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Abstract

Despite the advances in sustainability rating systems, and the introduction of Soft Landings (SL) and Building Information Modelling (BIM), little is known about the true environmental impact of buildings over their full lifecycle. There is growing attention in the full lifecycle assessment of buildings, including embodied, operational and decommissioning impacts, and an increased interest in rating systems and associated methodologies. As yet, however, these systems are largely unconnected. This paper presents the early findings of a funded project to investigate the sustainable efficacy of BIM, SL and sustainability indicators, used concurrently to deliver commercial buildings.

Keywords Building Sustainability Rating, Embodied Energy, Embodied Carbon, Building Information Modelling, Soft Landings

1.0 Introduction

According to Feifer (1) a core aspect of a sustainable building is that it provides for human wellbeing over the long term. In the case of the built environment, wellbeing as it applies to the effects on people can be argued to include a variety of issues, for example buildings which are healthy, safe, and create productive and enjoyable space, while at the same time being low consumers of energy and carbon.

Building assessment tools enable an evaluation of the environmental performance of buildings (2) together with having an aim of guaranteeing certain aspects of health and wellbeing (3). Such tools can be expected to reduce operating costs as well as increasing the productivity of building users, thereby enhancing commercial values and arguably contributing to the creation of sustainable communities (3).

The leading environmental assessment tools for buildings include the ‘Building Research Establishment Environmental Assessment Method’ (BREEAM) in the UK; the ‘Leadership in Energy and Environmental Design’ (LEED) in the United States; the ‘Green Star’ in Australia and the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) in Japan.

These assessment tools, described in Table 1, are criteria based tools which offer a way of assigning points to a range of parameters on a scale ranging between small and large environmental impacts.

Table 1 - Summary of building rating systems

Building rating system	Main market	Launch data	Latest version (update)
BREEAM	UK, partial European countries	1990	BREEAM 2014 (27th May 2014)
LEED	North America	1998	LEED v4 (end of 2013)
Green Star	Australia, New Zealand and South Africa	2003	Green Star 2014 (July 2013)
HK-BEAM	Hong Kong	1996	BEAM Plus v1.2 (2012)
CASBEE	Japan	2001	CASBEE for New Construction 2010 edition (2010)

However, in general such tools do not provide a comprehensive assessment. For example, the energy consumption that is embodied within the production processes used for many construction materials, as well as the energy that is used within the transportation and the eventual disposal of construction materials are not accounted for fully. Recent research argues that embodied energy potentially accounts for as much as 46% of the total life cycle energy (4). Therefore, it is arguable that the embodied energy consumption within construction materials ought to be appraised by environmental assessment tools. Life Cycle Assessment (LCA) is one approach used to assess the complete environmental performance of a product (5) and consequently is one method to capture the whole life embodied energy within construction materials. Few rating systems adopt LCA methods. BREEAM attempts this, but arguably contains flaws in its approach.

This paper describes a BREEAM pre-assessment case study which was carried out to investigate the potential environmental impacts of an academic building at the Riccarton campus of Heriot Watt University in Edinburgh. The Sir Charles Lyell Centre will be a world-leading centre for research and expertise in the earth and marine sciences (6), and is due for completion in 2015. The Lyell Centre will be constructed to BREEAM 'Very Good' standard and delivered using Soft Landings (SL) and Building Information Modelling (BIM) tools. Lessons learned from this pre-assessment will inform the ongoing research of a longer 42 month research project which has recently started. Three main tools are employed: BREEAM 2011 Pre-Assessment Estimator Template v2.61 (7), a publicly available tool for the assessment of potential building performance; Building for Environmental and Economic Sustainability (BEES) online tool (8); and Green Guide 2008 Ratings (9). All primary sources of data were collected directly from the construction project team. An appraisal of this pre-assessment is made and a discussion of the role of SL and BIM in designing truly sustainable buildings is offered.

2.0 Assessment Tools

The BREEAM 2011 Pre-Assessment Estimator Template (7) was used to assess the main elements of the Lyell Centre prior to construction. Scoring is based on a simplified pre-formal BREEAM assessment, and includes all assessment categories, as described in Table 2.

Table 2 - BREEAM Pre-assessment categories.

BREEAM 2011 environmental action list		Max. Credits Available
Management		**22**
Man 01	Sustainable Procurement	8
Man 02	Responsible Construction	2
Man 03	Construction Site Impacts	5
Man 04	Stakeholder Participation	4
Man 05	Life Cycle Cost and Service Life Planning	3
Pollution		**13**
Pol 01	Impact of Refrigerants	3
Pol 02	NOx emissions	3
Pol 03	Surface Water Run Off	5
Pol 04	Reduction of Night Time Light Pollution	1
Pol 05	Noise Attenuation	1
Materials		**13**
Mat 01	Life Cycle Impacts	6
Mat 02	Hard Landscaping and Boundary Protection	1
Mat 03	Responsible Sourcing	3
Mat 04	Insulation	2
Mat 05	Designing for Robustness	1
Water		**9**
Wat 01	Water Consumption	5
Wat 02	Water Monitoring	1
Wat 03	Water Leak Detection	2
Wat 04	Water Efficient Equipment	1
Health & Wellbeing		**17**
Hea 01	Visual Comfort	4
Hea 02	Indoor Air Quality	6
Hea 03	Thermal Comfort	2
Hea 04	Water Quality	1
Hea 05	Acoustic Performance	2
Hea 06	Safety and Security	2
Energy		**32**
Ene 01	Reduction of CO_2 emissions	15
Ene 02	Energy Monitoring	2
Ene 03	External lighting	1
Ene 04	Low and Zero Carbon Technology	5
Ene 05	Energy Efficient Cold Storage	2
Ene 06	Energy Efficient Transportation Systems	2
Ene 07	Energy Efficient Laboratory	3
Ene 08	Energy Efficient Equipment	2
Ene 09	Drying Space	N/A
Transport		**11**
Tra 01	Public Transport Accessibility	5
Tra 02	Proximity to Amenities	1
Tra 03	Cyclist Facilities	2

Tra 04	Maximum Car Parking Capacity	2
Tra 05	Travel Plan	1
Waste		**6**
Wst 01	Construction Waste Management	4
Wst 02	Recycled Aggregates	1
Wst 03	Operational Waste	1
Wst 04	Speculative Floor and Ceiling Finishes	N/A
Land Use & Ecology		**10**
LE 01	Site Selection	2
LE 02	Ecological value of site and Protection of Ecological Features	1
LE 03	Mitigating ecological impact	2
LE 04	Enhancing Site Ecology	3
LE 05	Long Term Impact Biodiversity	2
Innovation		**10**
Man 01	Sustainable Procurement	1
Man 02	Responsible Construction Practices	1
Hea 01	Visual Comfort	1
Ene 01	Reduction of CO_2 Emissions	5
Ene 04	Low and Zero Carbon Technology	1
Ene 05	Energy Efficient Cold Storage	1
Wat 01	Water Consumption	1
Mat 01	Life Cycle Impacts	1
Mat 03	Responsible Sourcing of Materials	1
Wst 01	Construction Waste Management	1
Wst 02	Recycled Aggregates	1

Twelve environmental criteria (Ene01, Tra01, Wat01, Mat01, Mat03, Mat04, Wst01, Wst02, LE03, LE04, Pol01 and Pol02) require the support of specific calculation processes. All calculation processes comply with the guide of BREEAM New Construction-Non-Domestic Buildings Technical Manual (10). Notably, Mat01 requires additional tools to support its calculation.

The BEES online tool (8) and Green Guide Ratings (9) online are employed to support the calculation of Mat01. The BEES software was developed by the National Institute of Standards and Technology (NIST), and is based on a life-cycle assessment approach and the ISO 14040 (5) standard series. For this initial research, the building elements assessed and presented in Mat01 include: external and internal walls, roof, windows, upper floor slab, and floor finishes/covering. The CO_2 emission data of these building elements are analysed using BEES. Summed with the embodied CO_2 of raw materials is the embodied CO_2 of transportation from manufacture to use.

For Mat01 each building element is also rated using the publicly available Green Guide 2008 rating tool (9). The ranking system of the Green Guide is based on LCA and BRE's Environmental Profiles Methodology (11). It ranks building constructions into six levels, from A+ to E. For the BREEAM pre-assessment, Mat01 requires a Green Guide ranking. By following the guide of BREEAM New Construction-Non-Domestic Buildings Technical Manual (10), the ranking of each element and corresponding CO_2 emissions are combined to reach a more accurate ranking.

3.0 Methods

Most primary data was collected directly from the construction team, architectural specifications, civil and structural documents, and mechanical and electrical documents, plus various construction drawings. Some specific data was collected from online maps and manufacturers' literature. Some data was gathered from the client requirements and building performance targets This study is based on the assumption that this data is applicable and dependable for pre-assessment.

As a higher education building, the Lyell Centre will provide offices, dedicated and shared facilities, research and communal spaces for more than 200 staff from the British Geological Society and Heriot Watt University to work together over three floors. The building has a floor area of approximately 5300 m^2.

Using the BREEAM Pre-Assessment Estimator, credits are evaluated based on the best building information available, with the exception of the twelve measurable elements mentioned above, which require calculation to determine the number of credits achievable. All calculation processes conditionally comply with BREEAM New Construction-Non-Domestic Buildings Technical Manual (10).

3.1 Mat01, Mat03 and Mat04 Calculations

A Bill of Quantities (BoQ) is required to evaluate the materials section. According to project data, the external walls are a steel framing system with clay facing brickwork. The windows are generally a curtain walling system. The upper floor construction is a steel frame with in situ concrete floor slabs on metal decking. The process of calculating BREEAM credits for building elements is similar for walls, roofs, floor slabs, windows and finishes. The calculation process for Mat01 is demonstrated in three steps using an external wall as example.

Step one - calculate the scoring for each external wall specification. Green Guide 2008 Ratings (9) are used to obtain a ranking according to wall construction. The ranking is translated into a number of points using Table 3. If the external wall construction consists of several different types, the overall points achieved for the external wall are recalculated depending on the area proportion of each type and relative ranking in Green Guide rating.

Step two - calculate the points uplift for each individual element of external wall and add to step one. BEES online is used to obtain CO_2 emission data of each individual element. The proportion of total environmental impact of the assessed element is replaced by the proportion of CO_2 emissions. Table 2 is used to translate the ranking into a number of Tier Max. points which is decided by the tier level of each individual element manufacturer. Where an independently verified third-party Environmental Product Declaration (EPD), covering part of or the whole life cycle, is available for a material/product that forms part of an assessed building element, this can be used to increase the contribution of that element to the building's Mat 01 performance. EPD Tier Level 1 refers to a third-party, independently verified EPD covering the whole life cycle (i.e. cradle-to-grave), while EPD Tier Level 2 refers to a third-party, independently verified EPD covering partial life cycle (i.e. cradle-to-gate partial life cycle).The overall points uplift of each element is calculated by multiplying the proportion of total environmental impact and Tier Max. uplift. The final points achieved for the external wall are calculated by adding total points uplift to the points achieved in Step One.

Step Three - calculate the building element score to achieve an overall score. The final Green Guide rating of roof, windows, floor materials etc. are calculated by the same method. Once completed the BREEAM system automatically generates an overall score for Mat01.

Table 3 - Green Guide points uplift by rating level and EPD type (10)

Existing Green Guide Rating	Mat01 Points	EPD Tier 1 Max points uplift	EPD Tier 2 Max points uplift
A+	300	1.0	0.75
A	200	1.0	0.75
B	100	1.0	0.50
C	50	0.5	0.25
D	25	0.25	0.125
E	0	0	0

Brickwork on Framed Construction has a Green Guide rating of "A+". The external walls consist of 102 mm facing brickwork, 50 mm cavity, 100 mm insulation breather membrane and 22 mm ply sheathing on a steel framing system. The total surface area of the building is approximately 3075 m^2. The area of the external walls is approximately 1,778 m^2. Table 4 details the input data required to calculate embodied carbon content for individual wall elements.

Table 4 - Green Guide points uplift by rating and tier level (12)

material	Tier level	EPD Tier level	Thickness (mm)	Area (m^2)	Mass (tons)	Transport distance (miles)	Embodied carbon (g/m^3)	Total Embodied carbon (kgCO_2)
Clay facing brickwork	T4	None	102	1778	256	300	5322	965
Cavity insulation	T4	T1	100	1778	6	327	338	60
Plywood sheathing	Not availabl e	None	22	1778	23	5	496	19
Light steel frame	T3	None	-	-	44	290	732	7785

For the correct Green Guide rating, the points uplift for each external wall type should be evaluated. Based on embodied carbon weighting and EPD tier level of each product, the final uplift points are 0.0068, based on Table 5. The overall rating of the external wall is "A+", which translates to 3 points. The final points achieved are 3.0068, which is translated to "A+".

Table 5 - Green Guide rating for external walls

External wall specification	Embodied carbon (kgCO2)	Proportion of element impact	EPD tier	Points uplift
Clay facing brickwork	965	11%	none	0

Partial fill cavity insulation	60	0.68%	1	0.0068*1
WBP plywood sheathing	19	0.32%	none	0
Light steel frame	7785	88%	none	0
Total uplift points				0.0068
Total points achieved for external walls				3.0068 ("A+")

Using the same method, the ratings for internal walls, roof, upper floor slab, windows and floor finishes were calculated. Table 6 summarises these findings.

Table 6 – Summary of points rating for building elements

Building element	Construction	Green Guide Rating	Uplift Points	Final Points (Rating)
Internal Wall with High Sound Resistance	Steel C studs (70 mm), 50 mm wool insulation within 72 mm cavity, and 15 mm gypsum wallboard with skim coat plaster to each side	A+	0.892	3.892 (A+)
Warm Deck Flat Roof	New concrete roof deck, internal parapet lining with insulation boards over plywood, vapour control layer, carrier membrane and waterproof coating.	B	0	1 (B)
Double glazed curtain walling	Aluminium framed double silicon glazed curtain walling	D	0	0.25 (D)
Upper floor slab	150 mm concrete slab on 0.9 gauge metal decking	A+	No BoQ available	A+
Floor finishes/covering	Vinyl Sheet Flooring, and	A+	0.822	1.832 (B)
	Carpet	B	0.584	
	Epoxy Resin	A+	0.426	

Figure 1 shows the Green Guide rating for each building element assessed in Mat01. Mat01 achieves 4 out of 6 credits and 0 innovation credits.

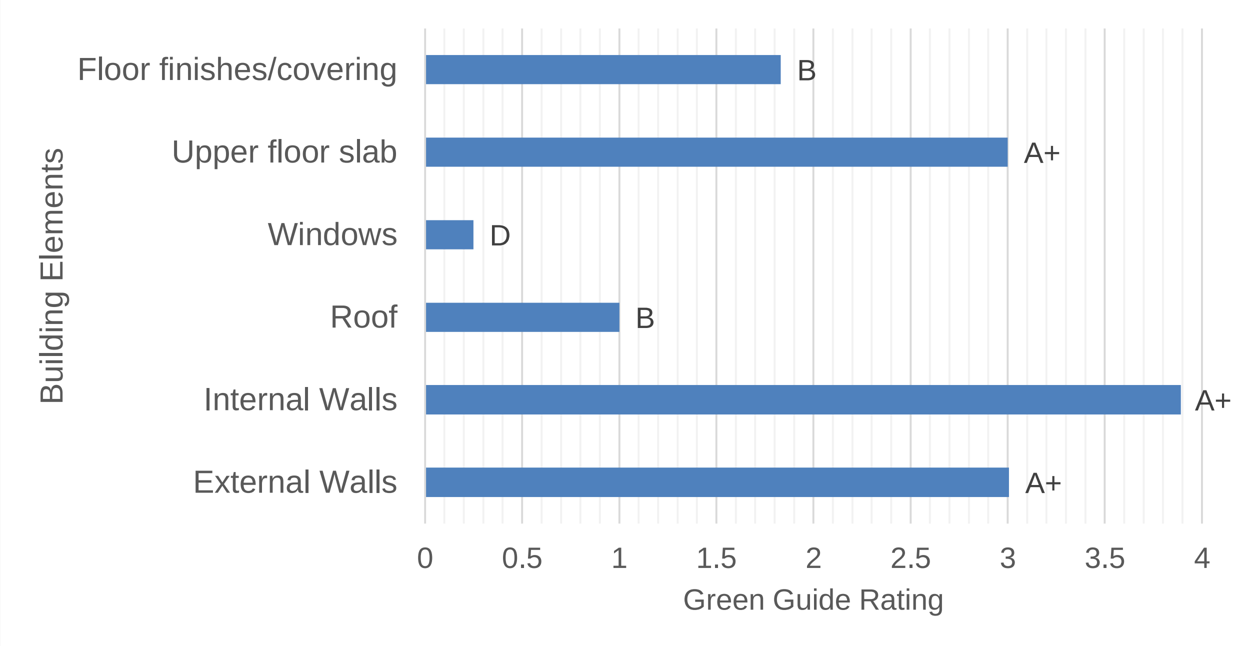

Figure 1 - Green Guide rating summary for Mat01 building elements

Mat03 and Mat04 credits relate to the responsible sourcing of materials, according to BREEAM (10). Both categories receive full credits but no innovation credits.

3.2 Ene01 Calculation

The score for Ene01, is dependent upon the Energy Performance Ratio (EPRNC) which is derived from the building floor area, notional and actual building energy demand and consumption, Target Emission Rate (TER)(12) and Building Emission Rate (BER)(12). Dynamic thermal simulation software, TAS was used to estimate the operational energy demand and emission rating for the building. During construction, metering will be installed to measure the actual energy consumption. During the pre-assessment phase, EPRNC is valued at 0.6, achieving 10 out of 15 credits and 0 out of 5 innovation credits.

3.3 Tra01 Calculation

Tra01 is a measure of accessibility of public transport. To evaluate these credits it is necessary to calculate the Accessibility Index (AI). Firstly, the Total Access Time has to be calculated, which is evaluated by combining Walk Time and Average Waiting Time. Walking distance is measured from the entrances of the assessed building to the public transport facilities (in this case, public bus only). An average walk speed of 4.8 km/hr is used. In this case, the walking route from the building to the bus stop is 400m (walk time 5 minutes). The Average Waiting Time is the average time of the gap between the arrival of a passenger at the bus stop, and the arrival of a public transport vehicle. In this case, the Average Waiting Time is specified at the end of the working day (5pm-7pm). During this period there are 29 buses arriving and leaving. Average waiting time, 4 minutes. Total Access Time is therefore 9 minutes. The AI is the sum of all Equivalent Doorstep Frequencies (EDF), which is based on the Total Access Time. AI is 3.3, which falls short of the minimum 4 required for full credits. The result is 1 credit of a possible 2 credits.

3.4 Wat01 Calculation

There are various water consuming components throughout the building need, including several WCs, taps (wash hand basins and kitchens), showers and commercial sized dishwashers. The Modelled Net Water Consumption (Tn_{Act}), Modelled Baseline Water Consumption (Tn_{Base}) and Total Default Occupancy Rate (Tn_{Occ}) are required for calculating the percentage of improvement of water consumption which can be translated into BREEAM credits (10).

Tn_{Act} depends on the consuming performance level of each water component required. Tn_{Base} for each component can be found from the water efficient consumption levels standards provided by BRE Global Ltd (10), shown in Table 7.

Table 7 - Water consumption per component, (10)

	$T1_{Act}$ (L/person/day)	$T2_{Base}$ (L/person/day)
WCs	17.7	26.5
Wash hand basin Taps	8.7	20.5
Kitchen Taps	13.6	14.9
Showers	33.6	78.4
Commercial sized dishwashers	18	28

The overall improvement is calculated using net and baseline values coupled with a default occupancy rate of one. An improvement of 45.6% was found, achieving 3 points in Wat01 because the overall improvement is less than 50%.

3.5 Wst01 and Wst02 Calculation

According to the general structural clauses for the Lyell Centre, the contractor shall provide evidence of the site waste management scheme and keep coordinating and cooperating with sub-contractors of the plan. There is no applicable pre-demolition audit for this project. At the same time, the target total percentage of recycled/ secondary high-grade aggregate is not available. Consequently, both Wst01 and Wst02 cannot achieve any credits at this stage.

3.6 LE03 and LE04 Calculation

For LE03, plant species richness is used to determine the change in ecological value; the diversity of plant species becomes an indicator for evaluating the project's impact. According to data from average total taxon richness by broad habitat in Green Britain provided in BREEAM New Construction-Non-Domestic Buildings Technical Manual (10), the ecological values for previously developed existing site and post-construction site are calculated. The final ecological impact, measuring the change in area and land richness over parking land, mixed woodland, hedge land and grassland is -1.89. Although the ecological impact is negative, it is not less than -9. Therefore, LE03 achieves 1 out of 2 credits.

In LE04, there is no evidence to show that an ecologist is appointed to improve the site ecology. Consequently LE04 cannot achieve any credits at this time.

3.7 Pol01 and Pol02 Calculation

The type of refrigerant adopted in the Lyell Centre project is R410A. A list of a number of refrigerant types with Global Warming Potential (GWP) produced by

DETR/DTI (13) shows that R410A refrigerant has a Global Warming Potential (GWP) of 1725 kg CO_{2eq}. To calculate the Direct Effect Life Cycle CO_2 equivalent emissions (DELC) required in Pol01, the refrigerant loss, retirement, GWP and cooling capacity are required. In this case, the chosen system is a chilled water system. Using manufacturer data relating to refrigerant charge, leakage rates and operational lifetime, and probability of catastrophic leakage, the DELC is calculated to be 359.2 $kgCO_2/kW$. A refrigerant leak detection system will be installed to meet Pol01 criteria whilst the building management system (BMS) is responsible for sending out a warning when it receives a sign of leakage from the detection system. As a result, Pol01 achieves 2 out of 3 credits.

Pol02 requires the data of NO_x emissions emitted by space heating systems and water heating systems. The Lyell Centre adopts Combined Heat and Power (CHP) engines to supply heat to the building space and Low Temperature Hot Water (LTHW) gas fired boilers to heat water. The NO_x emissions per unit of heat supplied by the CHP system (X_{CHP}) and LTHW boilers (X_{LTHW}) are calculated based on data regarding units of electricity from the national grid, consumption of natural gas, boiler efficiency, and heat to electricity ratio.

NO_x emission level for space heating system: X_{CHP} = -1123 mg/kWh

NO_x emission level for water heating system: X_{LTHW} = -761 mg/kWh

The calculation result shows that the NO_x emission level of either CHP or LTHW is negative. According to the BREEAM New Construction-Non-Domestic Buildings Technical Manual (10), they should be assumed to be 0 mg/kWh. As a result, Pol02 achieves full credits.

3.8 Summary of BREEAM pre-assessment

Assembling all sections of the BREEAM Pre-assessment and populating with the results above reveals a total final pre-assessment score for the Lyell Centre. This is shown in Table 8.

Table 8 - BREEAM Pre-Assessment Score Summary

Environmental Section	**Credits Available**	**Credits Achieved**	**Section Weighting (%)**	**Section Score**
Management	22	22	12	12
Pollution	13	12	10	9.23
Materials	13	11	12.5	10.58
Water	9	7	6	4.67
Health & Wellbeing	17	13	15	11.47
Energy	32	23	19	11.88
Transport	11	5	8	3.64
Waste	6	1	7.5	1.25
Land Use & Ecology	10	1	10	1
Innovation	10	2	10	2
Total BREEAM Score				**67.71**
			Rating	**"Very Good"**

Excellent scores are predicted for many of the early sections, including management, pollution, materials, water, and health and wellbeing. Energy achieves approximately one third of the available credits, while transport, waste, land use and ecology, and innovation have significant room for improvement.

Some immediate observations are notable.

- The low Green Guide rating for the specified curtain walling system leads to a 'D' rating for this element under Mat01.
- The absence of consideration of grey water and rainwater applications in the pre-assessment may lead to lower credits than is evident in the building construction.
- Better communication during the early design phases may have led to improved daylighting and natural ventilation design parameters.
- At the point of assessment, a Low and Zero Carbon Technology assessment had not been carried out, losing several credits within the Energy section of the assessment for renewable energy potential.
- A compliant pre-demolition audit would have added much needed strength to the waste section of the assessment.

4.0 Discussion

With regard to humans, sustainability is defined as the potential for long-term maintenance of wellbeing (1), which has environmental, economic, and social dimensions. So when discussing buildings, the core issues are long-term maintenance and wellbeing of the users, seen under the aspects of environmental, economic, and social dimensions. In order to ensure that best practice is upheld and repeated while poor practice is improved with successive construction projects, it is clear that a yard stick is required. This need for measurements and assessment is interpreted in the form of sustainability rating systems for buildings (BREEAM and others), and takes many forms globally. The benefit of these generic systems is that there is a recognised system of measurement and a comparable set of indicators. The temptation, however, is to become solely focused on points scoring and credit gains.

4.1 Soft Landings (SL)

Other initiatives entering the construction sector, aimed at lowering energy and emissions, and improving the construction process include Soft Landings (SL) and Building Information Modelling (BIM). SL, a form of graduated handover for new and refurbished buildings, aims to foster a common vision between all building stakeholders to ensure the continuity of low carbon aspirations throughout the construction process (14). Feedback about a building's operational performance to provide better understanding of whether the building is as effective in use as it was intended to be at the design stage is critical to the future design of sustainable buildings. SL is designed to close this feedback loop and allow designers to apply their learning to future projects. There is a strong focus on handover between building completion and operational readiness with excellent commissioning to avoid a 'hard landing'.

The research question is posed, that "If an imbalance of credits is seen across various sections of an assessment, does this in fact lead to a sustainable building or a hard landing?” When commissioning such a building will the deficit in some aspects of the building design in fact lead to reduced occupant wellbeing, or additional energy consumption and therefore increased carbon emissions?

As the remainder of this project unfolds careful investigation will be made regarding the role of the SL Champion in ensuring that energy consumption is as closely matched to that predicted during the design stages. A post-occupancy evaluation of the building and its occupants will also reveal important feedback on the procurement, construction, management and design of the building.

4.2 Building Information Management (BIM)

BIM is an innovative and collaborative way of working that is underpinned by digital technologies which provide support to the design, creation and maintenance of the built environment. Essentially BIM embeds key product and asset data within multi-dimensional (2D-6D) computer models that can be used for effective management of information throughout a project’s lifecycle. The managerial benefits of BIM focus particularly on the enhanced collaboration that can be provided within and between design and construction processes and in the construction project team. This is significant because the construction project organisation is always highly complex as a consequence of the levels of specialism, diversity, and sentience that naturally occur within the separate disciplines and which must be brought together to deliver the project outputs.

A number of technical benefits have been credited to BIM, including cost savings, schedule and time savings, environmental benefits during production, improved design and construction information, identification of clash detection, improved asset performance, and reduced waste (15). Most notable in the current design arena are benefits associated with environmental sustainability and carbon performance, achieved through dynamic thermal modelling tools. Changes to material selection, building geometry and orientation can be modelled in advance of construction and changes made to the architectural design in the early project phases, quicker and more efficiently than was previously possible.

It can be argued that as the Lyell Centre is being delivered using BIM, employing a SL champion, and meeting BREEAM ‘very good’ standards that the full award of credits under the Management section are achieved as a result. However, the results of the above pre-assessment demonstrate room for improvement in relation to energy use, and significant opportunity for improved learning across transport, waste, land use and ecology, and innovation sections. The temptation to score credits at any cost needs to be avoided if a truly sustainable and well commissioned building is genuinely sought. In fact, the economic profit aspects are the weakest dimension in terms of indicators generally; they are not considered at all in BREEAM. However, it is in the public interest that sustainable buildings stay within financial reach and social accessibility. Sustainability by definition must be within social reach, and not only available for affluent or public clients. The cost of long term health related issues; of lack of productivity and absenteeism of workers, exceed many times over the justification for reducing the upfront costs of sustainable buildings.

5.0 Conclusions

This paper describes a BREEAM pre-assessment case study which was carried out to investigate the potential environmental impacts of an academic building at the

Riccarton campus of Heriot Watt University in Edinburgh. The Lyell Centre, delivered under Soft Landings guidance, using Building Information Modelling tools, and specified to BREEAM 'Very Good' standard demonstrates how the construction industry in the UK has not yet developed a flawless building assessment method which allows the full life cycle impacts of buildings to be assessed in terms of environmental, social and economic sustainability. Lessons learned from this pre-assessment will inform the ongoing research of a longer 42 month research project which has recently started. This ongoing research aims to address a number of critical questions, including:

- Do sustainability rating systems for buildings actually produce low energy, low carbon buildings in practice?
- Does the simultaneous use of BREEAM, SL and BIM lead to the optimal building design and operation for its occupants? Is this excessive? Is this sufficient? Is there a better way?
- What is the impact on lifecycle carbon and energy of using responsibly sourced materials; using locally sourced labour and expertise; performing enhanced POE; and designing for recyclability?

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Acknowledgements

Thanks are extended to project sponsors, Arup, Max Fordham, Deloitte Real Estate and Gardiner Theobald, and to project client, Heriot Watt University Estates for help in providing timely and accessible data to complete this study.