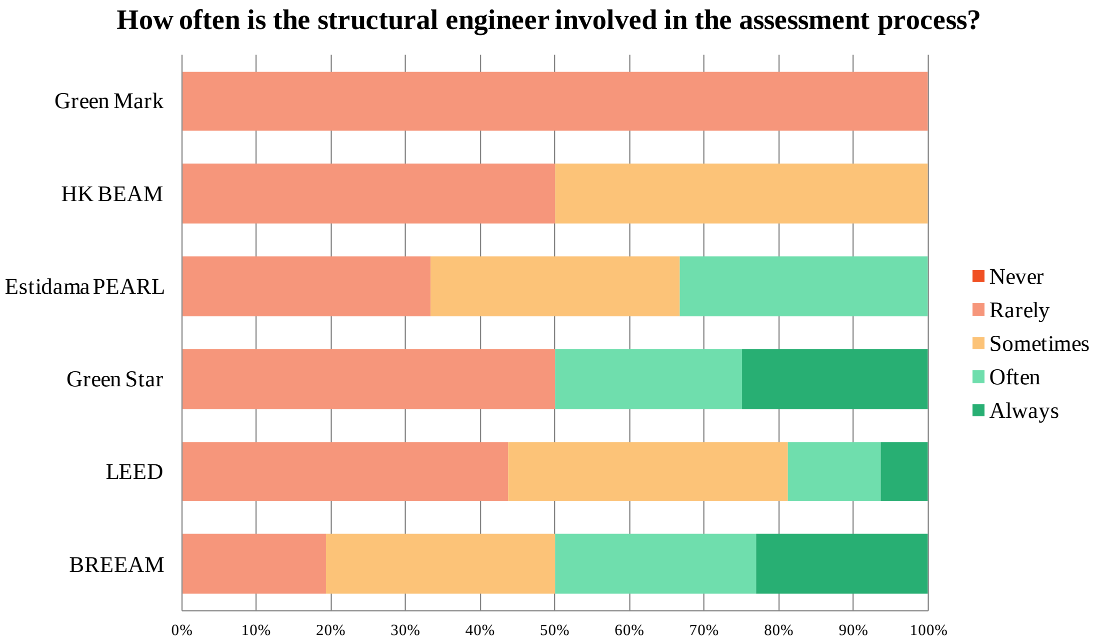

Figure 6: Engagement of structural engineer in assessment process

Although in BREEAM half of the respondents stated that structural engineers were always or often involved in the assessment process, this was often accompanied by comments which suggested that this was more of a passive involvement, rather than a meaningful contribution to the assessment.

Always involved, but our contribution is...usually limited to getting the easy credits. .. worthwhile changes to the structural... scheme never result from BREEAM...
The structural engineer is usually involved .., but usually no more than to contribute to the assessment ... Often, a structural engineer may be leading a multiple discipline team so will be involved in .. coordination...
In general, the input from the structural engineer is quite minimal at the important early design stages. The actual work required to demonstrate compliance... is often left to the contractor or materials subcontractors at a later design stage by which time opportunities for gaining credits have often been lost. ..

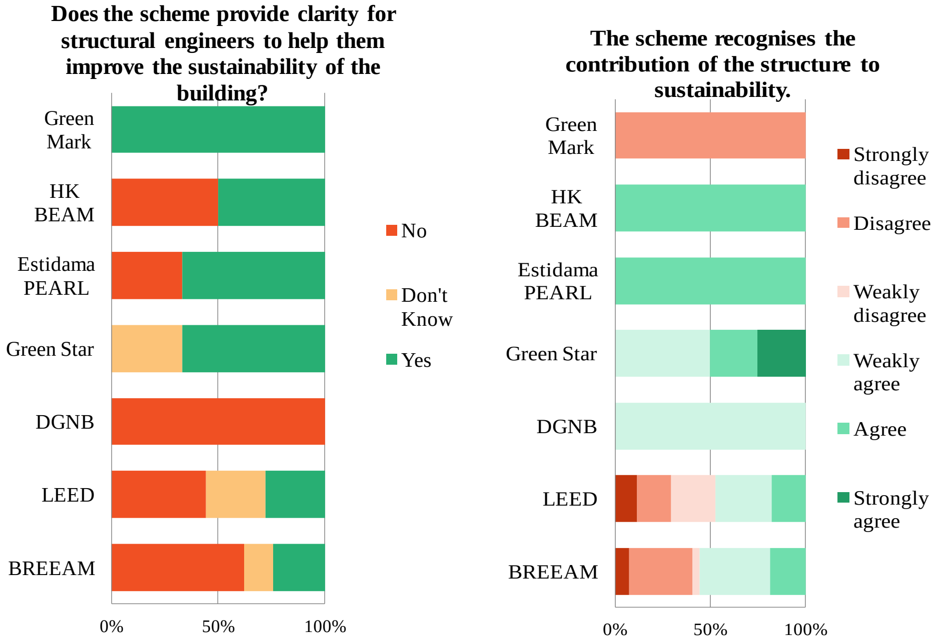

Figure 7: Alignment of schemes with the work of structural engineers

The respondents' views on the clarity of the schemes were varied. A number of the respondents who had indicated that the credits were clear or recognized structure also qualified this response with comments.

For BREEAM, LEED and DGNB the general nature of the credits was raised as a difficulty in terms of providing clarity for structural engineers. The credits in question apply to all materials rather than to structure alone. A comment on Estidama PBRS highlighted that the credits to do with material specification (recycled /regional material) were clear whereas the 'design' related credits (e.g. flexibility and durability) were less so.

With regard to sustainability, qualifications offered for BREEAM, LEED and Green Mark suggested that the credits only partially recognized the contribution of structure. Some respondents felt that credits recognized 'business as usual' and others that the actions required, while clear and sustainable, were not practical.

Rating System	*Comment from survey respondent*
BREEAM	*The BREEAM credits tend to be all-or-nothing... the practical options available to the structural engineer... do not earn credits.*
	only the 'floors' count - no frame, substructure etc.
LEED	*LEED encourages the use of recycled materials within steel and concrete, but does not recognize or encourage work beyond that.*
	Yes, but... LEED often rewards conventional practice.
Green Mark	*Clarity is given however only on a very narrow subject, namely the... (concrete usage index)... 'green cements' ...and ... recycled aggregates.*

There were also concerns over whether the schemes improved the sustainability of the structure. This can be explored further using a quantitative analysis of responses about the strengths and weaknesses of schemes.

Rating System	*Comment from survey respondent*
BREEAM	*BREEAM provides clarity on materials credits. I do not believe that it necessarily helps to improve the sustainability of the building...*
LEED	*It provides clarity, but rarely... improves the sustainability of buildings.*
Green Mark	*Green mark concentrates on the energy usage of a building.*

The combined results show that structural engineers felt less effectively engaged with the schemes that offered holistic assessment-based approaches; namely BREEAM, LEED and DGNB. The Green Star scheme was perceived to draw in the most effective engagement. This scheme has credits directly related to each structural material.

3.2 What are the strengths and weaknesses of the Green Building Rating Schemes?

The survey helps provide an overview of the relative strengths and weaknesses of the approaches to sustainability included in Green Building Rating Schemes. The strengths and weaknesses of rating schemes which had been identified in the desk study were presented in the survey. For each study credit, respondents were allowed to pick any multiple of issues and were not asked to rank them. The results in Figure 8 represent a frequency of the times the feature was identified as relevant compared to the total possible times it could be selected.

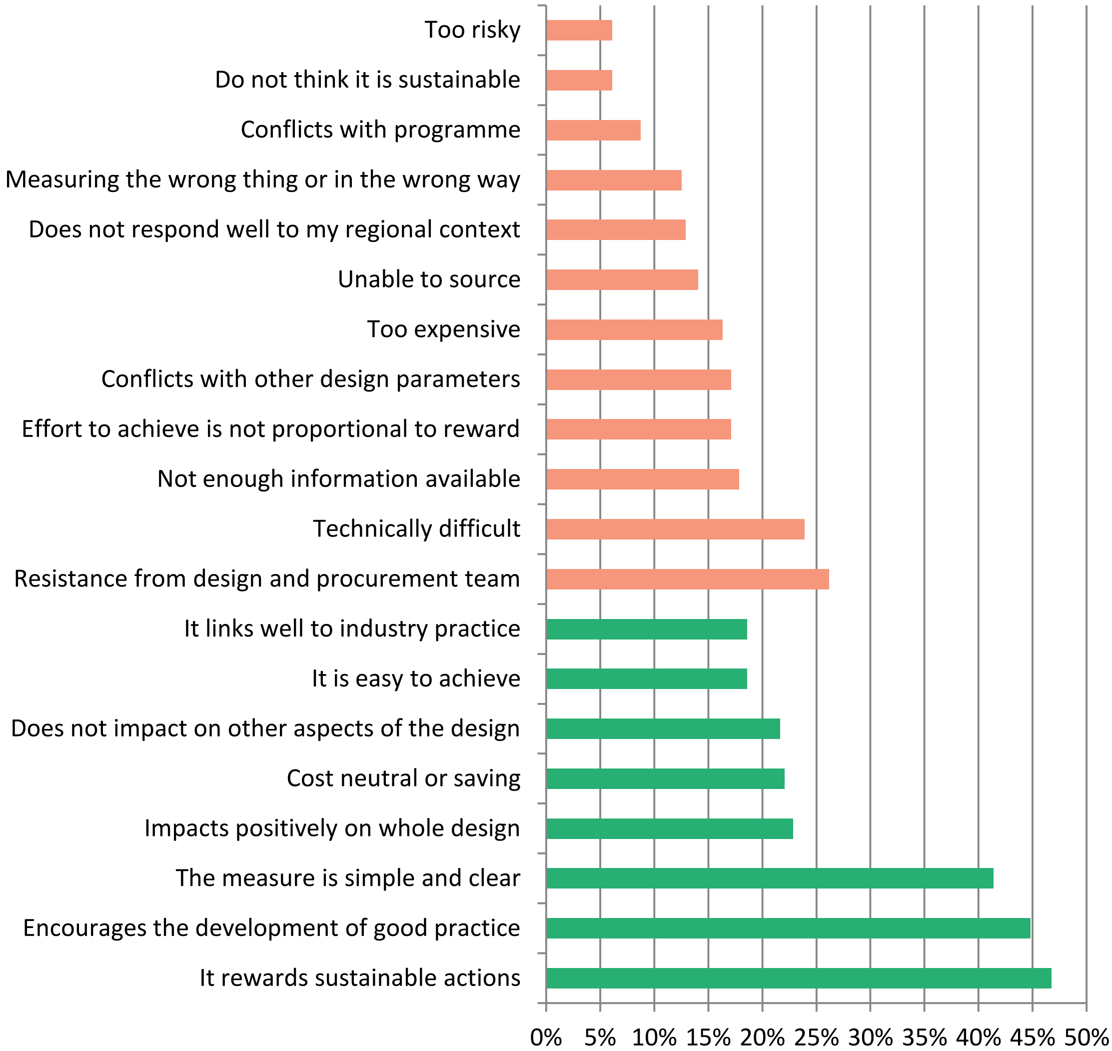

Figure 8: Relative strengths and weaknesses, all schemes, credits and regions

Although more negative attributes than positive ones were offered to respondents in the survey, Figure 8 shows that the overall consensus was positive. Based on the cumulative total of selections, positive features were selected roughly 30% more frequently than negative ones.

The most popular selections were those credits that rewarded sustainable actions, encouraged good practice and provided clear and simple measures.

However, even though these three characteristics were identified as a relative strength, they were selected by less than half of those who had the opportunity. Since the aims of the rating schemes are to improve the sustainability of buildings, the score for rewarding sustainable actions should have been closer to 100%.

3.3 Additional strengths and weaknesses

Text boxes were provided throughout the survey to enable people to add commentary to their selections from multiple choice questions. These were reviewed to see if there were additional strengths and weaknesses that should be considered. There were three issues raised in the comments which are not truly represented in the quantitative survey data above. These relate to the functionality of the scheme as a whole.

- **Some credits were perceived as rewarding 'business as usual'**. It is not clear if this is a strength or a weakness. In terms of providing a measure of sustainability to the client, if 'business as usual' is an example of good sustainable practice then this could demonstrate a strong scheme, cost effectively aligned with industry. However if the aim of the scheme is to provide incentives for improving the sustainability of construction, then rewarding 'business as usual' is counter-productive.
- **Some credits are simply not available to a project.** An obvious example is the re-use of building credit when applied to a green field site. Comments were received from regions such as Middle East where re-use is less common, and from BREEAM respondents referring to the pre 2011 Scheme. Schemes such as Green Star have responded to this by making it possible to exclude irrelevant credits from the target in the calculation of the percentage score.
- **Some credits were felt to be too broad or too simplified.** Examples are recycled content and regional supply requirements. In different situations and for different materials the strengths and weaknesses of aiming for a high recycled content, or high regional content will be very different.

3.4 Usefulness of average data

Figure 8 represents the percentage scores across the total possible selections for all schemes and credits. This comparison of strengths and weaknesses is only useful as an overview. Large variations in responses were found across all credits and all rating schemes. This confirms that the research needs to look at the different types of credits separately.

Figure 9 shows an example of a few BREEAM credits. The credits have different perceived strengths. These profiles are different from the overview in Figure 8.

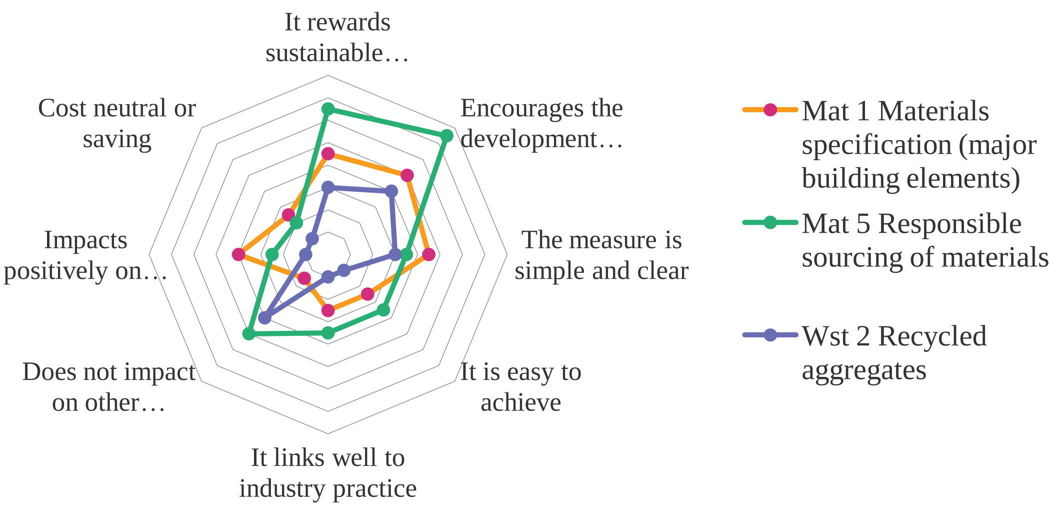

Figure 9: Variation in perceived strengths across different credits in BREEAM

3.5 How could the Rating Schemes be improved?

As well as providing insight into the practical experience of structural engineers working with the schemes, the survey generated general suggestions for improvements in terms of new or different credits. These are listed below along with the scheme that was being considered when the suggestion was made. Comments related to specific credits are also included in section 6 onwards.

BREEAM	Provide credits directly associated with actions by structural engineers as opposed to credits based on analysis. Examples listed were cement replacement, avoidance of unnecessary finishes.
BREEAM, Estidama PBRS	Require minimum scores in each section. Include structure in more mandatory credits.
BREEAM, LEED	Recognise structural efficiency, material efficiency & dematerialisation in design
BREEAM	Recognise actions which reduce embodied CO_2 emissions
LEED	Greater incentives for change and sustainable actions rather than measuring conventional practice.
LEED	Recognise all materials equally (perception that LEED favours steel)
LEED	Recognise the role of structure in other impacts, e.g. operating energy

LEED, Green Star	Include incentives for design for adaptability, design for deconstruction and cradle to cradle design
LEED	Develop LCA credit
LEED	Include incentives for durability or longevity
LEED	Include incentives for high levels of cement replacement
Estidama PBRS	Align credits with the development of regional systems
Green Mark	Adjust towards a 80% operation and 20% materials split in credits
Green Mark	Develop credits which recognize the issues associated with imported materials

3.6 Comparison with other consultations

Green Star Australia has published industry stake-holder reviews of the main structural material credits. The findings are generally in line with the findings of this research. The technical reviews and stakeholder engagement are welcomed.

The results can also be compared to UK Green Building Council (UKGBC) 2010 stakeholder consultation about BREEAM[20]. The stakeholders here represented a broad range of professions. Some relevant recommendations are summarised below. Apart from the topic of recycled content, these recommendations are in line with the findings of this research. These recommendations were not adopted in BREEAM 2011.

Comments from UK-GBC BREEAM Consultation[20]

Materials optimisation

Can/should BREEAM do more to encourage/recognise 'Design for Materials Optimisation', if so what/how?

Recommendation: It is recommended the overall weighting of the materials section increases, credits are simplified and minimum standards introduced. Greater transparency is required on the Green Guide and a wider range of materials – innovative and non-standard – are included in the Green Guide. BRE Global should publish the final version of the Environmental Profiles Methodology, and look to make available to stakeholders, the necessary data and life cycle models.

The calculator tools, in particular, responsible sourcing calculators, should be made publicly available. Any embodied carbon and energy component introduced in the future should be simple and refer to an industry accepted standardised methodology and database.

Operational and embodied carbon should be addressed collectively.

Materials - recycled content

Should BREEAM assess 'Recycled Content by Value' of buildings, and reward those that meet specific levels? WRAP has recommended this as an issue for BREEAM to consider.

Recommendation: Recycled content within buildings should be integrated into BREEAM but the approach should be carefully considered. The Cradle to Cradle approach and open access to the Environmental Profiles Database would provide useful information and guidance in this area.

Mat 1 Materials Specification: It was generally felt by members that the Green Guide required further work and a review. Particularly in the case of the high number of 'A' ratings, lack of transparency, lack of innovative materials and reasoning behind ratings. ... along with more transparency and user friendly labelling scheme on the environmental impacts of products.

Mat 3 & 4 Reuse of facade and structure: It was felt the reuse of façade and structure credits (Mat 3 and Mat 4) should be optional depending on the presence or absence of an existing structure or façade.

Mat 5 Responsible Sourcing of Materials: It was suggested the tier level table should split out all BES 6001 ratings for responsible sourcing; currently 'Excellent' and 'Very Good' are in the same tier.

3.7 Summary

Although there were many positive views expressed, on the whole participants felt that schemes could be more effective in providing either a practical tool or an incentive for structural engineers to provide sustainable solutions to their clients.

The potential strengths and weaknesses identified during the desk study were confirmed to be relevant factors in considering effectiveness. These attributes are used in following chapters to summarise opinions about individual credits. In addition respondents identified some credits perceived as rewarding 'business as usual', some which were not available (therefore irrelevant), and some which were felt to be too broad or too simplified

Although there were some consistent views expressed, none of the attributes regarding strengths and weaknesses was selected by more than 50% of respondents across all the study credits. It was found that there was significant variation between credits, between regions and between schemes. Hence the remainder of this research looks in more detail at the study credits.

Recommendation 3.1

The use of mandatory credits or minimum standards should be used for materials.

Recommendation 3.2

Credits which are irrelevant to a project should be excluded from the scoring system. (e.g. existing buildings on Greenfield sites, and materials that are a very small proportion of the project).

4 Direct project scores for structure

This chapter provides a numerical evaluation of scores on projects. The study explored how much of each rating scheme score comes from the 'study credits' which were identified in Section 2 and how often they were achieved on projects. It was found that such credits contributed approximately 5% of the total score consistently for nearly all the rating schemes studied, despite a large variety in the way they approached the building structure. Using BREEAM as an example, research has also shown a notable lack of correlation between the scores most directly associated with materials and the total rating scheme score. Subsequent chapters consider if this level is appropriate.

The eight rating schemes studied are considered below in turn.

4.1 BREEAM

The organisation of materials credits has changed with different versions of BREEAM. However, the changes have not significantly changed the structural engineer's approach to the scheme, and therefore analyses of previous BREEAM versions can be used. The results demonstrate that less than 5% of the score relates to the study credits.

The Building Research Establishment (BRE), who provide BREEAM, have kindly shared data on materials and waste credits which were gained on 657 projects assessed to BREEAM Offices 2005 and 2006, as shown in Figure 10 and Figure 11 below. This data demonstrates that the total number of study credits achieved remains fairly consistent across all rating levels, at around 5% of the total available points. The apportionment of credits available in BREEAM varies but is typically as shown in the "All credits" bar in Figure 10. Figure 11 shows that this consistent number of points translates into a diminishing overall proportion of study credits achieved on projects as the level of rating increases. The exception is the 'Responsible Sourcing' credit, which is increasingly targeted on higher-scoring projects.

The 'materials specification' credit represents the greatest proportion of the 'study credits' achieved. This is discussed in section 12 where it will be seen that much of this score relates to non-structural materials.

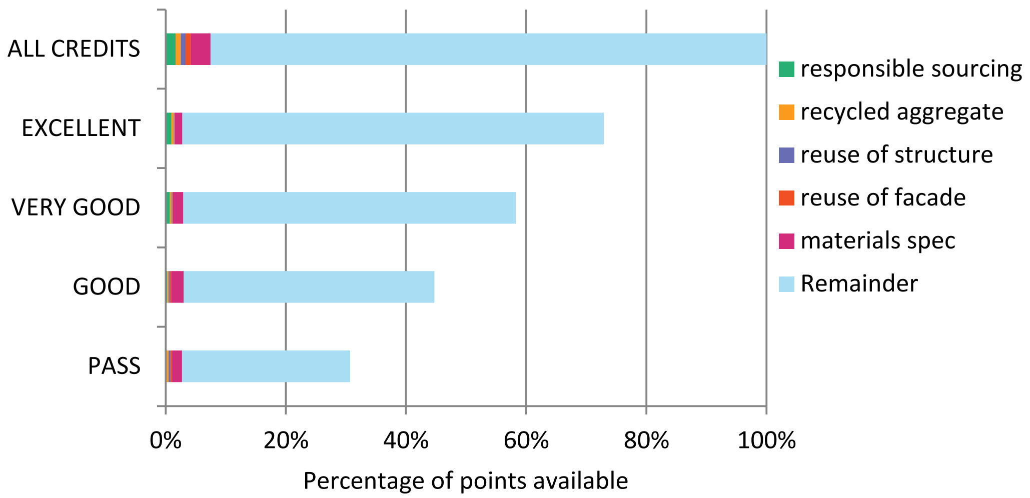

Figure 10: Average breakdown of points achieved, with ‘study credit’ highlighted, shown as a percentage of points available. (657 BREEAM Office assessments in 2005 & 2006)

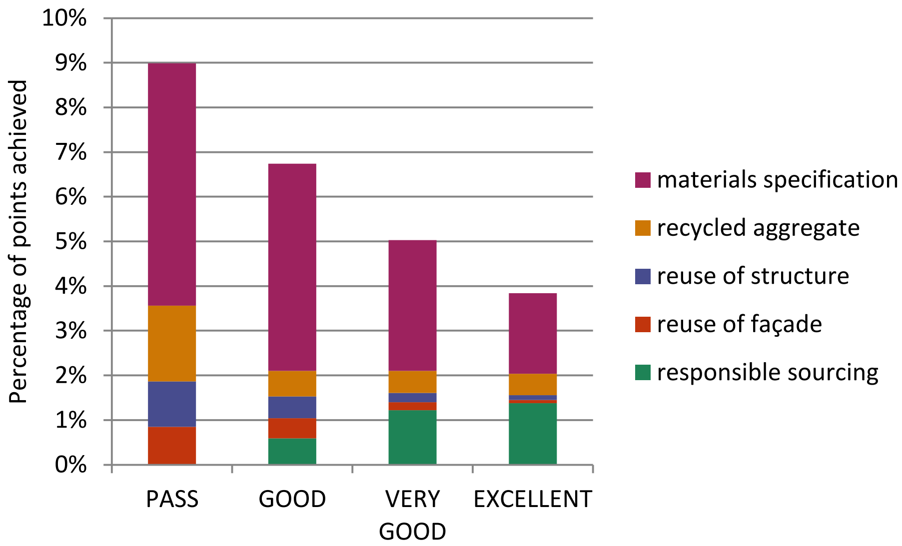

Figure 11: Materials-related credits achieved on BREEAM projects shown as a percentage of total credits achieved. (657 BREEAM Office assessments in 2005 & 2006)

BRE also provided selected data from 63 BREEAM 2008 assessments for a variety of building types, which confirms the 2005 & 2006 analysis results, and findings from Arup projects that the structural engineer is directly influencing less than 5% of the total score.

Further corroboration comes from an analysis[21] of 120 assessments extracted from the ‘Tracker Plus’ web-based BREEAM project delivery system. The analysis reported average targeted % scores for each credit and explored the distribution across quartiles to identify macro and specific issues. All the credits related to the work of structural engineers are targeted less frequently than credits related to the work of other professionals. The extracted figure below also shows that they are targeted at a lower frequency than expected when compared to the weighting intended by the scheme itself.

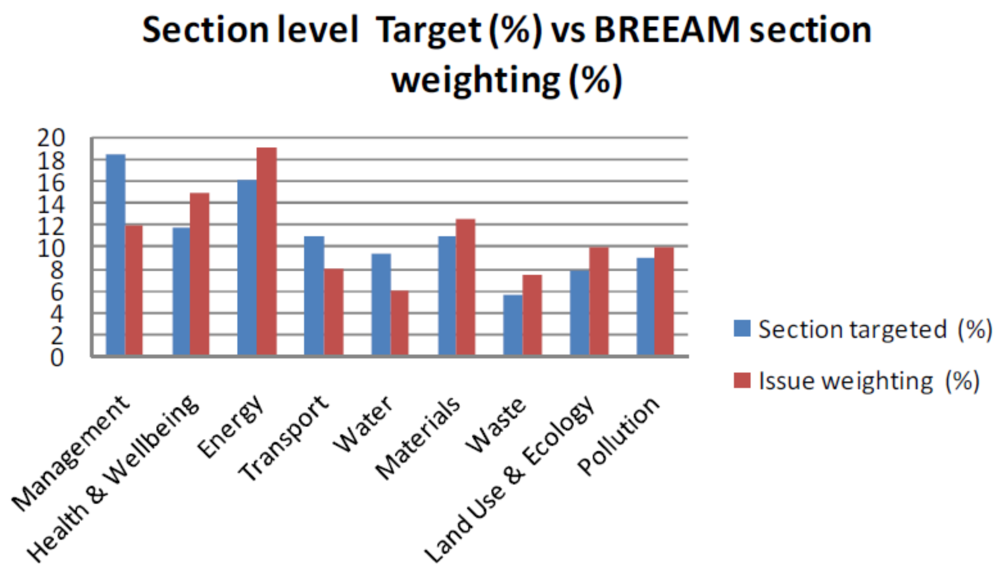

Figure 12: Actual project data plotted against scheme weighting. *Extracted from Cartmell et. al.*[21]

A further insight on this data is provided by Shamir Ghumra[22]. His research, using data kindly provided by BRE shows that there is very poor correlation between scores in the material section of BREEAM 2008 and the overall score. In contrast he repeated the same exercise with CEEQUAL and found a very good correlation. These findings imply that the materials credits in BREEAM are not effective in providing a clear route for improving the sustainability of the material aspects, or structure, of buildings.

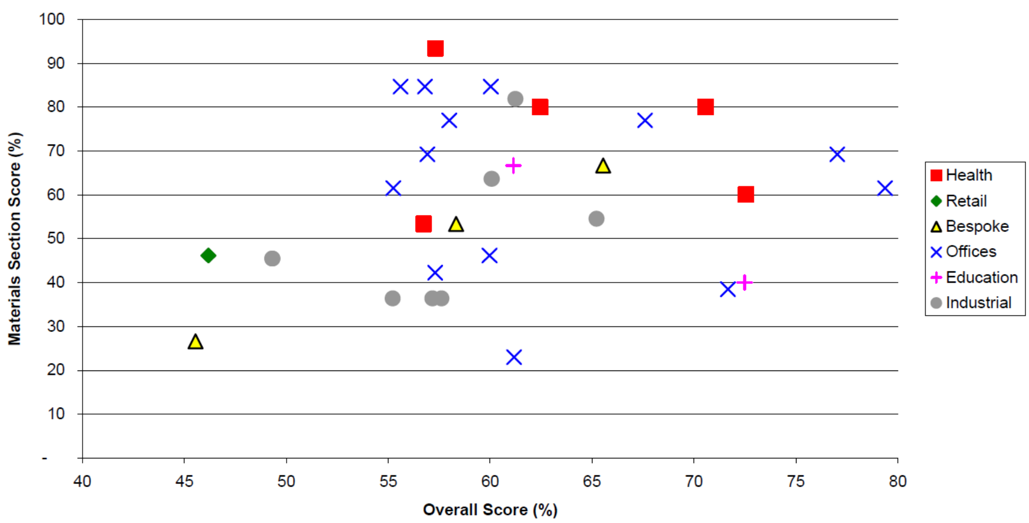

Figure 13: Actual project material scores plotted against total score in BREEAM. Extracted with permission from Ghumra[22]

4.2 LEED

Data was available for 750 American LEED projects which had been assessed to LEED New Construction v2-2.1. The contribution of material credits to the available scores and to the actual scores on projects for each level of certification is illustrated in Figure 14. Although later versions of LEED have a different credit weighting the survey respondents felt this has had little effect on the materials scores

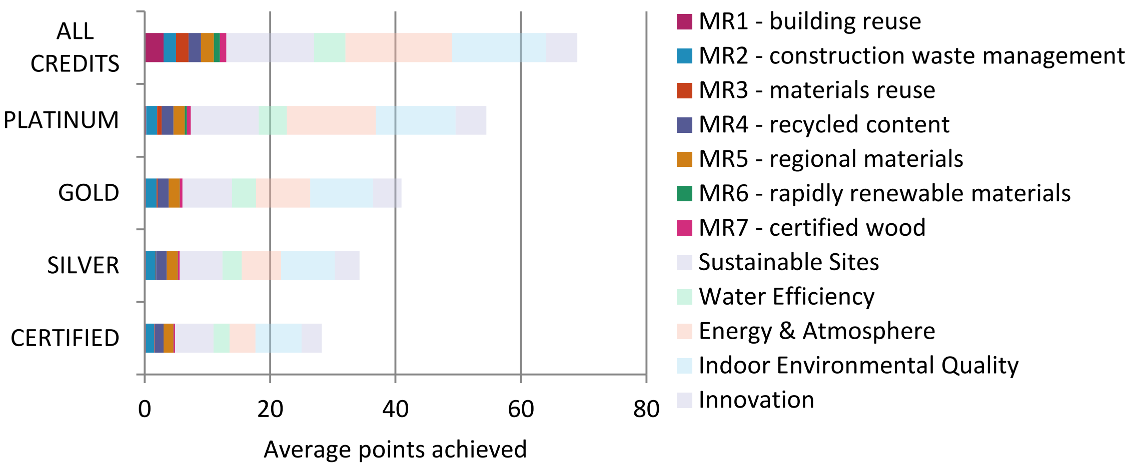

Figure 14: Average no. of points achieved over 750 LEED NC 2.0 & 2.1 projects

There was a slight increase in the total number of materials-related points achieved as the rating increased, however the actual proportion of the total score associated with all materials reduces as projects achieve higher levels, shown in Figure 15.

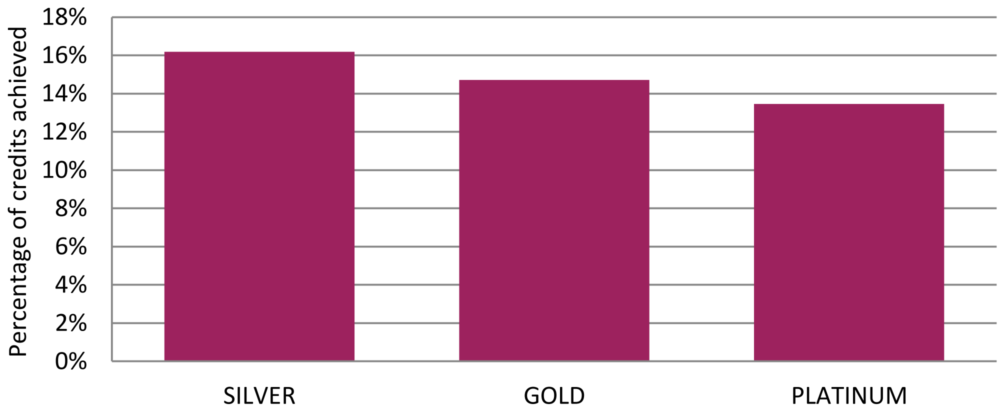

Figure 15: Percentage of credits achieved that are related to all materials (structure and non-structure)

LEED material credits are based on cost, but only an estimate of the total cost of materials is required in calculations. This means that submissions only need to include documentation for those materials sufficient to reach the LEED target levels. Therefore strategic decisions are often made during the LEED submission to base the evidence on 'easy wins'.

A detailed assessment was made of 8 LEED-rated projects from different parts of the world. A large variation was found in the proportion of structure used to achieve the credits. To find the proportion of material credits attributable to structure the average structural proportion from the detailed assessment was combined with the average scores from the large data set of platinum projects. On average, structure influences 36% of the materials credits for platinum projects and 5% of the platinum score overall.

Where the structural materials represent a high portion of the materials used for credits this is usually due to inherent properties of the materials such as the recycled content of steel in the US rather than the actions of individual structural engineers. Thus the same structural contribution to the material scores is often achieved for 'certified' as well as 'platinum' LEED buildings.

4.3 Green Star

Both Green Star Australia and Green Star South Africa were examined, again showing that structural credits amount to less than 5% of the total.

Green Star Australia

Green Building Council of Australia kindly provided non-attributable project data, plotted in Figure 16. Green Star project weighting varies due to excluded credits and regional weightings. Because of the data collection method, the weighting system used for each individual project was not available. Therefore the results may slightly underestimate the actual contribution made by the materials. However the associated error in the overall proportion will be relatively small as credits will also be excluded in non-material categories.

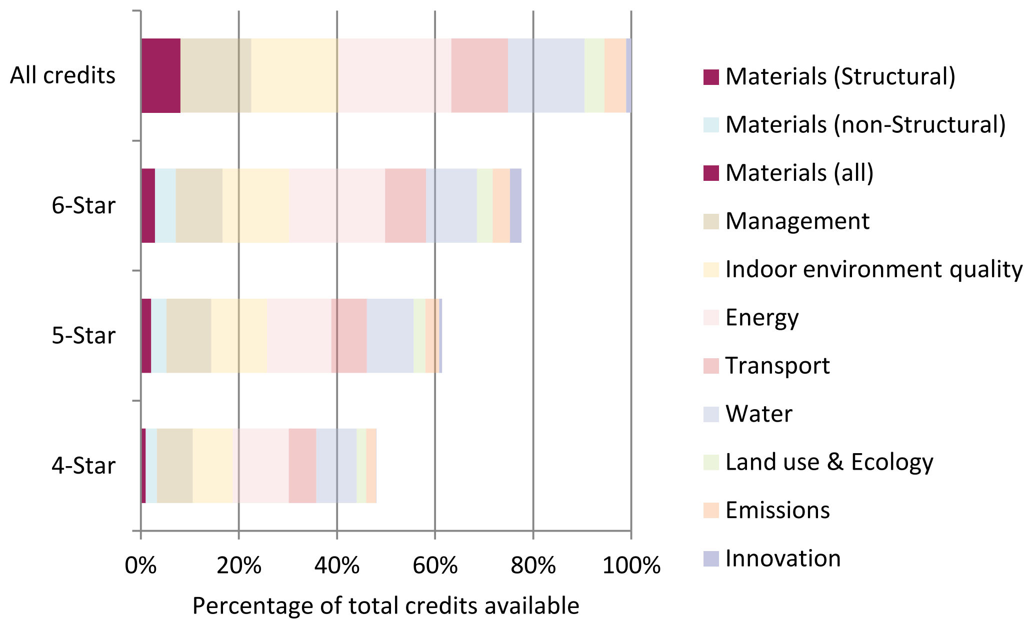

Figure 16: Average percentage of credits achieved from 229 Green Star Australia Office v2 & v3 projects

Scenarios were created based on assumptions about different levels of excluded credits. On average the structural credits ranged from 2% to 4% of the total score per project. Figure 17 shows that, unlike BREEAM and LEED, the proportion of material points achieved increased as the Green Star level increased.

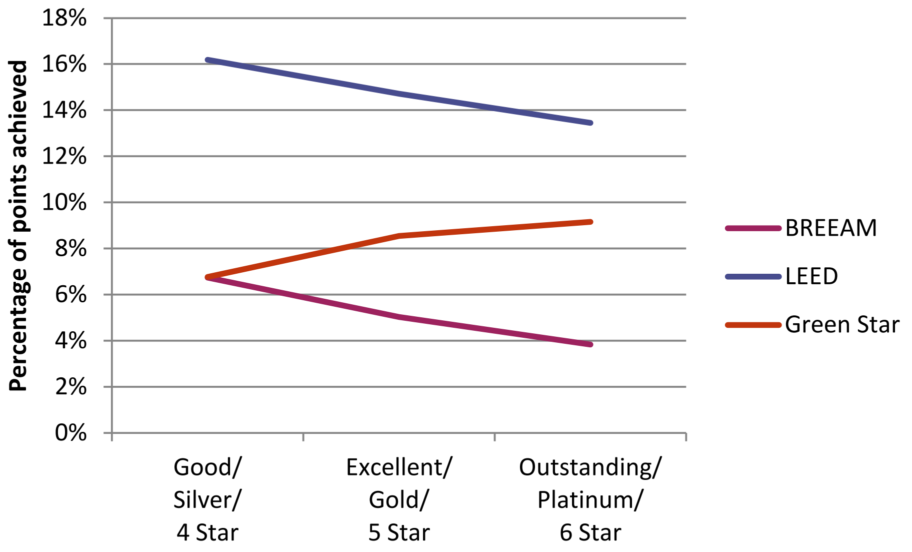

Figure 17: Percentage of points achieved attributable to materials (structure and non-structure)

There are credits for direct actions related to all the main structural materials in Green Star. Hence clarity is provided to structural engineers showing how they can influence the final result. However each action is worth a very small proportion of the overall score. Typically the structural engineer will gain only 0.6% of the total score for each action taken.

Green Star South Africa

This is a relatively new system and few projects have been assessed. Weightings are slightly different from Australia. A single project was reviewed, as shown below in Figure 18. Structure represents 4.5% of the total score.

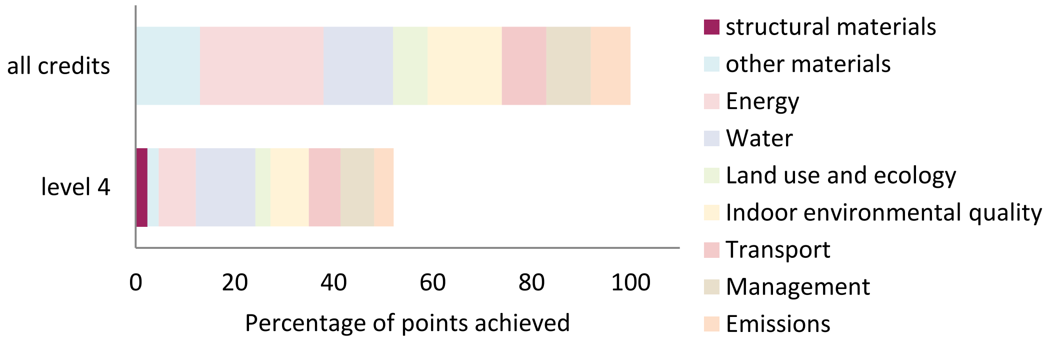

Figure 18: Percentage of points achieved in each area for a Green Star South Africa project

4.4 3 Star, Green Mark, and HK BEAM

Project submissions were reviewed for a small number of Singapore Green Mark, Hong Kong Beam, and the China '3 Star' projects. The projects did not entirely match the requirement of the project brief as they were generally much taller than the project buildings and included residential and hotel towers. However the proportion of structural credits is not expected to be significantly affected by this variation. The results are shown in the figures below. The proportion of credits directly associated with the building structure in these examples ranged from 1% for a Hong Kong BEAM example to 8% for a China 3-star example.

'3 Star'

China '3 Star' sets minimum scores as well as mandatory items in each category for each star level. The use of minimum scores for materials means that materials in '3 Star' will have a higher priority than for other schemes. The minimum requirements increase for each star level. From the project example shown in Figure 19 below, approximately 8% of the points achieved were attributable to the structure.

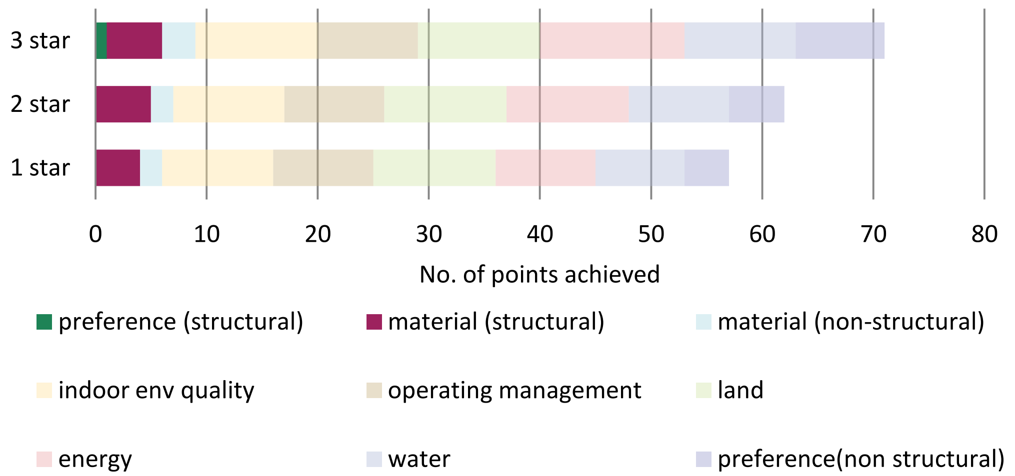

Figure 19: No. of credits achieved for a China '3 Star' project

Green Mark

The credits available in Green Mark for structure are clear and specific. There is a minimum pre-requisite level for structural points for both gold and platinum projects. Evaluation of a small number of projects targeting platinum level showed that the structure gained much of the available score. However the credits only cover a limited number of issues, and on average the structural credits accounted for 5% of the total score achieved, as shown in Figure 20.

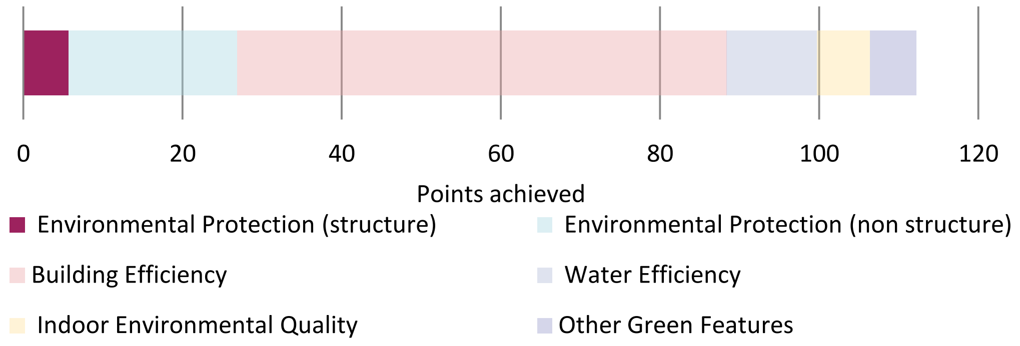

Figure 20: Points achieved on a Green Mark Platinum project

HK BEAM

Hong Kong Beam offers credits for building re-use, adaptability, offsite, modular construction and embodied energy of building structure. Due to the weighting system the embodied energy credit provides the most potential for the structure to contribute to the overall score.

For the small number of real projects examined the credits associated with the structure were not all targeted and qualifying credits amounted to only 3% of the total score, shown in Figure 21. If all the credits associated with the structure had been targeted then this percentage could have been up to 8%.

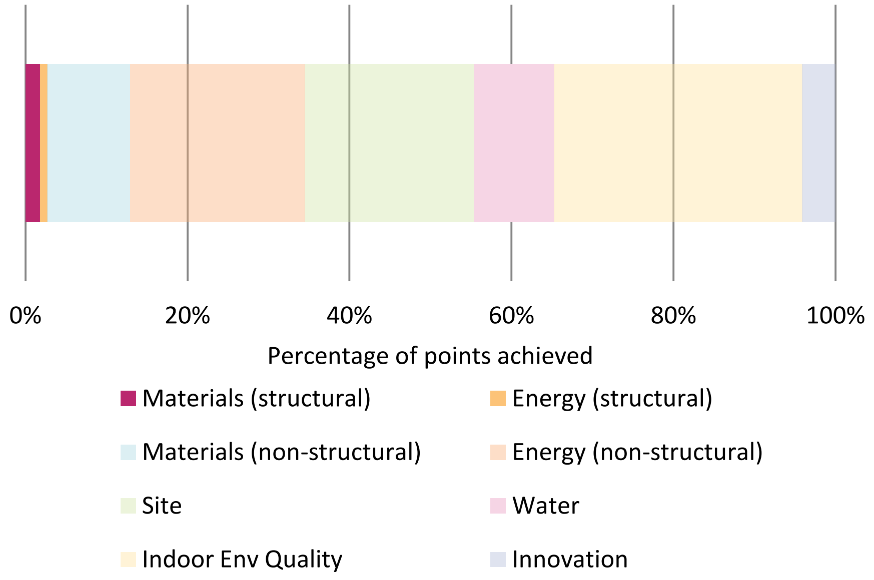

Figure 21: Average points achieved from a sample of HK BEAM projects

4.5 Estidama PBRS

The Estidama PBRS rating scheme is too new to provide numeric data regarding credits awarded. However Table 3 gives a qualitative evaluation of response to the credits and was provided by Abu Dhabi Urban Planning Council in August 2011. As with BREEAM, the construction management credits are popular. The design credits, which are of much interest to structural engineers, are achieved less often.

Table 3: Qualitative summary of frequency of credit achievement

SM-R1	Hazardous Materials Elimination	Required
SM-R2	Basic Construction Waste Management	Required
SM-R3	Basic Operational Waste Management	Required
SM-13	Improved Construction Waste Management	Very often
SM-14	Improved Operational Waste Management	Very often
SM-1	Non-Polluting Materials	Often
SM-5	Modular Flooring Systems	Often
SM-9	Regional Materials	Often
SM-12	Reused or Certified Timber	Often
SM-2	Design for Materials Reduction	Sometimes
SM-3	Design for Flexibility & Adaptability	Sometimes, but probably too easy
SM-6	Design for Durability	Sometimes, usually not well documented
SM-10	Recycled Materials	Sometimes
SM-15	Organic Waste Management	Sometimes
SM-4	Design for Disassembly	Rarely
SM-7	Building Reuse	Rarely
SM-8	Material Reuse	Rarely
SM-11	Rapidly Renewable Materials	Rarely

4.6 Summary

The rating schemes take completely different approaches to assessing the impact of structure.

Some data sets were available which enabled analysis of the distribution of points scored on real projects. Despite the variety of methodology, the structure contributes typically 5% to the final rating scheme score. This is typically about half of the available score. With the exception of Australian Green Star and China '3 Star' there is little evidence to show the structural solution helping to differentiate between low and high scoring projects.

Recommendation 4.1

The approach to credits related to materials should be re-considered in schemes where up-take is consistently low, and there is poor correlation between increased material scores and high performing projects.

5 The life-cycle contribution of structure

Looking at a variety of measures, the building structure would expect to contribute a higher proportion that is currently in rating schemes:

- at least 12% of the credits associated with initial impacts –based on cost.
- around 4% of credits in terms of life cycle costs.
- around 10 - 20% of credits for energy and CO_2 of high performing buildings
- up to 90% of material credits based on the mass of the building.
- 50% of the material credits based on embodied CO_2 and energy.

Structure should be achieving a higher score than is currently demonstrated.

The previous section showed a consistently low contribution of the structure and materials to the final score in rating schemes. Because of this, the structural and material contributions to the life cycle of a building were investigated in terms of cost, CO_2 emissions and energy use.

5.1 Cost

Trade associations in the UK such as the SCI (Steel Construction Institute) and the Concrete Centre publish studies of typical buildings in the UK. Data from such studies indicate that the structure is responsible for the following percentages of the total project cost and the total cost of materials installed on a project:

How much of a project cost is structure?				
	range			mean
Concrete Centre[23]	10%	to	16%	12%
SCI[24]	8%	to	16%	11%

How much of a project's material cost is structure?				
	range			mean
Concrete Centre	23%	to	38%	27%
SCI	17%	to	31%	23%

In the LEED scheme, the total materials cost of a project is often taken as the default value of 45% of the total construction cost. From the Concrete Centre and SCI studies, the data showed that this was a reasonable estimate.

Some schemes such as DGNB (and BREEAM 2011) provide credits for whole life costing. It can be seen from the tables above that the structural material cost generally contributes to approximately 12% of the total project construction cost. The total life-cycle cost of the building can be around 2-4 times greater than the initial construction cost including soft facilities management costs. The structure will contribute little to costs incurred after construction, as the life of the components is typically longer than the life-cycle cost period. It can be deduced that as a percentage of the total whole life cost of the project, the structure may comprise 2-7% with a mean of around 4%.

5.2 Climate change & CO_2

Avoidance of climate change is only one aspect of sustainability covered in the rating schemes. It is nevertheless a very important one. Climate change will impact on all aspects sustainability: economic, social and environmental. CO_2 is the most significant climate change gas associated with building structure.

The structure of a building influences the emission of CO_2 in 3 ways:

- The embodied CO_2 of the structural system itself throughout the building life cycle.
- The embodied CO_2 of finishes and materials used for space planning throughout the building life cycle (structure may reduce the need for finishes)
- The operational CO_2 emitted during use of the building (structure can provide fabric energy storage and facilitate efficient ventilation and lighting)

The second two points are taken as indirect effects in this study and are discussed in section 2.1. To further investigate the first aspect, a study of the whole life CO_2 emissions associated with a building provides some insight into the relative importance that structure should have within the credits.

Whole life CO_2 emission studies will be very context-sensitive. The energy use in buildings, and the CO_2 intensity of these operational impacts, will vary with different countries and climates. A study[25] of 73 buildings in 13 countries found that office buildings in tropical zones consumed between 1.5 and 3 times more energy than those in temperate zones. Embodied CO_2 levels have been found to be similar for buildings of similar form but different end uses[23]. The same is not true for operational impacts of buildings with different uses.

UK case studies: method

A simple study explored the potential differences in publicly reported figures regarding the relative importance of building structure compared to building operation. Data was drawn from the Arup embodied impact database, a review of published CO_2 values[17,34, 26] and Arup building monitoring measurements. The findings were used to create 60-year CO_2 profiles for the study buildings in a UK context. The profiles simply combined low, mean and high values of operational and embodied CO_2 to create different scenarios. A small allowance was made for recurring embodied emissions based on published papers[27,28,29]. In all, more than 100 data points were included.

The data chosen was most relevant to the study scope. The data:

- Covered a range of calculation methods for both operational and embodied emissions;
- Included city-centre and green-field developments;

- Represented current good practice or better (as the buildings defined in the study scope will be aiming for a green building rating);
- Included the operational impacts of relatively recent new build or recently refurbished office buildings in the UK.

Two different boundaries for the operational energy were used:

- Regulated energy use at design stage – the energy used to provide space heating and cooling, hot water and most lighting, as set out in Part L1A of the UK Building Regulations.
- Measured energy use in practice – actual measured data covering both the regulated energy use and unregulated energy use associated with appliances and computers.

The base values derived from the project data and used to create the scenarios are in Table 4 below.

Table 4: Base case data for 60 year CO_2 profile scenarios

	initial embodied kg CO_2/m^2	embodied structure $kgCO_2/m^2$	recurring and other embodied $kgCO_2/m^2$	regulated operational $kgCO_2/m^2/yr$	measured (total) operational kg $CO_2/m^2/yr$
Low	250	97	50	14	42
Mean	392	226	78	33	106
High	763	353	153	73	190

Additional scenarios were created from the low and mean measured energy data which considered grid de-carbonisation, based on a model for 80% de-carbonisation of electricity supply between now and 2050, supplied by the Committee on Climate Change[30]. This included assumptions about the split between electrical and thermal demand.

These 'real life' scenarios take account of the total CO_2 emissions including appliances, changes in electricity generation and successful incentives. Lower-bound and mean-operational scenarios were used, recognising that appliance efficiency will improve through legislation and behaviour will change. These likely changes are discussed in published documents such as the Fourth Carbon Budget[31] and the Innovation and Growth team recommendations to Government[32]. Also a progressive reduction in operational impacts is very likely after periodic refurbishment

Results

Figure 22 provides an overview of the proportion of life cycle CO_2 attributable to structure. The values range from 5% to 20% with a mean value of 14% for scenarios based on regulated operational CO_2. This measure of operational CO_2 is the basis of the main BREEAM energy credit and hence these scenarios may be most relevant to consider BREEAM score weightings.

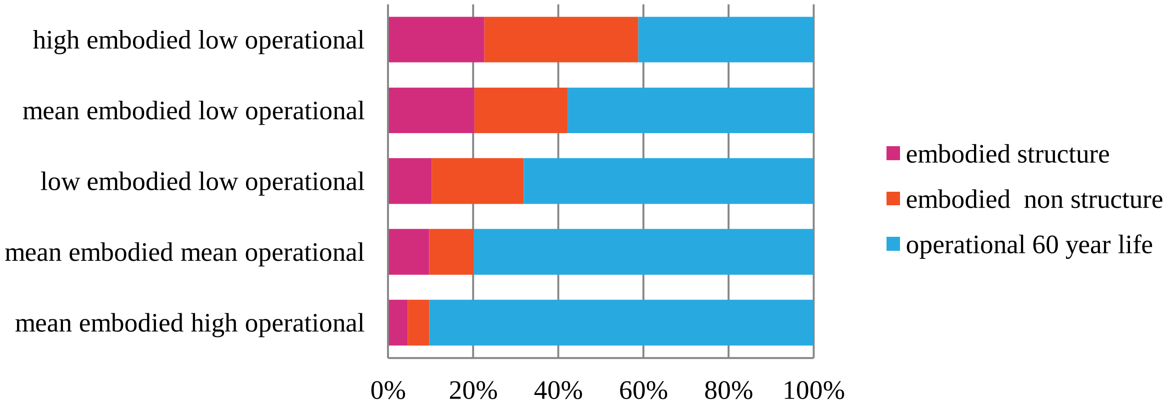

Figure 22: 60 year CO_2 profile, regulated energy (calculated)

The ‘more realistic’ or ‘more holistic’ scenarios for high performing buildings are shown below. For these, the embodied CO_2 of structure ranges from 9-19% of the total 60 year profile, as shown in Figure 23.

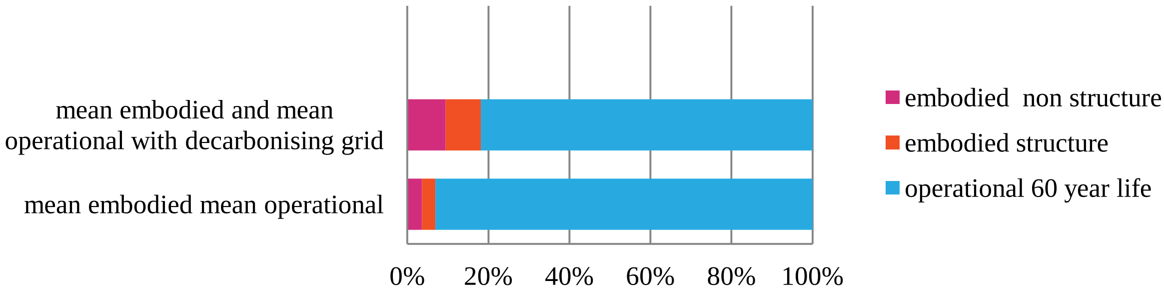

Figure 23: 60 year CO_2 profile, Regulated and unregulated energy (total measured) with de-carbonised grid

Comparison of results with other studies

The results can be compared with CO_2 profiles presented elsewhere. The RICS ‘Redefining Zero’[33] report shows total embodied impacts ranging from 50 – 90% of the regulated CO_2 footprint of a building as we move towards zero carbon buildings. This report omits sources of un-regulated consumption, such as appliances.

C. Jones[34] summarises studies that report embodied CO_2 emissions as 30% of the total life cycle CO_2 for offices including appliances and other un-regulated emissions. The buildings included steel, concrete and masonry construction. He strongly recommends that changes to the CO_2 intensity of the electricity grid are included in whole life studies. He confirms the results of many studies that building structure can be assumed to be roughly 50% of the total embodied impacts.

An alternative approach is to consider a broader boundary, rather than studies of individual buildings. The Innovation and Growth team report to Government[35] estimated CO_2 emissions that the construction industry could influence. The results are summarised in the table below. This would set the embodied vs. operational split as 83:17. If structure is 50% of these emissions, the structure would influence 8.5% based on 2008 operational performance levels. This confirms the findings shown in Figure 23.

Table 5: UK CO_2 emissions influenced by construction (2008)

Subsector	**% of total CO_2 influenced by the construction sector**
Design	0.5%
Manufacture	15%
Distribution	1%
Construction	1%
Operation	83%
Refurbishment/demolition	0.4%

Discussion

The data represented relatively new buildings. There can be a large difference in the actual compared to predicted energy use in these buildings[36]. In addition to grid decarbonisation it is likely that further demand reduction will occur with respect of operational emissions at the first refurbishment point due to:

- Technology improvements in plant and controls.
- Changes in monitoring, reporting, management and behaviour.
- Changes in plug-in technology e.g. 'standby' etc.
- Changes in office culture affecting occupancy densities
- Energy price changes and rent price increases which will drive these improvements
- Legislative incentives.
- Technology change away from heating using on-site combustion (e.g. gas/oil/biomass) to electricity (e.g. heat pumps) as grid decarbonises and energy prices change.
- Percentage of on-site renewable generation.

This means that the lower operational scenarios are more likely to be realistic. It is possible that the upper-bound embodied and recurring embodied CO_2 emissions used in the scenarios may be a little low. For the purposes of this study all these factors make the predicted structural proportion low and conservative. This is confirmed by reference to other studies.

It should be noted that the study buildings are relatively undemanding structures – if major basements or taller buildings were included, the embodied proportion would be higher. The exception is with regard to tropical climates. In this case the embodied proportion would be lower, due to much increased use of air-conditioning.

In BREEAM the largest allocation of CO_2 related credits are based on calculated emissions (omitting appliances) and hence these are the values most relevant to the comparison. BREEAM also encourages the reduction in un-regulated emissions through credits for energy monitoring and efficient equipment. However the credit weighting for these actions is much smaller.

Conclusion

Each individual scenario is somewhat simplistic. However, taking the scenarios as a whole a picture of the relative importance of materials and structure emerges, attracting from 5-20% of the total lifecycle carbon emissions. The data suggests that, taking climate change as a significant concern, actions related to structure should attract a higher credit weighting than the typical 5% value currently gained in the rating schemes.

Changes to operational CO_2 are likely to occur in different ways around the world, dependent on regional priorities. For example, in the UK, Building Regulations are setting progressively stricter targets for operational impacts.

Changes to embodied CO_2 are harder to predict. For materials, existing incentives include the need to provide cost effective structural solutions, and the effect of CO_2 regulations on raw material suppliers. However there are few direct incentives for structural engineers to reduce embodied CO_2 of structures, as many CO_2 reduction measures are cost neutral. For this reason, rating schemes need to increase the incentive to clients for requesting a low embodied CO_2 solution.

5.3 Other Embodied Impacts

As power supply becomes decarbonised, or security of energy supply becomes a more pressing subject, the 60 year embodied energy profile will become more important. The embodied carbon scenario study presented above was repeated with different data sets using energy instead of CO_2. Data was drawn from a study of the operational impacts of LEED rated buildings[37], and the work of Fernandez[38]. The data-sets for energy, shown in Table 6, are unrelated to those used to study CO_2 on the previous page. However the results, shown in Figure 24 are remarkably similar to the embodied CO_2 profiles.

Table 6: Base case data for 60 year energy profile scenarios

	initial embodied energy GJ/m^2	recurring and other embodied energy GJ/m^2	operational energy GJ/m^2/yr
Low	5	1	0.25
High	15	3	1.10
Mean	10	2	0.61

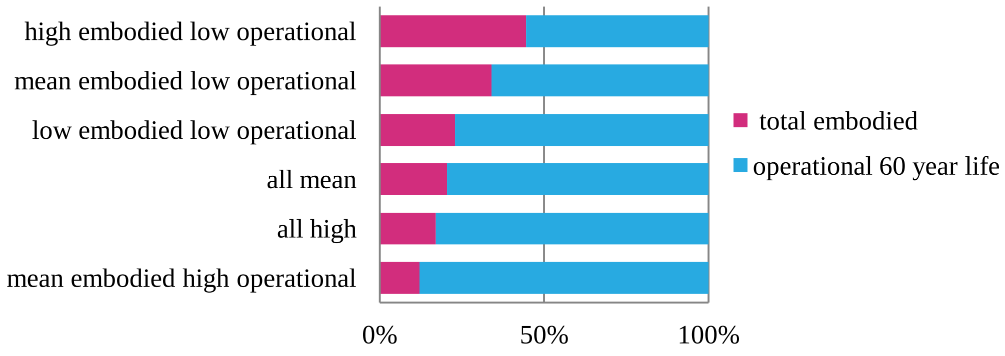

Figure 24: 60 year energy profile

Results

Structure can be assumed to represent ~50% of the initial embodied energy of a building and roughly 15% of the total 60 year profile. Interestingly, the LEED study found that some LEED platinum buildings in America had much higher operational impacts in practice than expected and would only achieve the mean operational values in the Table 6 above.

Comparison of results with other studies

The energy profiles can be compared to the study of 73 whole life energy case studies from 13 different countries between 1993 and 2009[25]. The studied buildings were of timber, concrete and steel, with a variation in the scope of the emissions included. The study showed that 'operationally self sufficient' buildings had higher life cycle energy than 'low energy', providing evidence that embodied impacts should be optimised as well as operational ones.

For offices the embodied energy was found to be 10-20% of the lifecycle energy, in line with our study above. The energy-use recorded for offices ranged from 1-2GJ/m^2/yr primary energy. These values fit with the high operational energy scenarios in the study.

Conclusion

The study of energy profiles shows that the initial embodied energy can account for 10-20% of the lifecycle energy of office buildings. This also suggests that materials should receive a higher weighting within rating schemes than is currently available.

5.4 Summary of contribution of structure

The sub sections above show that structure would be expected to contribute:

- at least 12% of the credits associated with initial impacts, based on cost
- around 50% of materials credits based on CO_2 and energy.

- 5% of credits associated with lifecycle, based on costs
- 8.5% to 15% of credits associated with lifecycle CO_2
- 10 to 20% of credits associated with lifecycle energy
- up to 90% of credits in terms of building material masses or volumes[39].

Project data presented in section 4 shows that structure is not achieving these proportions of the scores in building rating schemes. It is acknowledged that building rating schemes measure a broad range of sustainability issues, and that structural engineers can play a role in minimising impacts beyond the structural elements themselves. However the conclusion is that structure is relatively under-represented in the schemes.

The relevant credits constitute more than 5% of the **available** score, but the data shows that even high scoring projects are consistently **underachieving**. The rest of the report will consider how the available credits could be more effective.

Recommendation 5.1

Rating schemes should be providing a higher level of incentive to reduce impacts of structure than is currently demonstrated

This could be done through the use of minimum standards in the material related credits for high scoring buildings, an increased weighting for the materials section of the scheme, or a change in the content and wording of the credits themselves.

6 Detailed review of credits by topic

The following sections review some of the study credits and considers if the credits are effective. Recommendations suggest what could be changed to make them more effective in an aspirational rating scheme.

The following topics are covered:

- Reuse
- Portland cement reduction
- Recycled content
- Responsible sourcing (including certified timber)
- Local Sourcing
- Life Cycle Assessment (LCA)
- Efficiency & Future Proofing
- Health Implications

For each topic the sections consider what the credits measure; the relevance of the credit for structural engineers and how the credits work in practice. This is used to assess the effectiveness of the credit, measured against the framework in section 1.2.1.

The relevance of the credits to local priorities was also considered. In the UK, for example, rating schemes should provide incentives for building clients to contribute to the Government 'strategy for sustainable construction' [40]. This includes targets for LCA, responsible sourcing, waste and climate change.

Strategy for Sustainable Construction[40] 'To develop means of improving access for designers to product Life Cycle Inventory information.' '25% of products used in construction projects to be from schemes recognized for responsible sourcing.' 'By 2012, a 50% reduction of construction, demolition and excavation (CD&E) waste to landfill compared to 2008.' 'Reducing total UK carbon dioxide (CO_2) emissions by at least 60% on 1990 levels by 2050 and by at least 26% by 2020. Within this, Government has already set out its policy that new homes will be zero carbon from 2016, and an ambition that new schools, public sector non-domestic buildings and other non-domestic buildings will be zero carbon from 2016, 2018 and 2019 respectively.' '15% reduction in carbon emissions from construction processes and associated transport compared to 2008 levels.'

Recommendation 6.1

Credits should be provided for actions which support change across industry as well as an improvement in the sustainability of the project.

7 Review of reuse credits

Reuse of buildings and elements should be rewarded by rating schemes. However the approaches in BREEAM and LEED did not seem as effectively drafted as the approaches in other schemes.

Reuse should be rewarded in two ways; the avoided impacts of re-used elements should be recognised. In addition an innovation credit should be available for re-use of elements such as steel, where the project is helping to build capacity in the supply chain and demonstrating the feasibility of the approach.

The topic of reuse was covered in most of the ratings schemes, either at a material or element level.

7.1 Reuse of Building

Examples of credits covering reuse of structure & façade are summarised below. The new BREEAM 2011 scheme is targeted at new construction only, and these credits have been removed. A separate refurbishment version of BREEAM is expected in the near future[41].

The schemes measure building element reuse using volume, mass or area. In terms of minimising material impact & cost, the volume of material seems the most appropriate measure. In terms of the utility to the client, the area provided by reused components seems more appropriate. These credits, particularly reusing the structure will have a large impact on the structural engineer if they are being pursued as they will affect all other aspects of the project.

Reuse Structure					
BREEAM 2008	**%**	**LEED**	**%**	**GREENSTAR**	**%**
Reuse of Structures	1.0	*Building Reuse Walls, Floors and Roof*	1.0	*Building Reuse*	2.5
> 80% (by volume) of existing structure reused without significant strengthening (>50%) or alteration • reused structure should comprise > 50% (by volume) of the final building.	Mat1	Percentage reuse by area, 55-95% (1-3 points). Credit not applicable if project includes an addition that is more than 2 times the area of the existing building.	Mr1.1	Reuse 30-90% of existing building by volume (2-4 points)	Mat 2
ESTIDAMA PBRS	**%**	**HK BEAM**	**%**		
Building Reuse	1.1	*Building Reuse*	1.1		
A portion of the building structural system, by surface area, is reused •1pt: at least 25% •2pts: at least 50% Building reuse measured as a % of total surface area of existing structural system	SM-7	•Reuse of at least 30% (1pt) or 60% (2pts) of existing sub-structure/shell (by weight or volume) •bonus pt for 90%	MA 1		

Reuse Facade					
BREEAM 2008	**%**	**LEED**	**%**	**GREENSTAR**	**%**
Re-use of building façade	1.0	*Building Reuse Walls, Floors and Roof*	1.7	*Building Reuse*	1.3
• At least 50% (by area) of the total final building façade is reused. • At least 80% (by mass) of the reused façade comprises in-situ reused material.	Mat 3	Percentage reuse by area, 55-95% (1-3 points). Credit not applicable if project includes an addition that is more than 2 times the area of the existing building.	Mr1.1	Reuse 60-90% of existing façade by area (1-2 points)	Mat 2

7.1.1 How does the credit affect structural engineers?

In general the survey respondents felt that even when there was a building available to reuse, these credits were not regularly achieved. This view is confirmed by the project score data presented in Section 4 which showed that for BREEAM and LEED projects, re-use of structure or facade gained an average of only 0.1 – 0.2% of the achieved score. Survey responses for the Estidama PBRS scheme and Hong Kong BEAM also raised a relative lack of popularity/relevance of refurbishment in the region.

A detailed review of Arup high scoring refurbished BREEAM buildings showed that a re-used structure may not be submitted for this credit. Instead the reused structure may be used to achieve the waste credit for avoiding primary aggregate, regardless of the structural material of the existing frame.

Survey participants were asked to select which strengths and barriers, from a predefined list, were applicable to this credit:

		% of respondents agreeing			
	BREEAM Building Reuse Credit	**40-60**	**20-40**	**20-40**	**40-60**
Strengths	It rewards sustainable actions				
	The measure is simple and clear Encourages the development of good practice Cost saving or neutral Impacts positively on whole design				
Barriers	Conflicts with other design parameters Effort to achieve is not proportional to reward Resistance from design and procurement team				
	Technically difficult				

Opinion on these credits is divided. While most people feel that these credits reward sustainable actions, not everyone felt it was an action that should be rewarded in a rating scheme.

"It is very strange to me to have two credits that only apply to a very specific situation. I guess they are trying to reward/encourage reuse but often this is not practical or appropriate to the project." (BREEAM)

Comments suggested that relevant decisions were made early in the project, usually by the client and therefore there is little the design team can do to influence the outcome.

"Building and material reuse can be very owner driven." (LEED)

In addition, some questioned whether retaining a façade was actually a sustainable action, or one within control of the design team.

"Reuse of a building façade is very rarely a sustainable construction decision. It's a planning decision. It would be interesting to know which was better from long term energy in use view: an old façade vs. new super insulated facade." (BREEAM)

Retaining the existing façade and still meeting the energy efficiency requirements is likely to be a significant challenge and may require a large quantity of additional material.

In a number of regions there is a dedicated refurbishment version of the rating scheme available which focuses on upgrade of the building performance. The credits listed above are therefore only available to a sub-set of those projects which include a major structural refurbishment or a combination of new-build and element retention.

In LEED and BREEAM the credits are not available when reuse is combined by a significant extension of the building or significant alteration. These additional restrictions seem questionable. For large projects the impact of the material that is saved may still be significant & could be measured in absolute terms using tonnes or volume of material reused. Green Star and HK BEAM measure reuse as a % of the existing materials saved. Green Star also allows the re-use credit to be excluded if the building is on a Greenfield site.

With the exception of Hong Kong BEAM the credits did not address re-use of foundations. For congested city centre locations this is a major omission. These elements are the least likely to be recycled and can represent a high impact use of materials.

7.2 Material Reuse

Examples of credits covering materials reuse are summarised below. These credits are for incorporating re-used materials and elements into new construction. These materials may be sourced from elsewhere and in many cases cover both structural and non-structural materials. In this context ‘reused’ materials implies that the material has not undergone significant re-processing. This differentiates reuse from recycling.

Reuse Materials					
CHINA 3 STAR	**%**	**LEED**	**%**	**ESTIDAMA PBRS**	**%**
5.4.12	1.8	*Materials Reuse*	1.8	*Material Reuse*	0.6
The utilization rate for reused building materials shall be greater than 5%		• Sum of salvaged, refurbished or reused materials must be at least, by cost, 5% (1 point), 10% (2 points), of the total value of materials on the project. • Mechanical, electrical, plumbing and speciality items cannot be included. Include only materials permanently installed in the project.	Mr 3	Total material cost of reused and salvaged materials represents 3% of the total material cost	SM-8
				BREEAM	**%**
				See RESPONSIBLE SOURCING	

The rating schemes all use different reference measures: volume, mass or cost. The use of cost as the measure in LEED may prove a disincentive. The cost of the material may not reflect the cost of design, procurement & construction effort involved in sourcing reused structural materials. In BREEAM re-used materials also earn credits for being responsibly sourced and could help to achieve LCA based score.

7.2.1 How does the credit affect structural engineers?

The survey indicated that the structure does not commonly contribute to scores under these credits.

“Of structural materials, steel lends itself more easily to winning a re-use credit, though this has in fact hardly been achieved through structure.” (LEED)

Data from LEED projects showed material reuse scores for all materials varied from 0.06% of the achieved total for certified buildings sharply increasing to 0.7% for platinum buildings. The same sharp increase in the score for platinum buildings also occurs for the rapidly renewable materials credit. This may indicate that the strategy for architectural elements changes for platinum buildings and that the re-use credit is most likely achieved with non-structural materials.

“The intent is generally perceived as at odds with the professional high spec corporate finish that many projects are striving.” (LEED)

7.2.2 How does it work in practice?

Survey participants were asked to select which strengths and barriers, from a predefined list, were applicable to this credit:

		% of respondents agreeing			
	LEED Material Reuse credit	**40-60**	**20-40**	**20-40**	**>40**
Strength	It rewards sustainable actions Encourages the development of good practice				
Strength	The measure is simple and clear Cost saving or neutral Impacts positively on whole design				
Barrier	Unable to source Too expensive Resistance from design and procurement team				

Similar to building reuse, mixed opinions were found with this credit. While it was considered sustainable, practical barriers were defined.

"...it is quite difficult if it is large scale project. " (China 3 Star)

Reuse of structural materials sourced from outside the project is very challenging due to the lack of a high volume supply chain.

Research into the re-used steel supply chain in the UK, shows that it is more practical to source smaller quantities of re-used steel (e.g. equivalent to a portal frame shed) than to achieve a particular percent reuse level for an office building.

When trying to source reclaimed timber and brick for the BedZED[42] project, it was found:

"Many smaller yards were unable to cater for the large scale of supply."

"The possibility of reclaimed bricks was explored but rejected as the costs would be twice the price of new for an inferior product."

Hence target levels based on a proportion of the total building materials are very optimistic for larger buildings. This bears no relation to the reality of industry practice. Price may be highly variable and linked to scarcity and effort rather than value or impact so linking credits to cost may not be a good indicator of sustainability.

In conclusion none of the 'reuse materials' credits seem well aligned with current best practice achievable levels for structure.

7.3 Effectiveness of Reuse Credits

All reuse credits have a low take-up. Practical difficulties, lack of availability and conflict with other criteria are likely reasons. Even where structural elements of buildings are refurbished, the credits are not always gained.

In terms of providing an incentive for sustainable **actions,** re-using structure in-situ, or sourced from elsewhere, will represent a significant positive action. The action would reduce impacts from production of new materials and contribute to Government targets to reduce demolition waste, such as those from The UK

Government strategy: *'By 2012, a 50% reduction of construction, demolition and excavation (CD&E) waste to landfill compared to 2008.'*

However the impact on a project of decisions to re-use structure is so large that it is unlikely that a rating scheme score will be sufficient to affect behaviour.

Recommendation 7.1

Retention of existing building structure should be rewarded.

Foundations represent a significant proportion of a building's impacts. These are also less likely to be extracted and the material recovered for recycling. Therefore the reuse of foundations would improve the sustainably of a project.

Recommendation 7.2

Credits relating to re-using substructure should be developed.

In terms of providing a **measure** of the sustainability of the building for the client, reuse credits should recognise the avoided impacts from the re-used elements that are included in the building whilst ensuring that perverse incentives for poor overall performance are not created with respect to façade or future flexibility.

Recommendation 7.3

An innovation credit should reward changes to industry practice with regard to reused materials supply chains.

Recommendation 7.4

The avoided impacts of re-used and retained elements should also be recognised in assessments such as LCA or material efficiency.

In terms of providing a **practical tool** or a **framework** to define sustainable practices, the credits would be better if targets were adjusted to recognise the realities of the supply chain with respect to re-used structural materials, to remove disincentives for large developments. This topic provides an example of the recommendation in Section 3 with regard to excluding irrelevant credits. Credits for retaining existing structure should be excluded from the scoring for Greenfield sites.

Detailed recommendation 7.5

Targets should be based on the percentage of floor area of the existing structure that is retained. The minimum qualifying area should be a low percentage of the whole development (10% is suggested).

8 Review of Portland cement reduction credits

Reducing the Portland cement content of concrete produces a significant reduction in CO_2 emissions from construction with negligible knock-on effects to other elements.

Direct rewards for this action must be included in building rating schemes. This could form a pre-requisite for an LCA credit. However this should not demand an LCA in order for credit to be achieved.

A number of the schemes studied had credits specifically for the reduction in the use or impact of cement in concrete.

What do the credits measure?

Cement Replacement					
GREEN MARK	**%**	**ESTIDAMA PBRS**	**%**	**GREENSTAR AUS**	**%**
Sustainable Construction	0.4	*Recycled Materials - Cement replacement*	1.1	*Concrete (Draft)*	1.3
Replace OPC with green cements for at least 10% by mass for superstructure works	NRB 3-1	Demonstrate that the project has reduced the overall amount of Portland cement used and associated embodied GHGs	SM-10	Reduce Portland cement content by 30% (1 point) or 40% (2 points)	Mat 5

They all measure the reduction of the impact of Portland cement, however different methods are employed. Estidama PBRS gives embodied carbon targets for different types of concrete, the draft Green Star credit provides maximum Portland cement contents across a range of strengths and Green Mark requires a benchmark level for the project to be defined.

8.1.1 What is the relevance of the credit for structural engineers?

All of these credits include structural concrete within their boundary, with the Green Mark credit focussing purely on the superstructure of the project. Therefore the structural engineer can make a significant contribution to the gaining of this credit. In addition a cement replacement credit was included in the bespoke BREEAM assessment for the London 2012 Olympics

8.1.2 How does the credit work in practice?

The Singapore replacement levels are not very challenging in technical terms for many in-situ structures. Also the credit is worth only a maximum 0.4% of the overall score. Part of the difficulty for Green Mark may lie in adopting an overarching average replacement level for superstructure. The other schemes recognise the different opportunities with in-situ, precast and prestressed concrete.

Their impact is minimal, for example GGBS cement replacement is only required for 10% of structural elements, in the overall pictures this has almost no effect. (Singapore Green Mark)

Green Mark only considers the superstructure concrete. It would be better, and practically possible to also address the substantial amount of concrete in underground structures and foundations.

It is also true that the lower replacement levels required for Green Star would not be very challenging for suppliers who use GGBS as the replacement material in in-situ concrete. However GGBS is limited in supply in some places and the credits must also recognise the valuable contribution that other replacement materials such as fly ash can make to reducing Portland cement levels. In some regions fly ash is more likely than GGBS to become a waste and hence the credit levels should not exclude the use of fly ash even though it can only replace a smaller percentage of Portland cement than GGBS.

This example serves to show that the detail of these credits is important. It has been found that specifying a secondary cementitious replacement percentage may not be sufficient to ensure a sustainable outcome. Suppliers may respond by increasing the overall cementitious content in order to achieve the original volume of Portland cement. This is an undesirable outcome and the phrasing of the Estidama PBRS and Green Star credits recognise this: *'Reduction in absolute quantity of Portland cement'.*

8.2 Effectiveness of Portland Cement reduction credits

In terms of providing incentives for sustainable **actions** these credits target a reduction in a material which is a significant contributor to the emission of CO_2. In some circumstances the credit may also provide an incentive to incorporate a waste material. Therefore a Portland cement reduction credit should be included in an aspirational scheme; however the detailed wording of these credits is important.

In terms of providing a comparable **measure** of the sustainability of buildings, this credit cannot be seen as a 'stand alone' measure as it only applies to one material. Combined into a rating scheme score as a whole, the credit definitely contributes to demonstrating the overall sustainability of the project. It will be important however to included the substructure in the measure to ensure the rating scheme is having as much impact as possible.

Recommendation 8.1

Absolute reduction in Portland cement levels in structural concrete (including foundations) should be rewarded.

In terms of providing a **framework** to define sustainable design practices for professionals these credits provide a means to demonstrate that good practice has been adopted. These levels can be incorporated into national specifications and industry can work to align itself with the requirements.

Detailed recommendation 8.2

Compliance levels should recognise the different opportunities with in-situ, precast and pre-stressed concrete. Rewards associated with different replacement materials should be included. Over time the CO_2 footprint of the concrete should be used as the method of measurement.

In terms of working as a **practical tool** which can cost effectively be deployed during the procurement of buildings, these credits seem to have set levels which lie within industry current and best practice.

The Portland cement reduction credits provide a simple and effective tool to encourage and recognise a beneficial action. Replacing Portland cement does not generate knock-on negative environmental impacts in other aspects of construction and these credits can usefully be included alongside any more sophisticated approach.

9 Review of recycled content credits

The following chapter indicates that although 'whole building recycled content' credits have a good take-up in the US, this was not found to be a successful approach for improving the sustainability of building structure.

If recycled content credits are included in rating schemes then a response for each of the main structural materials should be considered during credit development. However recycled content credits can generate perverse outcomes for the sustainability of structure.

Recycled content is covered in different ways by the rating schemes.

LEED and HK BEAM provide credits based on an overall level of recycled content for the building. China 3 Star allows the freedom to choose a material to target for recycled content. Other schemes, such as Estidama PBRS and Green Star (South Africa), provide rules for the recycled content of particular materials like steel and concrete. In contrast, BREEAM incorporates recycled content into the responsible sourcing credit, with the exception of recycled aggregates, which is encompassed in the waste criteria.

These different approaches are discussed below.

9.1 Whole Building Recycled Content

LEED and HK BEAM provide credits based on recycled content for the whole building. HK BEAM allows freedom to choose units which suit the project information. LEED uses recycled content by value as a means to combine the data but offers a simplified method for documenting the total material cost.

Recycled Content - General			
HK BEAM	**%**	**LEED**	**%**
Recycled Materials	0.7	*Recycled Content*	1.8
10% recycled materials (measured either by mass, volume or cost but consistently). Points for structure and facade	MA7	Post-consumer recycled content + half pre-consumer recycled content > 10% (1 point), 20% (2 points), of the total materials value (by cost)	Mr4

For the structural materials in the study scope the achievable recycled content will depend on the material:

- For steel it will depend on the local availability of steel produced by electric arc furnace or basic oxygen furnace.
- For concrete it will depend on the local availability of appropriate secondary aggregate and, to a lesser extent, on supplementary cementitious materials.
- For masonry blocks there may be a local choice of recycled content,
- For structural glass it is not possible to include recycled materials due to the risk of impurities.

- The recycled content credit is normally irrelevant for structural timber

For steel, masonry and aggregate long distance road transportation in order to achieve a recycled content credit may not be a sustainable action.

9.1.1 How does it work in practice?

Analysis of LEED project data showed that recycled content scores typically represented 1.6% of the achieved credits. The actual score is largely unchanged from certified to platinum buildings. The maximum available score is about 2%. This either suggests that the credit may be too easy to achieve or that the credit is mature and that industry has responded to the incentive and is aligned with the requirements. The credit rewards both architectural and structural materials and the contribution of structure varies widely. Figure 25 shows the range in the contribution of the structure to the recycled content credit in four LEED buildings

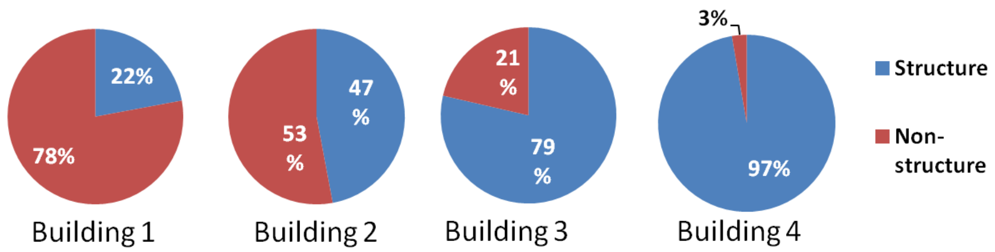

Figure 25: Pie charts for four LEED buildings showing the contribution of structure to the recycled content score.

A detailed analysis of selected LEED projects from around the world showed that the submissions often used the simplified assumption for total material cost and submitted only as much information as needed to meet the target credit level. With this approach the credit does not provide the client with a true measure of the recycled content of their building.

The approach to these credits appears very tactical. In America, contractors have provided ‘top ten lists’ of high cost, high recycled content materials that can be sourced with the appropriate information quickly and easily. Hence the American market has aligned itself with LEED and the credit has provided an effective framework for the project team to work within. In this context a development of the credit to differentiate higher performing projects could be considered.

In other regions the story can be very different and this was born out by the global survey, in which the respondents from the US had a much more positive opinion of the credit than those from other parts of the world. The key differences were found to be around the practicalities of achieving the credit.

Survey participants were asked to select which strengths and barriers were applicable to this credit, from a predefined list:

	LEED Recycled Content Credit Strengths & Weaknesses	% of respondents agreeing: North America	% of respondents agreeing: Elsewhere
Strength	The measure is simple and clear	**80%**	30%
	It is easy to achieve	**80%**	20%
	Cost neutral or saving	**70%**	30%
Barrier	Resistance from design and procurement team	0%	**20%**
	Not enough information available	10%	**20%**
	Measuring the wrong thing or in the wrong way	**20%**	10%

More detailed insights on LEED outside America were offered in respondents' comments. For example:

"..generally targeted by all of our European projects...The hard part of the implementation is collating the data from manufacturers who are generally very unprepared to make official declarations regarding composition or sourcing of their products."

"... unless there is a market for recycled materials you cannot do it. Working in the Middle East skews best practice."

In America steel is readily available with a high recycled content from electric arc furnace which leads to the opinion that the recycled content credit will not generate any change in the sustainability of the structure and that the credit favours steel:

"...LEED often rewards conventional practice. It seems to favour steel structures because of the credit for recycled content. "

"The single recycled percentage threshold is not responsive to actual material recycled content, such that structural steel, which represents no improvement to industry norms, can overwhelm the calculation ..."[43]

"There is actually a 3rd option in LEED for concrete that allows one to use the secondary proportion of total cementitious materials as the % RC of the concrete. However, these somewhat equalizing opportunities are not well known."

Responses from other regions also questioned if this credit provides incentives for sustainable actions with regard to structure. Depending on the local supply chain the view about steel will vary:

"[On] European projects ... at least one point is usually achieved without any extra thought being given to material selection."

"The total insanity of trying to get steelwork with a high recycled content from a fabrication yard within a certain radius of the site is counter-productive in terms of getting sustainability into buildings. It simply makes the designers believe that the whole sustainability debate is a farce, whilst simultaneously making it difficult to make genuinely more sustainable design decisions."

In summary the concept of a whole building recycled content credit is generally well received. However there is evidence that it is making very little positive **impact** on the sustainability of the structure which represents a very high proportion of the mass of the materials deployed, as stated in section 5.

The rating schemes which provide credits tailored to the individual structural materials are discussed in the following sections.

9.2 Single Material Recycled Content (China 3 Star)

Recycled Content	
CHINA 3 STAR	**%**
5.4.10	1.8
Under the condition of ensuring performance, the consumption of the building materials made of waste shall make up not less than 30 % of the consumption of the same kinds of building materials	

The China 3 Star credit is unusual in that it does not target a whole building measure, neither does it set levels for particular materials such as aggregate; you have to choose one material and satisfy the criteria for this material, however this could be a material which only makes up a small proportion of the volume of materials used.

The China 3 Star system is interesting for structural engineers because unlike LEED, Green Star and BREEAM there are mandatory minimum credit levels designated for materials. This means that the 3 Star credits have to be worded to be applicable to a large range of buildings. It appears to recognize that the practical, sustainable level of recycled content will vary for different materials and location. The strength of this approach is that the principle of including recycled material is promoted across the whole design team. The weakness may be that it can be approached cynically, allowing one to select a material of small volume or a material for which the 30% threshold is merely business as usual.

9.3 Aggregate

Credits for recycled aggregates are included in BREEAM, Green Mark and Estidama PBRS. The topic is also included in the draft revision of Green star's concrete credit.

Recycled Content - Aggregate					
GREENSTAR AUS	**%**	**GREEN MARK**	**%**	**ESTIDAMA PBRS**	**%**
Concrete (Draft)	0.6	*Sustainable Construction*	1.7	*Recycled Materials - Recycled aggregates*	1.1
EITHER 40% coarse aggregate replacement OR 25% fine aggregate replacement	Mat 5	Coarse Tonnes RCA > 0.03x(GFA in m^2) Fine Tonnes Washed copper slag > 0.03x(GFA in m^2) up to 4 points for each if this is doubled up to a maximum of 5 points	NRB 3-1	1pt: 15% recycled aggregate (by volume), in structural and non-structural applications. 2pts: only recycled aggregates and/or aggregates from industrial waste by-products are used as base, sub-base or backfill	SM-10
BREEAM	**%**				
Recycled aggregates	1.1				
Amount of recycled and secondary aggregate specified is at least 25% (by weight or volume) of the total high-grade aggregate uses for the building.	Wst2				

BREEAM provides a credit which combines all the uses of recycled or secondary aggregate together. For structural concrete in the UK the target replacement level cannot (and possibly should not) be achieved with recycled concrete aggregate.

In the UK this means that the credit is more accessible to:

- projects which do not have a concrete structural frame. This credit is then claimed for the aggregate used in non-structural applications.
- refurbishment projects where the existing building structure replaces the need for primary aggregate for structure.
- projects close to a ready source of secondary aggregate (china clay stent, spent rail ballast or Port Talbot slag).

The use of recycled or secondary aggregates is not always possible due to limited availability and is not always the most sustainable outcome where the materials can be better deployed in other applications. In addition, suppliers may increase the Portland cement to reduce perceived risks associated with secondary or recycled aggregate, which may result in an increased embodied CO_2 value for concrete.

Different approaches to secondary aggregate should be taken with regard to course vs. fine proportions, and structural vs. non-structural applications. Hence for BREEAM the credit is not well aligned with practical issues related to structural concrete and may be creating unexpected results which, in the case of increased embodied CO_2 of the concrete are probably more damaging to the environment than the use of primary aggregate.

The survey results tended to confirm this view. Here are the respondents' selections from the predefined list of strengths and barriers of credits:

		% of respondents agreeing			
	BREEAM Aggregate Credit	**>40**	**20-40**	**20-40**	**40-60**
Strengths	Encourages the development of good practice Does not impact on other aspects of the design It rewards sustainable actions The measure is simple and clear				
Barriers	Effort to achieve is not proportional to reward Too expensive Measuring the wrong thing/in the wrong way				
	Unable to Source Resistance from design and procurement team Does not respond well to my regional context Technically difficult				

Many respondents added comments demonstrating the strength of negative feeling about the BREEAM aggregate credit. These were fairly consistent and covered unhappiness with cost, transport, wording and inappropriateness of the credit when applied to structural concrete.

Respondents also noted that aggregates were plentiful in the UK and that recycled aggregates were more efficiently and sustainably deployed in other applications. Respondents went on to call for a concrete credit which instead focussed on reduction of Portland cement. This is discussed in more depth in section 8.

"It is almost impossible to commercially achieve credit... unless you have lots of hard landscaping to do the % is too high for concrete and misses the opportunities in cement replacement measures which arguably have a much higher impact on sustainability"

"There is some benefit to reduction in waste but aggregates are plentiful in the UK so the impact on resource depletion is... insignificant."

Each of the other ratings schemes studied has a different approach to the recycled aggregate credit:

- Estidama PBRS adopts a similar approach to BREEAM; however, there are separate targets for different applications. (15% structural & non-structural, 100% base and fill)
- The draft Green Star credit stipulates either a coarse (40%) or fine (25%) aggregate replacement; also this is linked to requirements regarding Portland cement content.
- Green mark has a different metric which relates the amount of aggregate replacement to the gross floor area. It is difficult to compare to the replacement levels in the other schemes. It also specifies the type of secondary aggregate to be used.

These approaches address some of the shortcomings apparent in the BREEAM credit. They also demonstrate regional differences which are to be expected, given the local nature of the supply chain for secondary aggregate.

The survey response to these three schemes was noticeably more positive than the reaction to BREEAM. The concerns that were raised were associated with regional supply and uncertainties associated with technical issues.
Structural engineers tend to be less inclined to use recycled aggregate due to unreliability in the strength of the concrete, so they will not go for this credit. (Australia Green Star)

Structural engineers are a conservative bunch and don't like to do things differently. The use of recycled aggregates and cement replacement very rarely comes up. These are typically used where a supplier can take responsibility for the product (Singapore Green Mark)

In summary this is a topic where technical and supply issues mean that the exact wording of the credit and the regional context is important. Consideration needs to be given to both local availability of secondary aggregates and sustainable, practical levels of inclusion in structural concrete. When viewed against the global demand for aggregate the availability of these materials may be small. However, where such waste streams are available their full use should be encouraged. The potential knock–on effects on the embodied CO_2 of the concrete should be considered.

9.4 Steel

Generally recycling rates for steel are very high indeed (estimated 83% worldwide[44]). The influence of the recycled content of steel in LEED is discussed in section 9.1 above. The topic of recycled steel is also covered explicitly in Estidama PBRS and the South African version of Green Star.

Concerns were identified for Estidama PBRS with regard to regional supply and sourcing. Discussion relating to rewarding steel recycled content in rating schemes can be found in consultation conducted for Green Star Australia, which previously had a credit on this topic[45].

The issues are discussed in a paper in ‘The Structural Engineer’ about sustainable structures in Australia by Simon Jewell[46].

‘One of the primary suppliers of steel sections in Australia, OneSteel does not agree with this differentiation of steel based on the steelmaking method or the level of recycled content as a useful environmental strategy. The application of this approach may create market distortions, environmental inefficiencies and cost impacts within the steel and scrap industries with no net improvement in global sustainability. Specifying a minimum level of recycled content in steel can lead to re-routing of products resulting in increased environmental, freight and cost burdens through the transportation of steel scrap.’

‘The market for steel scrap is already well established, with recycled steel being of great value. So stipulating minimum recycled content in steel products does not drive the recovery of steel materials.’

9.5 Effectiveness of Recycled Content Credits

In terms of providing an incentive for sustainable **actions,** the effect of the whole building recycled content measure is variable. For most of the structural materials in the study scope there is not a genuine local choice of recycled content and where choice does exist it does not necessarily lead to a reduction in the impact of construction as a whole. It may reward business as usual or generate perverse outcomes for the project, or for the broader construction supply chain. There is evidence that including structure (such as electric arc furnace steel in America) provides disincentives to increase the recycled content of non-structural elements where a genuinely sustainable choice exists.

Recommendation 9.1

Super-structure should be excluded from credits which reward whole building recycled content. *(Other means of measuring reduced impact of structure should be deployed.)*

With regard to individual structural materials the use of recycled content as a proxy measure for sustainability is not successful and this action may be better recognised in responsible sourcing and LCA based credits, or through specific credits relevant to the individual materials.

In terms of providing a **measure** of the sustainability of the structure to enable comparison between buildings, the recycled content credits may not provide what clients imagine due to tactical approaches to target levels and differing industry norms. To achieve a reliable measure a simpler reporting mechanism using industry default values would be more appropriate. A tool which provides such a measure is available in the UK from WRAP[47]. This also identifies best practice.

In terms of providing a **framework** to define sustainable design practices for professionals, the recycled content credits have successfully engaged industry in America. They may also be generating an incentive for increased reporting and product development in other regions. Hopefully this initiative will develop into the declaration of other environmental information. However, for structural materials, recycled content credits need to be linked with other requirements in order to prevent perverse outcomes.

Recommendation 9.2

If an individual recycled content for structural concrete is included this should include a pre-requisite to reduce Portland cement content, and practical achievable levels of including a known locally available secondary material in the concrete.

Detailed recommendation 9.3

Individual credits which specifically reward recycled content of steel are not an effective use of a building rating system.

Detailed recommendation 9.4

If an individual recycled content for masonry is included this should include a pre-requisite to avoid significant road transport impacts.

In terms of working as a **practical tool** which can cost effectively be deployed during the procurement of buildings the results depend on the wording and target levels. This is particularly illustrated by the recycled aggregate credit.

The use of recycled or secondary aggregates is not always possible due to limited availability and is not always the most sustainable action where the materials can be better deployed in other applications. Therefore a credit rewarding this action specifically may not be appropriate. It would be more appropriate to recognise the use of secondary aggregates as a form of responsible sourcing, similar to how other recycled materials are recognised in BREEAM.

10 Review of responsible sourcing credits

A tiered approach to responsible sourcing, following largely the approach in BREEAM was found to be an effective way to improve the sustainability of building structure. In the UK this also addresses Government targets for sustainable construction.

At the highest level these credits address impacts of the building well beyond the project boundary and as such these actions should attract high scores relative to other sections of the rating schemes.

Responsible sourcing credits must also provide achievable entry level opportunities, Opportunities for small organisations, and for developing products and supply chains.

Responsible sourcing rewards thoughtful procurement that brings together environmental, social and economic factors throughout the supply chain.

At its lowest level, responsible sourcing may consider only a single process in the supply chain. Reward may be given for the use of an environmental management system such as ISO 14001[48].

At the higher levels of compliance, responsible sourcing addresses the 'off-site' impacts of construction which are ignored in other aspects of building rating schemes. At this level, in addition to reducing the impacts of materials, it will support good employment practice, reduce the impacts of production, extraction or harvesting on surrounding communities, and enforce these practices at all downstream levels of the supply chain. For production activities it can include management of resources, waste, water, energy and emissions. For timber it can include forestry management, impact on local water courses etc. The highest level of responsible sourcing shows consideration of the full life cycle of a material.

All these activities may be argued to be far more significant than some of the site specific aspects traditionally rewarded in building rating schemes such as the recycling space for occupants and areas of green roofs on city centre sites.

10.1 BREEAM Sourcing Credit

The responsible sourcing credit in BREEAM uniquely encompasses topics which are covered by separate credits in other schemes.

> At least 80% of the applicable materials that comprise a number of building elements should be responsibly sourced.
>
> **BREEAM Offices 2008 Mat 5 (2011 BREEAM MAT 03)**

The approach recognises certified timber, products produced under the control of environmental management systems, recycled and re-used materials, and products with sustainable supply chain management certification. Scores differentiate between different levels of compliance with BES 6001: Framework standard for the Responsible Sourcing of Construction Products[49] using a tiered approach to designate the level of responsible sourcing achieved.

This credit has changed and developed in recent versions of BREEAM alongside developing industry standardisation and increased up-take in the UK. The responsible sourcing of materials is an emerging area and as such further evolution and development is expected as it matures.

10.1.1 What is the relevance of the credit to structural engineers?

This is one of the two most frequently targeted credits for structural engineers in BREEAM. In 2008 this credit was worth around 2% of the available score and relative scores for BREEAM 2011 are not expected to significantly change compared to BREEAM 2008[50].

Applicable building elements include structural frame, ground floor, upper floors, roof, external walls and foundation. All the structural materials in the study scope can score points under the responsible sourcing credit. Concrete has been achieving increasing scores in the UK due to industry-wide sustainability initiatives that have been developing in the UK concrete sector. EU and UK Government developments related to timber sourcing are also included in BREEAM 2011.

The survey responses demonstrate a deep understanding of the significance of this credit. Early engagement with sustainable procurement involves consideration of how elements are made as opposed to consideration of performance alone. Results from analysis of BREEAM projects show responsible sourcing is the only BREEAM credit relevant to structural materials that helps to differentiate higher scoring projects from lower scoring ones, as shown in Figure 26.

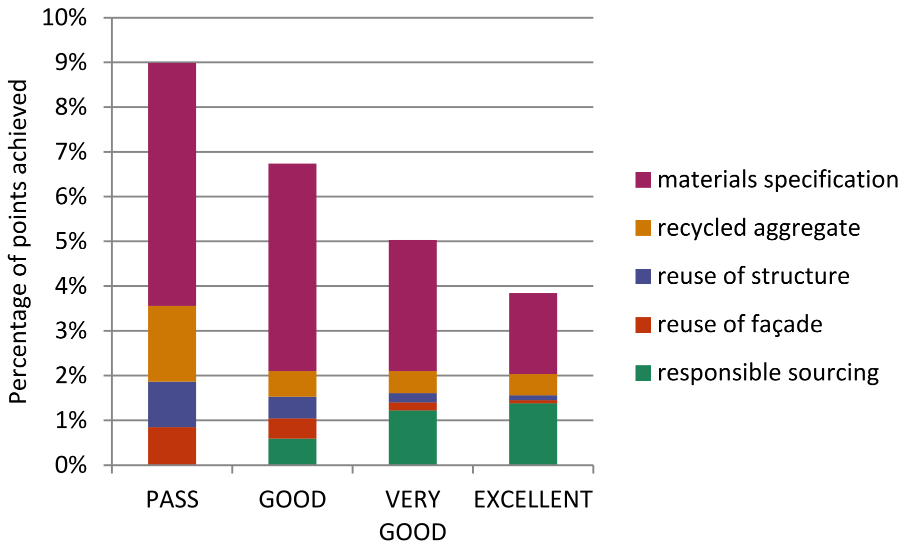

Figure 26 Contribution of BREEAM credits related to structural materials to overall score

10.1.2 How does the credit work in practice?

Here are the respondents' selections from the predefined list of strengths and barriers of the credit:

		% of respondents agreeing			
	BREEAM Responsible Sourcing Credit	**60-80**	**40-60**	**20-40**	**20-40**
Strengths	Encourages the development of good practice.				
	Does not impact on other aspects of the design. It rewards sustainable actions.				
	The measure is simple and clear. It links well to industry practice It is easy to achieve Impacts positively on whole design				
Barriers	Resistance from design and procurement team. Effort to achieve is not proportional to reward. Does not respond well to my regional context. Not enough information available				

This table shows that the credit is generally well received. The negative comments centre on the availability of suitable products and information.

'Collating the evidence can be quite time consuming. The credit is often down to the contractor's choice of where they source their materials.'

'Contractors seem to have a lot of paperwork to achieve the responsible sourcing. I suspect the cheaper subcontractors can't deal with it.'

'Mat 5 should be easy to achieve but often the paper trail is not good enough.'

The industry has been working through a learning curve as the requirements become more defined. This is demonstrated by the higher scoring BREEAM excellent projects where the project team has worked together to meet the requirements of the new framework standard. The early adopters of this approach have tended to be very large companies.

It is possible that over the next 5 years achieving compliance in the UK will become more streamlined. Contractors who have adopted sustainable procurement principles within their organisation will find this increasingly easy to achieve. Although the number of respondents for BREEAM international was relatively few, and the requirements of BREEAM International differ from the UK version, the data indicated regional differences in the attitudes for the following aspects:

	% of respondents agreeing	
BREEAM Strengths & Weaknesses	UK	Elsewhere
Does not impact on other aspects of the design	**45%**	15%
It is easy to achieve	**35%**	0%
Resistance from design and procurement team	20%	**45%**
Effort to achieve is not proportional to reward	20%	**30%**
Does not respond well to my regional context	10%	**45%**
Not enough information available	25%	**45%**

10.2 Timber Credits

For most of the rating schemes timber is the only material which receives credit for responsible sourcing. This is because schemes for timber are well developed globally compared to other building materials.

10.2.1 What do the schemes measure?

DGNB	%	LEED	%	GREENSTAR	%
Use of sustainable resources / Timber	1.1	*Certified Wood*	1.0	*Sustainable Timber*	1.3
If timber is used in the building (site activities are not included in the evaluation), this should come from certified forests and have a Chain of Custody document.	Sb 08	FSC certified > 50% by cost (1 point), of total value of all new wood. Components include, structural framing and gen framing, flooring, sub-flooring, wood doors and finishes. Include only materials permanently installed.	Mr 7	Any combination of reused recycled or FSC (1 point) 50% by cost (2 points) 95% by cost	Mat 8
HK BEAM	**%**	**ESTIDAMA PBRS**	**%**		
Sustainable Forest Products	0.4	*Reused/Certified Timber*	1.1		
> 50% timber from sustainable/recycled timber. (mass/volume or cost but consistent)	MA6	50% (1 pt) or 70% (2pts) by cost of all wood products, including temporary construction timber is reused or certified under given schemes (e.g. FSC, PEFC) AND all timber is legally sourced and not endangered.	SM-12		

The rating schemes all make use of existing timber industry initiatives. The most commonly used are the Forest Stewardship Council (FSC) requirements and Programme for the Endorsement of Forest Certification (PEFC). The BREEAM responsible sourcing credit recognises seven different timber certification schemes and assigns different score levels according to the rigour of the scheme, based on the view taken by CPET[51]. This encourages the certification schemes to develop towards the higher levels of responsible sourcing, whilst also allowing an entry level accreditation. Most rating schemes also include recycled or reused timber as sustainably sourced within the timber credits.

The level of credits available in LEED, Green Star, DGNB and Estidama PBRS are roughly the same, and most of the schemes set an entry level target as 50% of timber. However there is a large variation in the amount of timber required to achieve maximum credits, from 50% to 100%. Most schemes measure percentage by cost.

All rating schemes cover multiple applications of timber including structural, and architectural. However they vary in their incorporation of timber used during temporary works.

When considering the topic of sustainably sourced timber, the rating schemes operate against a developing context, for example the Green Star timber credit has been adjusted to align with the government's evolving definition of best practice in forestry management[52]. The timber certification schemes themselves will develop, as will standards and legislation, such as forthcoming EU legislation in March 2013[53]. Expected developments in all regions concern a ban on purchasing illegally logged timber and the adoption of a broader definition of responsible sourcing, such as that encompassed by the BREEAM credit.

In some regions local policy is serving to encourage a higher consumption of timber in construction, such as the Wood First Act in British Colombia[54] and the BioPreferred Program in the US[55]. This may lead to increased scrutiny of timber sourcing.

10.2.2 What is the relevance of the credit to structural engineers?

For structural engineers the products of relevance are most commonly glue laminated softwood beams, softwood plywood/OSB/chipboard, sawn structural softwood, cross-laminated softwood and timber 'I' joists. In many locations the timber for these particular applications will be sourced from well managed sources and fabricated through relatively industrialised processes. The sustainability issues surrounding these types of elements may be different from the issues associated with timber façade and finishes (which are more likely to use tropical hardwoods).

Timber used in temporary works, however, will include ply and elements which could potentially have come from illegally logged sources[56 57]. To address these issues structural engineers would need to ensure that the requirements for elements such as shuttering are set out in the relevant specifications.

Including temporary works in targets for certification significantly increases the challenge, but has been shown to be possible[58].

10.2.3 How does the credit work in practice?

The credits were generally well received by survey respondents. Here are the respondents' selections from the predefined list of strengths and barriers of the credit:

		% of respondents agreeing			
	All Schemes FSC Timber Credit	**40-60**	**20-40**	**20-40**	**>40**
Strengths	Encourages the development of good practice The measure is simple and clear It rewards sustainable actions				
	Does not impact on other aspects of the design It links well to industry practice Impacts positively on whole design It is easy to achieve				
Barriers	Too expensive Resistance from design and procurement team Unable to source				

The table shows combined global responses for all schemes. Although the FSC scheme is globally administered, the response to these credits will depend to some extent on regional context.

Because structural timber is generally softwood and therefore from plantations (compared to tropical hardwood which is generally from rainforest), a view is often expressed in the UK and Europe that FSC requirements are not very valuable, as the timber is likely to come from well managed sources in any case. Hence the use of certified wood for structure is no longer perceived as being a differentiator for highly sustainable projects.

In contrast, project experience in Africa reveals that certified wood is being exported to the West and hence is too expensive for local use. It also reveals well managed timber sources which do not achieve stewardship certification due to cost and difficulties associated with the certification process.

In America, proposals for improvements in LEED, called for the bio-based origin of timber to be rewarded and for a two tier (responsible sourcing) approach to stewardship certification[59].

This is in line with survey results, where survey respondents raised concerns that FSC was the only system recognised in LEED.

'In the US, most wood is CSA (Canadian) or SFI certified, so the wood industry is fighting for LEED to recognise other certifications besides FSC, which is the most stringent and costly.'

'LEED provides points to FSC certified timber, however in combination with the credit for regional materials this is hard to achieve as there are mainly PEFC certified forests and processors in Europe. As the points are accredited based on costs, the structure very often has a large contribution.'

Respondents noted that for structure responsible sourcing was a procurement rather than design issue.

'These (credits) tend to come down to the contractor sourcing the materials'

This indicates that for many regions choice of timber for structure was not limited by the requirements.

Others noted that if there was only a small quantity of timber permanently installed on the project this was a credit that was possibly too easy to achieve and may be approached cynically.

Despite the relatively positive approach from the survey respondents, LEED data shows that the credit is not having a large impact on rating scheme scores, being targeted on only 20-40% of projects[60].

However, Figure 27 shows that the timber credit in LEED was a differentiator between lower and higher scoring projects.

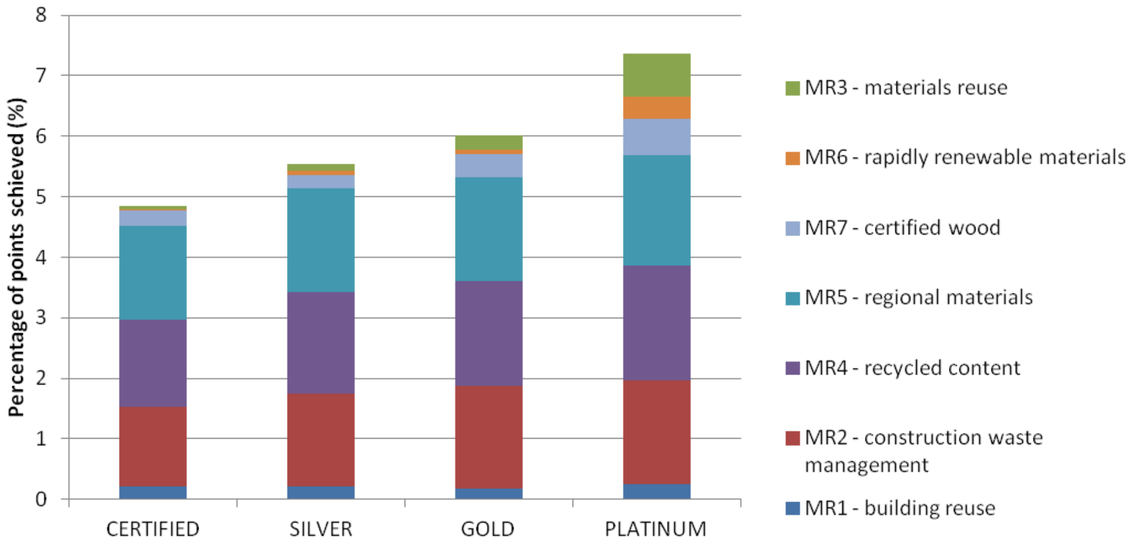

Figure 27: Contribution of LEED credits related to structural materials to overall score

10.3 Effectiveness of responsible sourcing credits

Despite the relatively positive view of these credits, there is evidence that the rating schemes could be developed further.

In terms of providing incentives for sustainable **actions,** responsible sourcing credits, such as the approach in BREEAM, can provide incentives to reduce impacts throughout the supply chain. This has an effect beyond the boundary of the building itself. The approach is important to the UK government which in 2008 set an aim for '*25% of products used in construction projects to be from schemes recognised for responsible sourcing.*'[40]

BREEAM shows that this approach can be applied to more materials than timber.

This expansion to other materials does not need to be limited to the UK. In Australia the Green Star steel credit includes a requirement for responsible sourcing and an industry steel stewardship scheme is under development[61]. Environmental management to ISO 14001[62] can be found in many locations, and the CARES organisation in the UK has shown that it is possible to certify reinforcement producers in China and Turkey for responsible sourcing.

Current score levels of less than 2% seem low compared to the effort involved and potential outcomes of achieving a high level of responsible sourcing.

To provide a **measure** of the sustainability of the structure, to enable comparison between buildings, the sourcing credits would need to require whole building assessments. Where the principles of responsible sourcing are well established, for example FSC timber supplied for structural timber, the credits may appear to reward business as usual.

Recommendation 10.1

Responsible sourcing credits should be available for all materials and follow a tiered approach which provides both entry level requirements through to beyond best practice requirements. Reward for high performance should form a substantial element of the overall rating score.

Recommendation 10.2

Additional responsible sourcing credits should be available for materials used in temporary works.

The FSC scheme was an early example of responsible sourcing principles. However, responsible sourcing principles can go further than the issues traditionally covered in timber certification schemes. Social issues, monitoring and reducing environmental impacts of processes and transportation are included as well as the chain of custody issues which are a familiar feature of the timber schemes.

Detailed recommendation 10.3

The rating scheme should be based on existing industry initiatives and provide a means to identify higher performing systems. The requirements should be set out such that the rating schemes influence the development of the stewardship schemes that they endorse.

All the approaches to sustainable sourcing have successfully provided a **framework** to define sustainable design practices for professionals. This is demonstrated in the widespread adoption of timber stewardship certification and response of UK industry to responsible sourcing. An aspirational scheme should work with the best practice demonstrated by these credits. It should seek to engage regional industry and develop the credits through consideration of the supply chains for the major material streams associated with construction.

In terms of working as a **practical tool** which can cost effectively be deployed during the procurement of buildings all these credits rely on establishing supply chain documentation. This incurs a significant initial cost and may favour large projects (such as the 2012 Olympics), suppliers and contractors.

Detailed recommendation 10.4

There must be a means for smaller enterprises to demonstrate good practice with responsible sourcing.

Detailed recommendation 10.5

The credits must achieve a reasonable balance between action and evidence. An example approach would be to set the maximum target for evidence of 90% rather than 100% of the element or material type in question to reduce paperwork associated with sundry elements[52].

The responsible sourcing credit in BREEAM aligns quite well with the requirements of the aspirational scheme. The timber credits in other schemes appear less successful.

11 Review of local sourcing credits

Local sourcing credits feature in quite a few schemes. This was not found to be a successful approach for improving the sustainability of building structure. This was mainly because the purpose of the credit was often not clear enough.

It was shown that, for structure, requirements relating to local issues and transportation were more effectively included in other credits.

Regional sourcing is included in many of the ratings schemes studied and the credits are summarised below.

BREEAM does not include an incentive for local sourcing but transportation impacts of products will be managed through the responsible sourcing framework.

LEED	%	GREENSTAR	%	CHINA 3 STAR	%
Regional Materials	1.8	*Local Sourcing*	1.2	*5.4.3*	1.8
• Region is within 500 miles of project site. • These materials must comprise at least, by cost, 10% (1 point), 20% (2 points), of the total materials value. • Mechanical, electrical, plumbing and speciality items cannot be included. Include only materials permanently installed in the project.	Mr 5	20% total contract value sourced < 400 km of the site (1point). 10% total contract value sourced <50 km of the site. excluding non-permanent and services Sourced = Extracted, harvested, recovered	Mat-11	The weight of the building materials produced within 500km of a construction site shall make up more than 60% of the total weight of the materials	

ESTIDAMA PEARLS	%	HK BEAM	%
Regional Materials	1.1	*Regionally Manufactured Materials*	0.7
Transport <500 km from the furthest point of origin to the project site. Cost as a % of the total material cost: •1pt: 10% •2pts:20% Materials by airfreight do not qualify.	SM-9	Materials manufactured < 800km of site. 10% (1pt), 20% (2pts) of all materials either by mass/volume/cost	MA9

11.1.1 What do the schemes measure?

The schemes generally set targets for a percentage of the total materials installed on the project by cost, weight or volume.

The limiting distances defining ‘local’ are of a similar order of magnitude. 400 – 800km. However the definitions of the activities to fall within this radius vary from ‘extracted, harvested and recovered’ through to ‘manufactured’ (HK BEAM) and ‘produced’ (China 3 Star). This will make a significant difference for materials that are globally traded as raw materials or semi-finished product but locally manufactured such as metals, and timber.

Hence, although the scheme requirements look fairly similar, they may not be in practice. China 3 Star is at most variance from the other schemes, requiring 60%

production within 500km. This is a more onerous % mass level for a much less onerous point-of-origin requirement than LEED.

Estidama PBRS is the only scheme to include recognition of mode of transport; a material does not qualify if it has travelled by air at any point, you must include 100% of any distance travelled by road or rail, but only 10% of any distance travelled by sea.

11.1.2 How does this credit work in practice?

Here are the LEED respondents' selections from the predefined list of strengths and weaknesses of credits:

		% of respondents agreeing			
	LEED Local Sourcing Credit	**40-60**	**20-40**	**20-40**	>**40**
Strengths	The measure is simple and clear Cost neutral or saving Encourages the development of good practice It is easy to achieve				
	It rewards sustainable actions Does not impact on other aspects of the design It links well to industry practice				
Barriers	Unable to source Conflicts with other design parameters Not enough information available Do not think it is sustainable Measuring the wrong thing or in the wrong way Effort to achieve is not proportional to reward				

The responses show a similar pattern to those for recycled content. Taking the respondents comments into account the survey shows that there are regional variations in both supply and the supply chain's readiness to provide the documentation required for the scheme. As with recycled content, American contractors can supply information fairly readily and can target procurement to achieve the credit. In other regions suppliers are unable to provide the documentation required and for some structural materials, the raw materials are simply not available within the required distances.

For LEED this is a credit which is targeted wherever possible.

Based on the LEED project data, the average score for this credit, across all levels was 1.3% out of the possible 1.8% available, showing that this credit is gained in almost every project. Respondents offered comments demonstrating that the credit availability will vary according to the supply chain for structural materials rather than the choices of the design team.

The regional sourcing requirement was mentioned in comments related to other credits, which illustrates that the requirements can be in conflict with each other. The rating schemes do not provide a means to identify the best practical sustainable option by comparing production and transport impacts.

Responses for the schemes other than LEED were mixed with no clear pattern emerging. This reflects the wide variation in what the credit requirements will mean in practice in different regions and for different materials:

For the locations served by Estidama PBRS, HK BEAM and Green Mark the majority of the raw materials will be imported.

The Singapore scheme does not include a local sourcing requirement.

The Hong Kong scheme uses manufacture, rather than extraction as the point of origin.

The Estidama scheme seeks to limit more extreme transport impacts and it was felt that the requirements were often achieved.

Effectiveness of local sourcing credits

Local sourcing credits are **ineffective** because they do not provide clarity about what sustainable outcome is intended – reduction of material transport or supporting local industry.

When considering the embodied carbon of construction materials in the UK, it was found that the impact of transportation was generally less than 10% of the total impact.

The sourcing radii are very large distances which would represent significant impacts if transport of heavy structure was by road. Hence in many regions these credits **cannot** be seen as reducing transport impacts.

The exception is an approach such as the Estidama PBRS scheme which addresses transport mode and the higher level requirement of Green Star which imposes a very small distance.

If the requirements are aimed to reduce transportation impacts then the credits should either include a mode of transport, or place limitations on the final leg of the journey. This approach has been demonstrated by the London plan[63]. However these restrictions can only apply in locations where there is sufficient pre-existing infrastructure.

Hence, with the exception of Estidama PBRS the regional and local sourcing credits can only be viewed as a proxy measure to encourage supporting local industries. Given this conclusion, the requirements for sourcing to be measured from point of extraction, harvesting or recovery seems inappropriate. Taking metals as an example, the iron ore may be sourced from Brazil, but significant employment and industry processing the metal may take place within the target distances from the site.

Overall, this credit does not appear to influence the choice of structural material or the mode of transport and is more likely to recognise ‘business as usual’ if a local source happens to be available.

Recommendation 11.1

Structural materials should be excluded from the local sourcing credits

It is possible that a local sourcing credit is being included to try and challenge perverse outcomes from other credits. Examples include long distance import of recycled steel or aggregate when other alternatives exist closer by. This is not an appropriate method to achieve this aim, as the most sustainable choice will depend on the issue in question.

Recommendation 11.2

The local sourcing requirements should be replaced by more targeted measures.

- Limiting distances/modes of transport as prerequisites for particular material credits.
- Responsible sourcing requirements.

12 Review of life cycle assessment (LCA) credits

LCA related credits should follow a declared 10 year trajectory to support incremental change in industry. Structure should be included in credits related to LCA.

Credit should be awarded for actions which support the necessary changes in industry, including the reporting of data and establishment of tools, benchmarks. Credit should also be awarded for the use of LCA to reduce the impact of the building by design process.

With regard to structure the approach must be based on combining quantities, specifications and impact data together, rather than the use of pre-defined elements.

The topic of life cycle assessment (LCA) is covered in a number of the rating systems. Example requirements are summarised below.

BREEAM	%	DGNB	%	HK BEAM	%
Materials specification	1.9	*LCA credits*	3.0	*Embodied Energy in Structural Systems*	1.7
• Points are awarded based on the Green Guide rating for the following elements: external walls, windows, roof, upper floor slabs, internal walls, floor finishes/coverings.	Mat 2	LCA tool used for whole lifecycle	Sb 01-05 10 12	1 credit for demonstrating the embodied energy in the major elements of the building structure of the assessed building has been studied through a Life Cycle Assessment (LCA). 1 BONUS credit for demonstrating the major materials with low embodied energy are used in the project utilizing the LCA results.	EU4

A number of the ratings schemes that do not currently have a credit on this topic are in the process of developing a credit, such as LEED[64].

'Future work by the GBCA may involve a life cycle analysis or assessment (LCA) which compares the environmental and health impacts of all building materials.' (Green star Australia)[65]

12.1 What do the schemes measure?

Life Cycle Assessment (LCA) is a form of systems analysis for quantifying environmental impacts for a chosen scope of activity. Numerous standards exist for its application. It can include a wide range of environmental impacts such as global warming potential, non-renewable resource use and toxicity to land, among others.

Life Cycle Assessment can be a complex process. The challenge with LCA in rating schemes comes with respect to the methodology, tools and data which need to be developed in order for the process to be practical and cost effective on a building project. The simplifications necessary to include LCA in a building rating scheme will affect what can be measured by the scheme.

The current schemes which use LCA have all adopted slightly different approaches.

DGNB uses a tool which carries out a full life cycle assessment of the design including the operational impacts. This reports a wide number of impacts. Each impact is compared against a benchmark and points are awarded accordingly. The applicant supplies quantity information for the tool.

BREEAM has simplified the process for the user, by producing a 'Green Guide to Specification'[66]. This evaluates predefined building components across a range of environmental impacts over a 60 year period. The impacts are simplified into a single measure the 'ecopoint' and compared against other solutions to the same design requirements. This leads to a rating for generic types of construction of floors, walls, roofs etc. A calculator combines the ratings for all the different elements and generates a score for the whole building. Most commonly, the applicant selects pre-defined elements from the guide.

In contrast, **Hong Kong BEAM** uses one indicator, embodied energy, to assess the building structure. The assessment covers the main elements that comprise the building structure, façade the roof and the foundations. The design team is required to submit a calculation for the embodied energy of the design. An additional point is available for using materials with low embodied energy.

12.2 How does this affect the structural engineer?

Compared to other building elements, structure is simpler to deal with in LCA tools because the list of materials to consider is small, and quantities are usually quoted in mass or volume, rather than a m^2 of a composite construction. However this small list of materials covers some difficult topics with regard to LCA methodology:

Material	Issue/modelling challenge
Steel	Global market, regional data. Impacts vary with process. Material is commonly recycled
Concrete	Cannot be treated as a single product. CO_2 figure highly dependent on Portland cement content and individual specification. Locally sourced material. Waste materials may be used for fuel. Resource use high, leading to landscape & biodiversity impacts from quarrying. But CO_2 associated with aggregate is low. Aggregate is a plentiful resource. End of life results in carbonation of crushed concrete and the down-cycling of Portland cement to aggregate.
Concrete, masonry,	Secondary & waste materials can be included. Very long life span. LCA boundary may impose end of life impacts at an earlier point than necessary.
Precast concrete, structural glass and masonry	Road transport impacts to site may be significant so 'cradle to factory gate' numbers are unrepresentative.
Timber	Carbon sequestration and end of life impacts cancel out over the timber life cycle but each is greater than impacts of construction. Bio-fuels used for drying. End-of life options (landfill or incineration) lead to a very different result if a short life-span is considered.
Structural Glass	Little data specifically for structural glass

Comments throughout the survey showed that structural engineers are keen for rating schemes to recognise their efforts to reduce environmental impacts through reduction in quantities, or low impact specifications. LCA should provide a means to combine these parameters with impact data and facilitate comparison with benchmarks. However the implementation of LCA within some of the rating schemes does not achieve this.

12.2.1 DGNB & LCA

While DGNB allows a comprehensive analysis of quantities it appears that the current available data cannot model a broad range of specifications.
The survey response to DGNB also raised two weaknesses in terms of lack of information and the effort compared to the reward.

"The structure does contribute largely to the LCA, because it is mostly the largest building element by volume. Alternatives can be assessed using the LCA method, however whether this is actually done...."

12.2.2 The Green Guide in BREEAM

BREEAM has attempted to reduce the effort for users with the use of simplified ratings in the Green Guide to Specification[66]. Here are the BREEAM respondents' selections from the predefined list of strengths and barriers of credits:

		% of respondents agreeing			
	BREEAM LCA Credit	**40-60**	**20-40**	**20-40**	>**40**
Strengths	The measure is simple and clear Encourages the development of good practice It rewards sustainable actions				
	It links well to industry practice It is easy to achieve Impacts positively on whole design Cost neutral or saving				
Barriers	Not enough information available Conflicts with other design parameters Too expensive Measuring the wrong thing or in the wrong way Resistance from the design team				

Despite this positive response, many respondents added negative comments about difficulties specific to **structure** with this credit. The Green Guide assessment ignores major structural elements such as vertical load bearing elements, substructure and primary beams. By ignoring the primary beams BREEAM may be ignoring some of the highest impact structures, particularly in the case of ultra-minimum depth steel structures.

“only the 'floors' count - no frame, substructure etc.”

“The major elements spec is really skewed towards the building fabric specified by architects”

By adopting generic solutions the Green Guide method makes no attempt to ascertain the efficiency of the actual solution.

The process of minimising the impacts of structure should not be based on the choice of material or scheme because the majority of schemes will provide a similar range of impacts. The reduction occurs through the skill of the structural engineer choosing a scheme which is suited to the particular building constraints. This is followed by appropriate material optimisation and careful specification. The resulting design will then fall in the lower portion of the range of possible answers. This is illustrated in Figure 28 which shows that even if the Green Guide did include the major frame, the Green Guide process of selecting a floor type, like a product, completely misses these important aspects. For structure, for the assessment to be meaningful, it needs to be based on actual quantities and specifications required to efficiently perform the function.

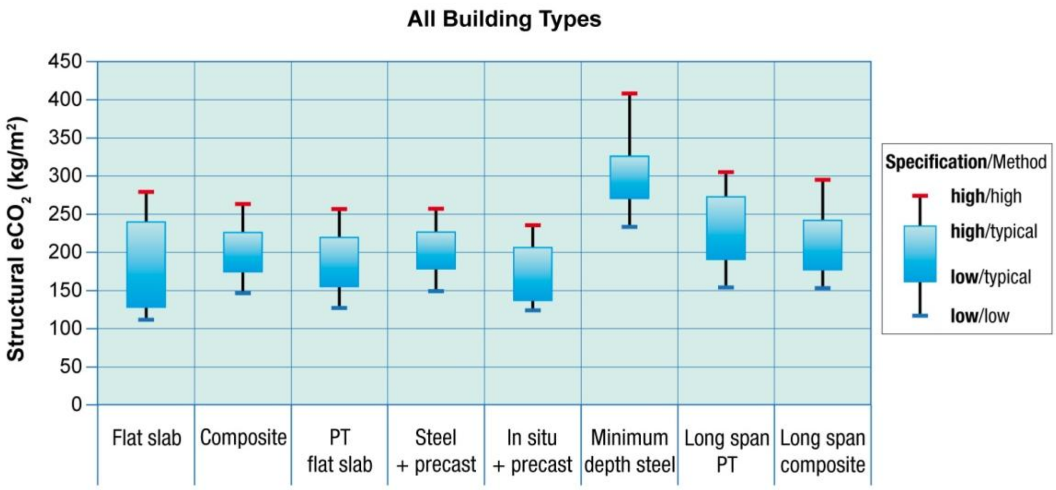

Figure 28: Variation in embodied carbon of structure due to differences in specification and method. *Extracted from Concrete Centre/Arup research study* [67]

In addition there are concerns that the pre-defined floor elements are assessed on an undemanding specification; the criteria used in the Green Guide do not match those in common practice. Typical requirements such as those used by the Concrete Centre[68] and the SCI[24] in their cost model studies are higher than the criteria used to generate low impact solutions in the Green Guide.

The result is that some building elements are compared to options in the Green Guide which would not be able to meet the more stringent performance requirements that are used in practice. If the office does not meet quality standards it will be less desirable and less likely to be retained in the future. This will lead to higher impacts within the 60 year life than the comparison implies.

"The credits are based on a very limited understanding of what structural engineers do in terms of frame efficiency."

On the positive side the 'ecopoint' takes account a broad range of environmental issues over a 60 year life cycle. Hence the life cycle assessment using the ecopoint would, if applied to the actual structure, provide a fuller picture than the simple embodied CO_2 and embodied energy calculators available to structural designers.

Unfortunately the ecopoint values for structural materials are not publicised and the BRE are unable to quickly answer queries on non-standard constructions[14]. The result is that the ecopoint cannot be used in tools during design development, and innovation, or indeed best practice, cannot be recognised.

"In most cases the Mat1 system is opaque, complicated, counter-intuitive and not linked to significant sustainability improvements. If you change to a high fly ash concrete or a lightweight steelwork structure, you should get credits."

"Hundreds of combinations of floor build-ups and lengthy discussions with the BRE have made it harder, not easier, to make those sorts of simple, positive sustainability-driven design choices"

Project experience shows that even when an A rated floor is selected it does not necessarily improve the overall score for the building, due to the calculator method. Because structure and substructure has been shown (Figure 29)to be at least 50% of embodied CO_2 and energy impact of a whole building, it is of concern that these elements are not well addressed in the Green Guide.

"Choosing an A rated floor over a B rated floor sometimes makes no difference to the overall result."

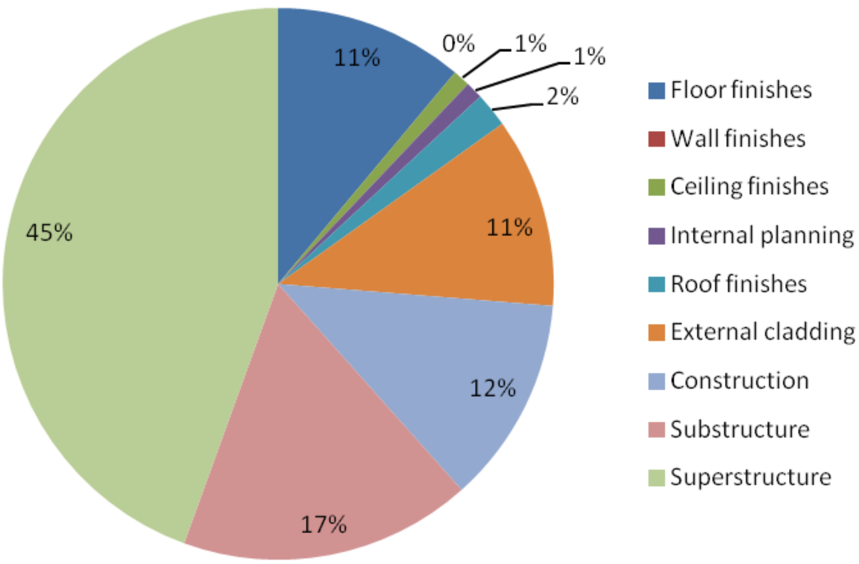

Figure 29: Relative contributions to embodied CO_2 of office buildings. *Extracted from Concrete Centre/Arup research study*[67]

12.2.3 Hong Kong BEAM and LCA

Hong Kong BEAM provides a more open credit than the two schemes above. The approach is very different and is much more aligned with the work of structural engineers.

"Few years back, many people won't even try to attempt this credit since not many engineers familiar to EMSD software. Having said that, this credit is getting more and more people attention since the LCA study becomes part of the requirement of all new government projects nowadays. I think this is a good motivation to let structural engineer involving in sustainability design."

12.2.4 LEED and LCA

It is expected that there will be an LCA-based credit in the next version of LEED and that this will include structure. This is welcomed.

"The move to LCA should force an even earlier consideration of material selection into LEED projects and will, I hope, increase the importance of structural material selection."

However, comments[69] during the trial of the pilot LCA credit concerned a desire for the tool to include more elements and the ability to take account of different thicknesses and quantities of material included in the pre-defined assemblies.

".. the LEED LCA calculator does not have a place to input the impacts associated with foundations and footings. For our project this was about 10-15% of our impact."

"All assemblies in EcoCalculator (EC) are presented holistically, that is to say that the results reflect the impact measures of the entire assemblies, and you can't separate the individual materials from each other and scale them separately."

The final version of the LEED LCA credit may address these comments. However the comments support the experience of BREEAM users that, for structure, the value of including LCA would be to take account of the quantities used in the structural design, rather than the choice of generic solutions.

12.3 Effectiveness of LCA credits

The current context for LCA credits around the world is:

- Designers are seeking a method, such as LCA, which enables them to combine quantities, specifications and impacts to inform the design process.
- Data related to materials and processes is not available in all regions, and the different methods used to report the data lead to variation in the results.
- Benchmark data, to help compare options to industry norms is also lacking.

There are initiatives in a number of regions to address this and rating schemes have a part to play in supporting this development. In Europe a standard for reporting building LCA results already exists[70] which will soon be followed by Product Category Rules for the Europe-wide generation of Environmental Product Declaration for construction products[71]. Recommendations to the UK government provide[35] a timeline showing a route to establish embodied CO_2 reporting for buildings over the next 10 years.

In 2008 the UK Government set targets for construction which are relevant[40]:
'To develop means of improving access for designers to product Life Cycle Inventory information.'

'Reducing total UK carbon dioxide (CO_2) emissions by at least 60% on 1990 levels by 2050 and by at least 26% by 2020. '

And similar issues are reported by the US Green Building Council:

In addition to discovering new ways to integrate life-cycle thinking into LEED, USGBC hopes that this pilot credit will lead to increased reporting of life-cycle data on materials, products, and assemblies to publicly available databases (LEED[64]).

Therefore in terms of providing incentives for sustainable **actions,** the rating schemes must support the process described above with a reasonable allocation of points as there are few other incentives in existence. Without these developments there is no incentive for industry to innovate to reduce impacts.

All the LCA based credits have provided a **framework** to define sustainable design practices for practitioners. The application of LCA in rating schemes is always going to be somewhat of a compromise while tools and data develop. An example is the shortcoming in approach to structure described above for the Green Guide in BREEAM. While methods are developing the various material suppliers are very actively promoting methods of analysis which favour one material over another. Commercial providers of tools (including the rating scheme developers themselves) are also promoting their approach above others.

Tools should be accessible to independent evaluation. The rating scheme should set out the basis for calculation. This should be based on existing and developing open, regionally agreed standards. For example in Europe schemes should follow the framework defined in the standards being developed by TC350. Where standards and data are missing it should provide requirements that facilitate an independent view of the different characteristics of structural materials.

In terms of providing a **measure** of the sustainability of the structure to enable comparison between buildings the position is less clear. Although LCA provides a numerical result, the result requires interpretation and judgement. The results are dependent on the quality of data and all comparisons must be viewed with an understanding of the uncertainty band associated with the results.

LCA results are often not as precise as implied by their numeric nature and the focus should be on relative results more than on absolutes. (LEED)[72]

There are two distinct approaches which have been adopted;

- meeting targets for a whole building measure, as is the approach of DGNB or
- the use of LCA to measure impact reduction for key elements, as is the approach of Hong Kong BEAM.

A tiered approach to an LCA credit could facilitate both these approaches. In addition there are some actions which should not need to be justified by a project level LCA and are described in other sections.

In order to provide a **practical tool** which can cost effectively be deployed during the procurement of buildings the use of LCA in rating schemes will inevitably involve some simplification. For building structure, the multiplication of structural quantities by constants, representing impacts is a practical reasonable requirement, if default impact data and simple tools as described above are available.

This process becomes significantly more complex for non-structural elements, and for pre-fabricated assemblies which are not traditionally broken down into constituent materials by mass or volume.

HK BEAM and BREEAM can be seen to represent two complementary approaches. The former is more suitable for structure, whereas the latter is more suitable for non-structure.

12.4 Recommendations for LCA credits

Rating schemes should facilitate the calculation and reporting of the impact of structure and substructure. This is because:

- Structure and substructure represent around 50% of embodied impacts.
- There are relatively few structural materials compared to finish, fit-out and façade. Therefore less data is required and tools can be developed.
- There are relatively few negative knock–on effects on non-structural elements brought about by reduction in structural impacts[67].
- Local sourcing, recycled content and other available comparisons do not provide good proxy indicators for the impact of structure.

Rating schemes should also provide incentives to industry.

Recommendation 12.1

LCA credits should follow a declared 10 year trajectory to support incremental change in industry.

Recommendation 12.2

The rating schemes should aim to be setting benchmarks for different building types based on multi-indicator, whole life assessments.

Recommendation 12.3

LCA Credits should consider the impact of structure and substructure based on actual quantities and specification.

Detailed recommendation 12.4

A clear basis for comparison of functional equivalence should be established based on current and predictable future best practice.

Detailed recommendation 12.5

LCA Credits should reward the reporting of data.

Detailed recommendation 12.6

Rating schemes should provide clarity and openness for providers of LCA tools and data. Requirements should provide a transparent and accessible platform for industry to engage with LCA.

Detailed recommendation 12.7

A tiered approach should provide high rewards for early adopters and provision for entry level engagement:

Possible Entry level rewards:

- Pre-defined actions which reduce the impact of the structure and do not generate knock-on effects to other elements e.g. Portland cement replacement, material reduction for a given scheme, or re-use of substructure.
- Proof of the consideration of impact reduction of the building structure during design, using a single indicator, such as CO_2 or energy and an agreed source of default data.
- Use of suppliers who have published environmental product declarations or the results of LCA.

Possible higher level rewards:

- Submission of an assessment of the whole building or key elements to be collated into publicly available benchmarks.
- Projects which have developed supportable project specific whole-life, whole building benchmarks and have shown a reduction in impacts against these benchmarks.

This should evolve in a predictable way over time.

13 Review of efficiency & future proofing credits

The concept of efficiency and future proofing credits was welcomed although little or no direct experience was offered for some of the schemes. Approaches ranged from a simple measure of the volume of concrete/m^2 of building through to reward for producing deconstruction information.

Not all strategies are appropriate for all buildings and care should be taken to avoid perverse outcomes. Hence these credits should be worded carefully.

A useful impact reduction strategy is to use materials more intensely. This can involve using less material, making buildings last for longer, or designing such that materials can be recovered and re-used. There are trade-offs between these strategies.

13.1 General Approach to efficiency and future proofing

Compared to other topics covered in building rating schemes these issues are not easily quantified or standardised. Nevertheless some recently developed credits have addressed these topics. Feedback shows some uncertainty as to how to provide evidence for the requirements.

Recommendation 13.1

Rating schemes should provide a method to establish benchmarks and provide examples of acceptable evidence.

The first strategy, material reduction, may come into conflict with the latter two, design for re-use and long-life, because reducing materials can require optimised forms and reduced redundancy, while the latter are aided by standardised pieces and contingencies for unknown loads/events. Material reduction savings are certain and realised immediately, while re-use/long-life benefits are uncertain and will happen many years in the future, if at all.

- Where the building is likely to change ownership many times and future occupant needs are difficult to predict, material reduction is preferred. Studies show that steel savings of 15-30% are achievable through inherently ‘lightweight’ concepts and reduced rationalisation during construction[73].
- However where future needs can be estimated with some confidence, it can be environmentally beneficial to have an adaptable design. Adaptable features should be targeted at specific, realistic scenarios rather than applied indiscriminately.
- Designing for re-use is also expected to aid long-life, as having reversible connections, good information, a deconstruction plan, etc. will aid refurbishment. However if highly-optimised structures include bespoke components or unusual connections, they are unlikely to have a market for

re-use at end-of-life. Therefore there is little benefit in pursuing design for re-use on such projects.

13.1.1 Studies of different strategies

The trade-offs between these different strategies can be studied through LCA. Two studies were reviewed, one in the USA[74] and one ongoing in the UK[75].

The US study investigates embodied carbon impacts of the strategies against a base case design. The results for 'design for long-life' illustrate that extra structure was included for adaptability, but how long this extends life, if at all, is uncertain.

The UK study examined two common floor-systems: a 're-useable' design consisting of non-composite precast concrete planks on steel beams, and a 'lightweight' design with composite concrete decking on steel beams. The results are plotted in Figure 30, which shows that while the re-useable floor system is more carbon intensive initially, much more of it can be recovered at end-of-life. The figure also shows the increasing material required to support extra load, highlighting the CO_2 cost of flexible space.

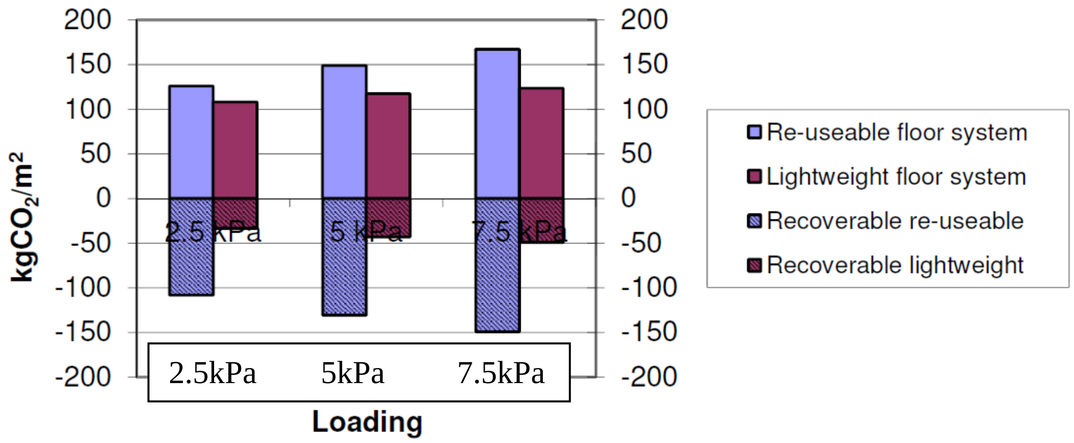

Figure 30: Embodied carbon for two floor systems and three live loads

These studies illustrate that credits in this area risk rewarding a marginal, or even negative action. However big savings are also possible. The results are confusing which illustrates that presenting evidence in this field is difficult. It is not recommended that such studies become part of a standard credit submission until LCA credits are very well established.

A cultural change is needed in industry and rating schemes need to support innovation with respect to these strategies. Credits should provide incentives for changes in industry practice, as well as reductions for individual projects.

13.2 Material reduction

Using less material sits at the top of the waste hierarchy of 'reduce, reuse, recycle'. In BREEAM and LEED this topic is not addressed directly in a credit. A very compelling feature is that these credits can be directly linked to the existing professional services of the design team.

Efficiency					
CHINA 3 STAR	**%**	**ESTIDAMA PBRS**	**%**	**GREEN MARK**	**%**
5.4.11	1.8	*Design for Materials Reduction*	0.6	*Sustainable Construction*	2.1
An architectural structural system that consumes a small amount of resources and has little effect on the environment shall be adopted		Demonstrate that fewer materials are used in the final building design than in a typical building of the same type	SM-2	Concrete efficiency 1 point for $<0.7m^3/m^2$ Up to 5 points for $<0.35m^3/m^2$	
		HK BEAM	**%**		
		Modular and Standardised Design	0.4		
		>50% listed elements	MA2		
				GREENSTAR	**%**
				Dematerialisation	0.6
				20% less structural steel (mass) OR any **2** of a selected list of strategies including floor/ceiling exposed structure	Mat-10

Results from the survey show that the Green Mark concrete credit appears to be working well. Project experience suggests that 2 points can be fairly readily achieved, with Platinum buildings targeting 4 points out of the 5.

"Concrete efficiency ties in with the contractors or clients aims, it reduces construction costs and simply relies on the structural engineers reviewing their design and trimming down elements where possible." Green Mark:

The effort to achieve the Estidama credit was felt to be too high compared to the reward, however it is achieved some of the time.

Green Star uptake has been low.

"The very low take-up of the dematerialisation credit high-lights ...the credit is not clear.., (we need)... *a clearer explanation of the reference case (that the % reduction of structural materials is compared to) and extending the structural materials that can be considered."* (Green Star)

Green Star also recognises the contribution of structure to avoiding finishes in the same credit. This is also a positive step which would lead to a significant reduction in construction waste as discussed in Section 2.1.2.

Some of the schemes may need to be adjusted to be more accessible but the principle is well received. Respondents who work with schemes that don't include such credits saw this as an omission.

"There also needs to be a greater measure of structural efficiency. You could have a structure that has half the structural content and get no mark but one that in less efficient and uses twice as much material but because it is of the correct type it gets a credit..?! " (BREEAM)

"The biggest gap is that none of these materials credits measures or rewards using less overall material in the structure, nor is there a measure for durability or longevity. These are areas where the structural engineer can have the greatest influence." (LEED)

Credits of these kinds will provide incentives for sustainable **actions**, some **measure** of the sustainability of the project and a **framework** and targets for professionals to aim for.

Material efficiency for structure could be demonstrated using performance utilisation factors, such a stress ratios. Alternatively it could be demonstrated with respect to a benchmark established using the same type of material. There may be a concern that if the measure is simply based on material weight, then substitution of a heavy low-impact material with a light high-impact material may cause a perverse outcome. For structural materials this is possible, even within one material type, in the example of substituting in-situ with post-tensioned concrete. However studies have shown[23] that despite the higher impact concrete, post-tensioned solutions can be equal or lower impact than the equivalent flat-slab. Despite this small risk of a perverse outcome, credits for material efficiency seem to be working in Singapore and would be more effective than either the recycled content credit in LEED or the current LCA/Green Guide credit in BREEAM.

Recommendation 13.2

Measured material efficiency should be rewarded. This could form a lower tier entry to an LCA based credit.

Indirect rewards for reduction in materials are also evident in the rating schemes. In some regions where lower grade steel is available, the use of higher strength steel is rewarded as a measure of dematerialisation. There are also other efficiency credits aimed at waste reduction through prefabrication and optimisation.

CHINA 3 STAR	%	GREENSTAR AUS	%	HK BEAM	%
5.4.5	1.8	*Steel*	0.6	*Prefabrication*	0.7
High-performance concrete and high-strength steel shall be used reasonably as building structural materials		Structural and reinforcing steel must meet or exceed a minimum strength grade (in addition to other criteria)	Mat-6	20% (1pt), 40% (2pts)off-site <800km of site for listed prefab elements (by weight or volume)	MA3

'Compared with on-the-spot mixed concrete, pre-mixed concrete guarantee concrete quality, and ... guarantee on strength can be more than 95%; it can reduce... material damage and loss.. If the strength of main... (concrete reinforcement)*... is improved to 400 ~ 500 N/mm², then steel amount can be saved by around 10%... And if concrete can be of strength between C30 ~ C40 and part of buildings reach C80, then the amount of concrete can be saved by around 30%.'* (China 3 Star)[76]

The sustainability benefits of prefabrication and optimisation are well documented, as components can be produced in a factory environment, often on automated lines that can manufacture optimised designs and better tessellate orders. This results in less material up front, fewer off-cuts and other wastage, as well as giving cost, quality and health & safety benefits[77].

However, because these **actions** are indirectly linked to the sustainable outcome there is a risk that in some cases they are not providing appropriate incentives.

Examples where the measures may not reward sustainable actions are:

Rewarding higher strength material where performance is governed by serviceability.

Rewarding high strength concrete (above 60MPa) where the embodied CO_2 increases because Portland cement replacement is not practical.

Rewarding prefabricated elements where transport or process impacts are higher than on-site construction.

The conclusion is that high strength materials and pre-fabrication should not be rewarded. Instead the material efficiency itself should be proved as recommended above.

13.3 Design for long life

Future proofing strategies include designing for quality, adaptability and durability. These are multidisciplinary credits.

HK BEAM	%	DGNB	%	ESTIDAMA PEARLS	%
Adaptability and Deconstruction	0.7	*Multiple Use Adaptation*	2.3	*Design for flexibility and adaptability*	0.6
•1pt spatial adaptability: •1pt flexible engineering services: •1pt structural adaptability: •70% of listed items	MA4	Provide a flexible structure in order to allow a multiple use adaptation. Structure is 1 of 4 components considered	*SB17*	Meet specific requirements (floor-floor heights, movable internal walls, windows distribution etc)	SM-3

Survey respondents were generally positive about these credits but they were felt to be technically difficult and to generate resistance from the design team. An assessor's view of the Estidama PBRS credits was that although they were sometimes achieved the durability plan is usually not well documented and the flexibility credit was felt to be too easy.

Including a set of specific actions that improve adaptability would be an achievable and meaningful way of encouraging longer-life buildings. Such actions, e.g. providing for addition of storeys, or providing methods for strengthening for stair-case openings during tenant fit-out should be sector-specific as health, office, education, retail etc. buildings have different life-spans, ownership models and design trends. In some cases, future adaptability will result in higher initial impacts. In order to be rewarded in a rating scheme these savings would need to be shown to be likely to prolong the life of the building.

In the case of the study buildings (offices), quality guidelines, for example in the British Council for Offices guide[78], set out performance requirements which should ensure that the building is commercially desirable in the future. For office buildings there may be a difference in the commercial case for adaptability between urban-centre and green-field sites. Hence these actions should feature in other aspects of a rating scheme, and not an explicit credit.

Recommendation 13.3

Specific adaptable design features should be listed in the rating scheme and be rewarded.

Detailed recommendation 13.4

Functional units for material efficiency and LCA type credits for structure should take account of industry good practice regarding future adaptability. (See also detailed recommendation 12.4)

13.4 Design for deconstruction

Finally there are direct credits for deconstruction. In addition to the credits listed below, the Green Star steel credit requires steel to be physically marked with grade. This is a significant step towards enabling steel re-use.

GREENSTAR	%	DGNB	%	ESTIDAMA PEARLS	%
Design for Disassembly	0.6	*Demolition, dismantling and recycling*	1.1	*Design for Disassembly*	0.6
Dfd for 50% (by area) of structural framing, roof, and façade systems OR - 95% of the total façade	Mat-9	Easiness in dismantling elements; Easiness in separating materials; Recycling/waste disposal scheme/concept. Structure 1 of 4 elements considered	Technical SB 42	Develop a Building Disassembly Plan and demonstrate amounts designed for disassembly	SM-4

The topic was also raised with respect to other rating schemes.

"The issue of demountability and cradle to cradle design is something that I also hope will play a bigger role in the future of LEED as it continues to develop." (LEED)

The Estidama PBRS credit is rarely targeted. Responses to this credit were fairly negative although respondents acknowledged the basic sustainability aims of the credit. The weaknesses were:

- Technically difficult
- Resistance from design and procurement team
- Not enough information available
- Measuring the wrong thing or in the wrong way
- Conflicts with other design parameters

Uptake for Green Star is also very limited. GBCA confirmed that only 4 projects have achieved either the dematerialisation or disassembly credit. Structural engineers are interested in the topic; however it is currently not aligned with industry practice for commercial buildings. The credit is not available for industrial buildings, because this was felt to reward 'business as usual'.

"Current legislation and policy does not efficiently tackle demolition or deconstruction, and waste management charges are too low to act as an incentive to recycle/reuse materials" (Green Star)

"The examples of buildings achieving the Green Star credit for DfD had demountable facades. This is because demounting the facade of a building is easier and more cost effective currently than the structural frame of a building in Australia. Although the Green Star credit point is a driver to design a building for disassembly, there are cheaper and much easier ways to achieve one credit." (Green Star)

These credits earn a maximum of 0.6% of the rating scheme score from structure. This group of credits will, in principle reward **sustainable actions.** However the current rating schemes are clearly not providing sufficient **incentive.**

Also, critical thought needs to be given to the sustainable action that is being targeted. There is no point carefully disassembling elements which will then be destructively re-processed during recycling. Where re-use is highly unlikely, and separation and recycling is well established this credit may not result in improvement in performance. An example where this is the case is in-situ concrete in the UK. Rating schemes should reward planning for end of life that enables conservation of resources, rather than design for dis-assembly specifically.

The credits provide a **framework** for professionals, however it is not possible to predict if they are a good **measure** of the sustainability of the building or a **practical tool** as they are largely untested.

Design for Deconstruction principles are set out in a number of references[79]. As a base level it is essential to avoid a short-life element causing pre-mature end of life to a longer-life element.

Recommendation 13.5

Planning for end of life should be rewarded by providing a checklist setting out the principles. Incremental scores should reward the extent to which these are achieved.

Detailed recommendation 13.6

A minimum 'pre-requisite' standard should be that the following building components must be easily separable from each other.

1. Building services
2. Façade
3. Structure

14 Review of health implications credits

Health implications are addressed in indoor air quality requirements, as well as some specific requirements. The requirements which are relevant to structure depend on the existence of local legislation. The scheme may need to supplement local requirements.

A number of the schemes studied include credits focussing on specific actions that are associated with health implications. Often, they were mandatory. Some examples are shown below.

Health			
ESTIDAMA PBRS		**CHINA 3 STAR**	
Hazardous Materials Elimination		*Harmful Matter (mandatory)*	
Demonstrate that no Asbestos Containing Materials (ACMs) are used and that no chromated copper arsenate (CCA)-treated timber is used on the project	SM-R1	The harmful matter content in a building material shall accord with the requirements in existing national standards including limits on ammonia emitted from concrete admixtures and amount of Radioactive Nuclide in building material	5.4.1

The health credits are most commonly aligned with local Government priorities (e.g. the asbestos credit in Estidama PBRS).

A pilot credit for the next healthcare version of LEED are looking at limiting the mercury content of supplemental cementitious material derived from coal-fired power plant wastes.[80]

In addition the ready-mix credit in China 3 Star has health and construction site impact implications to do with noise, dust pollution and treatment of waste water and concrete. This credit directly addresses Government priorities in China which prohibit on-the-spot concrete mixing in urban centres.

In other rating schemes wider health implications are covered in higher levels of responsible sourcing schemes, indoor air quality requirements and requirements for specific materials.

For structural engineers, credits which stipulate requirements for specific materials, such as those mentioned above, may be significant if this restricts the supply chain available. These credits become a matter for specification.

In many regions health implications are covered in other regulations, and hence the supply chain is well aligned with the requirements. Where this is not the case it is the duty of the rating scheme to ensure these aspects are covered. Rating schemes rely on the standardisation of measurement, reporting and the setting of levels in order to be able to include requirements in schemes.

Credits associated with Health issues should develop in response to local needs, based on a review of approaches available internationally.

15 Conclusions: An Aspirational Rating Scheme

The review of common topics showed that rating scheme credits can play an important part in supporting sustainable construction if devised correctly. The survey demonstrated an enthusiasm from structural engineers to contribute, both to the sustainability of buildings, and to the development of rating schemes which provide appropriate evaluation.

Some observations emerge from the above analysis:

For the rating scheme to be effective, structure should be scoring more than the current typical level of 5% of the credits (Section 4). This finding is supported by consideration of the **broader sustainability effects** of responsible sourcing beyond the project boundary (Section 10); the **avoidance of waste** through design and materials efficiency credits (Sections 7 and 13); and the **reduction in impacts** of the materials actually deployed (Sections 5, 8 and 12).

Taking the reduction in impacts alone, consideration of climate change or embodied energy places structural materials as 10% to 20% of the whole life impact of new buildings built to rating scheme standards. Therefore increased attention should be devoted to structure for sustainable buildings. The overall proportion needs to be balanced with the broader sustainability aspirations of each scheme and local priorities.

It was found that whole building measures (such as recycled content) are intellectually compelling. However the practical implementation was generally unable to address the impacts of structure appropriately. The exception is responsible sourcing, as this works with industry schemes which can be tailored to the relevant material supply chain.

To avoid cynical use of credits which only apply to one material, a minimum quantity should be stated below which the credit is deemed excluded from the scheme. This approach is used in Green Star.

The reasons for the low scores for structure emerge on detailed analysis of each topic area. The recommendations are for improved drafting of some individual credits and an overall approach which provides a mixture of actions relating to particular materials, combined with assessment of responsible sourcing, impact reduction, and planning for end of life. The recommendations for each topic area are presented together below.

15.1 General Recommendations

The approach to credits related to materials should be re-considered in schemes where up-take is consistently low, and there is poor correlation between increased material scores and high performing projects. (Recommendation 4.1)

Rating schemes should be providing a higher level of incentive to reduce impacts of structure than is currently demonstrated (Recommendation 5.1)

Credits should be provided for actions which support change across industry as well as an improvement in the sustainability of the project (Recommendation 6.1)

Credits associated with construction management should receive a lower weighting than those associated with the materials deployed in the building structure. (Recommendation 2.1)

The use of mandatory credits or minimum standards should be used for materials. (Recommendation 3.1)

Credits which are irrelevant to a project should be excluded from the scoring system. (e.g. existing buildings on Greenfield sites, and materials that are a very small proportion of the project). (Recommendation 3.2)

15.2 Reuse

High Level Recommendations

Retention of existing building structure should be rewarded. (Recommendation 7.1)

Credits relating to re-using substructure should be developed. (Recommendation 7.2)

An innovation credit should reward changes to industry practice with regard to reused materials supply chains. (Recommendation 7.3)

The avoided impacts of re-used and retained elements should also be recognised in assessments such as LCA or material efficiency. (Recommendation 7.4)

Detailed Recommendations

Targets should be based on the percentage of floor area of the existing structure that is retained. The minimum qualifying area should be a low percentage of the whole development (10% is suggested). (Detailed recommendation 7.5)

15.3 Portland Cement Reduction

High Level Recommendations

Absolute reduction in Portland cement levels in structural concrete (including foundations) should be rewarded. (Recommendation 8.1)

Detailed Recommendations

Compliance levels should recognise the different opportunities with in-situ, precast and pre-stressed concrete. Rewards associated with different replacement materials should be included. Over time the CO_2 footprint of the concrete should be used as the method of measurement. (Detailed recommendation 8.2)

15.4 Recycled Content

High Level Recommendations

Super-structure should be excluded from credits which reward whole building recycled content. (Recommendation 9.1)

(Other means of measuring reduced impact of structure should be deployed.)

If an individual recycled content for structural concrete is included this should include a pre-requisite to reduce Portland cement content, and practical achievable levels of including a known locally available secondary material in the concrete. (Recommendation 9.2)

Detailed Recommendations

Individual credits which specifically reward recycled content of steel are not an effective use of a building rating system. (Detailed recommendation 9.3)

If an individual recycled content for masonry is included this should include a pre-requisite to avoid significant road transport impacts. (Detailed recommendation 9.4)

15.5 Responsible Sourcing

High Level Recommendations

Responsible sourcing credits should be available for all materials and follow a tiered approach which provides both entry level requirements through to beyond best practice requirements. Reward for high performance should form a substantial element of the overall rating score. (Recommendation 10.1)

Additional responsible sourcing credits should be available for materials used in temporary works. (Recommendation 10.2)

Detailed Recommendations

The rating scheme should be based on existing industry initiatives and provide a means to identify higher performing systems. The requirements should be set out such that the rating schemes influence the development of the stewardship schemes that they endorse. (Detailed recommendation10.3)

There must be a means for smaller enterprises to demonstrate good practice with responsible sourcing. (Detailed recommendation 10.4)

The credits must achieve a reasonable balance between action and evidence. An example approach would be to set the maximum target for evidence of 90% rather than 100% of the element or material type in question to reduce paperwork associated with sundry elements[52]. (Detailed recommendation 10.5)

15.6 Local Sourcing

High Level Recommendations

Structural materials should be excluded from the local sourcing credits. (Recommendation 11.1)

The local sourcing requirements should be replaced by more targeted measures.

- Limiting distances/modes of transport as prerequisites for particular material credits.
- Responsible sourcing requirements. (Recommendation 11.2)

15.7 Life Cycle Assessment (LCA)

High Level Recommendations

LCA credits should follow a declared 10 year trajectory to support incremental change in industry. (Recommendation 12.1)

The rating schemes should aim to be setting benchmarks for different building types based on multi-indicator, whole life assessments. (Recommendation 12.2)

LCA Credits should consider the impact of structure and substructure based on actual quantities and specification. (Recommendation 12.3)

Detailed Recommendations

A clear basis for comparison of functional equivalence should be established based on current and predictable future best practice. (Detailed recommendation 12.4)

LCA Credits should reward the reporting of data. (Detailed recommendation 12.5)

Rating schemes should provide clarity and openness for providers of LCA tools and data. Requirements should provide a transparent and accessible platform for industry to engage with LCA. (Detailed recommendation 12.6)

A tiered approach should provide high rewards for early adopters and provision for entry level engagement: (Detailed recommendation 12.7)

15.8 Efficiency & Future Proofing

High Level Recommendations

Rating schemes should provide a method to establish benchmarks and provide examples of acceptable evidence. (Recommendation 13.1)

Measured material efficiency should be rewarded. This could form a lower tier entry to an LCA based credit.(Recommendation 13.2)

Specific adaptable design features should be listed in the rating scheme and be rewarded. (Recommendation 13.3)

Planning for end of life should be rewarded by providing a checklist setting out the principles. Incremental scores should reward the extent to which these are achieved. (Recommendation 13.5)

Detailed Recommendations

Functional units for material efficiency and LCA type credits for structure should take account of industry good practice regarding future adaptability. (Detailed recommendation 13.4)

A minimum ‘pre-requisite’ standard should be that the following building components must be easily separable from each other.

1. Building services

2. Façade

3. Structure

(Detailed recommendation 13.6)

15.9 Next Steps

It is hoped that the research presented in this document will assist in a dialogue with building rating scheme providers. The aim is to ensure that structural engineers can play an active part in multi-disciplinary teams delivering sustainable buildings.

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