Whole life appraisal of building components for zero carbon buildings

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ABSTRACT

There is significant industry and academic attention being paid to the design and operation of zero carbon (ZC) buildings. The UK Government has set targets for domestic buildings to be ZC by 2016, and for non-domestic buildings to be ZC by 2019. For buildings to be truly ZC requires the consideration of energy and carbon emissions of manufacturing, transporting, constructing, using, maintaining and disposing of building materials and components. Information on the environmental impact of these lifecycle stages is increasingly sought after in voluntary and other environmental appraisal systems. In order to assess the lifecycle of a material or component an assessment of its service life and maintenance requirements is required; commonly termed the *estimated service life*. Time, cost and quality indicators remain paramount in the construction industry; thus the financial cost of initial and on-going costs is needed to complete most specification requirements. This paper presents a methodology for service life, financial and environmental appraisal of building components and materials, and discusses a case study of the method applied to timber windows.

KEYWORDS: Life Cycle Assessment, Service Life Planning, Whole Life Costing

1. INTRODUCTION

1.1 Zero carbon buildings

The definition of ZC buildings in the UK has undergone several changes in recent years to reflect the ability of new developments to meet ZC guidelines. Until 2008 the ZC definition required all CO_2 emissions to be reduced to zero through on-site means. Both *regulated* (from heating, cooling, ventilation and lighting) and *unregulated* (from household appliances) emissions had to be accounted for. In 2009 the concept of *allowable solutions* was proposed by the UK Government. By paying into a fund (to establish carbon-saving projects elsewhere), a lower on-site emissions target could be set for developers, while preserving the ZC policy initiative. In March 2011 unregulated emissions were removed from the definition (Zero Carbon Hub, 2013)

This definition, while improved, and more achievable fails to encompass any issues relating to the embodied carbon of raw materials and processing. The construction industry is the highest consumer of materials globally, consuming around 6 tonnes of material per person per year. A fair and considered building whole life appraisal must account for the longevity of these components, the life cycle costs of their purchase and maintenance, and the environmental impact of lifecycle processes.

This paper describes how these considerations can be brought together in one model for simultaneous consideration, and presents a case study of its application.

1.2 UK perspective

The UK is dominated by two lifecycle inventory datasets; the Building Research Establishment (BRE) Green Guide to Specification (BRE, 2009), which provides information the BRE Environmental Assessment Method (BREEAM, 2011) and the Code for Sustainable Homes (CfSH, 2008); and the Inventory of Carbon and Energy (ICE, 2011) originating from Bath University and now managed by the UK Building Services Research and Information Association (BSRIA, 2011). The BRE Green Guide is a construction specific Life Cycle Assessment (LCA) based tool which is defined by the Environmental Profiles methodology (BRE, 2007). Its strengths lie in the breadth of construction components covered by the tool, but it is limited in use to expert LCA practitioners because of its lack of transparency, repeatability and data representation.

The ICE database is the most comprehensive LCI dataset specific to the UK and widely used in LCA studies with good coverage of basic industry and construction materials. Care needs to be taken when using any data, as different, non-explicit, boundary conditions apply to datasets from different sources. For example some sources include transport effects while other omit them, and some report cradle to gate data, while others report cradle to grave or cradle to site data.

1.3 EU/rest of world perspective

IES (Integrated Environmental Solutions) Virtual Environment software launched "Impact" in late 2012. Impact brings together embodied carbon data from the BRE Green Guide, with cost data BRE Envest2 (BRE, 2013) to provide a ready and quick tool for estimating embodied carbon and life cycle costs. Both these sources of data provide a top-down and very general guide to carbon and cost, based on an analysis of service life. The ability to interrogate individual design materials and to investigate changes to materials, processes, sources and disposal is not available.

CILECCTA (2013) software is being developed which is capable of assessing the Life Cycle Cost (LCC) and environmental impacts (LCA) throughout the life cycle of a building. This EU-FP7 project is developing a software demo that is compatible with codified price banks as well as life cycle inventory results across Europe.

Hernandez and Kenny (2010 and 2011) produced two papers describing an approach for building life cycle energy ratings, and a definition for life cycle zero energy buildings. The first relies on setting a reference building embodied energy value and then "charging" embodied energy for variations to the reference building. While this might be useful in removing the complexities of analysing whole building embodied carbon values, it does not afford the granularity of data to explore individual life stage issues. Life cycle zero energy buildings are defined as buildings which produce sufficient energy throughout their operational phase to "pay for" the embodied carbon of the construction phase, and a method of analysing this process is offered in the second of these papers.

2. WHOLE LIFE APPRAISAL METHOD

Establishing the Estimated Service Life (ESL) of a building component or material is an essential precursor to the LCC and LCA analyses that follow for a full whole life appraisal to be made. They are inextricably linked; for example, a component maintenance event is likely to require materials and resources, having both financial and environmental costs attached, while the selection of a component with a longer ESL may have a higher capital cost, but lower LCC over the life of the building. The extended service life is also likely to lower its environmental impact in LCA terms due to fewer components being used over the life of the building. Figure 1 shows the whole life appraisal system.

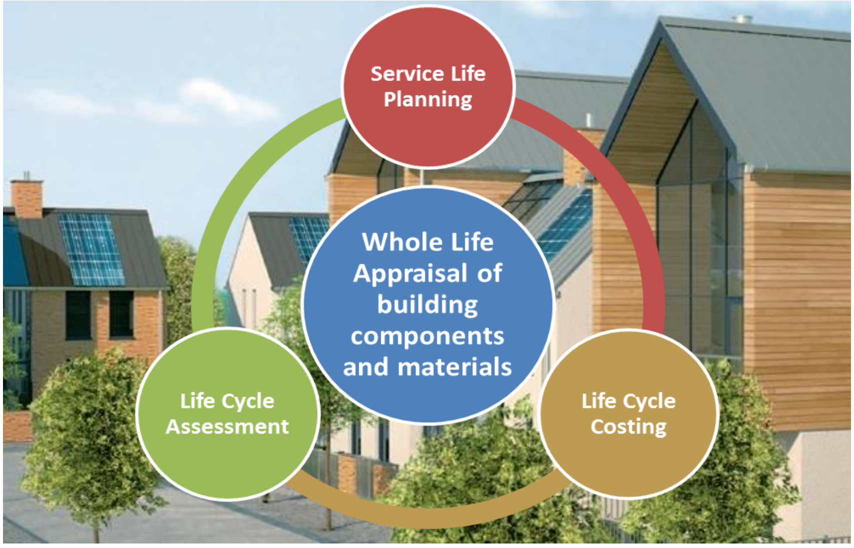

Figure 1. Whole Life Appraisal system

2.1 Service Life Planning (SLP)

ISO 15686 is the international standard governing SLP of a building, constructed work or component. ISO15686-8 (ISO, 2008) lays out the methodology to give a structured response to establishing normal service life from a reference or estimated service life framework. It allows variances in performance, design, maintenance, use or exposure environments to inform the likely service life of the item. The objective of SLP is to provide reasonable assurance that the estimated service life of a building or construction on a particular site, with appropriate maintenance, is at least as long as the design of that building.

2.2 Life Cycle Costing (LCC)

LCC can be assessed using a standard discounting method, Net Present Value (NPV), which allows the time value of money to be allowed for in the value of future payments or incomes. A simple NPV discount model provides a useful tool for comparing the whole life costs of different investment options and varying investment episodes, using appropriate inflation and investment rates. A building design life needs to be established in order to compare alternatives. In accordance with many studies, including the BRE Green Guide, this was taken to be 60 years.

2.3 Life Cycle Assessment

Life Cycle Assessment (LCA) is an internationally recognised tool for assessing the environmental impact of products, processes and activities. It is a methodology for evaluating the environmental load of processes and products during their whole lifecycle and is one of various environmental management tools currently available for assessing impact and sustainability. There are a number of standards governing the execution of LCA studies, including, ISO 14040 (ISO, 1996), PAS2050 (BSI, 2011 and CEN TC 350 standards (CEN, 2013).

Energy is needed to create buildings through extraction and processing of raw materials; manufacture of finished products and components; during construction; to transport materials and products to site; to maintain components; and to process materials at their End of Life (EoL) to recycle and/or dispose of materials [Consoli et al., 1993]. If a boundary is drawn around this lifecycle and an assessment of inputs and outputs which cross this boundary is made, some attempt is given at assessing a building's Life Cycle Assessment (LCA), Figure 2.

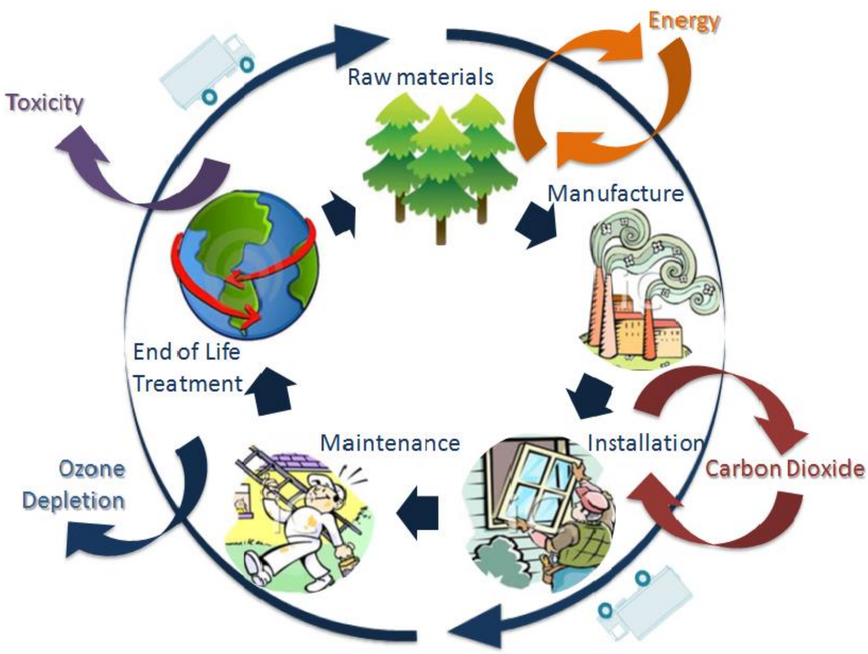

Figure 2. Life Cycle Assessment

3. TIMBER WINDOW CASE STUDY

Using the methods defined above, the service life, ownership cost and environmental impact of timber, modified timber, aluminium-clad timber and PVC-U frames window were compared. A standard window (1230 x1480 mm with one side-opening light) in each of the four frame materials was considered, taking into account the relative durability of the materials and their maintenance requirements.

Timber windows referred to here are constructed from high quality, preservative treated softwood; constructed from a defect free enhanced substrate (heartwood); and with endgrain and construction joint sealing. Although the analysis here is limited to frame materials only, all window units are factory glazed and assumed to be installed in a recess. Modified timber is defined as timber which has undergone acetylation. This technique creates a high performing wood which can be used in demanding outdoor applications. Acetylation converts the hydroxyl groups present in timber, to acetyl groups by reaction with acetic anhydride. The resulting timber is more dimensionally stable, indigestible (rot resistant) and durable. Aluminium-clad timber windows have a full powder coated aluminium profile clad to the exterior of the window, which can be repainted after 20-30 years to maintain good aesthetic appeal, or left untreated with no loss of functional performance. The aluminium profile can also be removed, recycled, and a replacement clipped into place. PVC-U windows referred to here are constructed from 70mm extruded PVC-U extrusions with mild steel reinforcement.

3.1 Results

Figure 3 shows timber frames to have an expected service life of between 56 and 65 years. Acetylated timber frames show an expected service life of 68-80 years, and timber frames, clad with profiled aluminium, 71-83 years. These estimates are calculated using modification factors, based on a number of design parameters. These parameters are listed in Table 1, while the reference service lives to which these factors are applied are listed in Table 2.

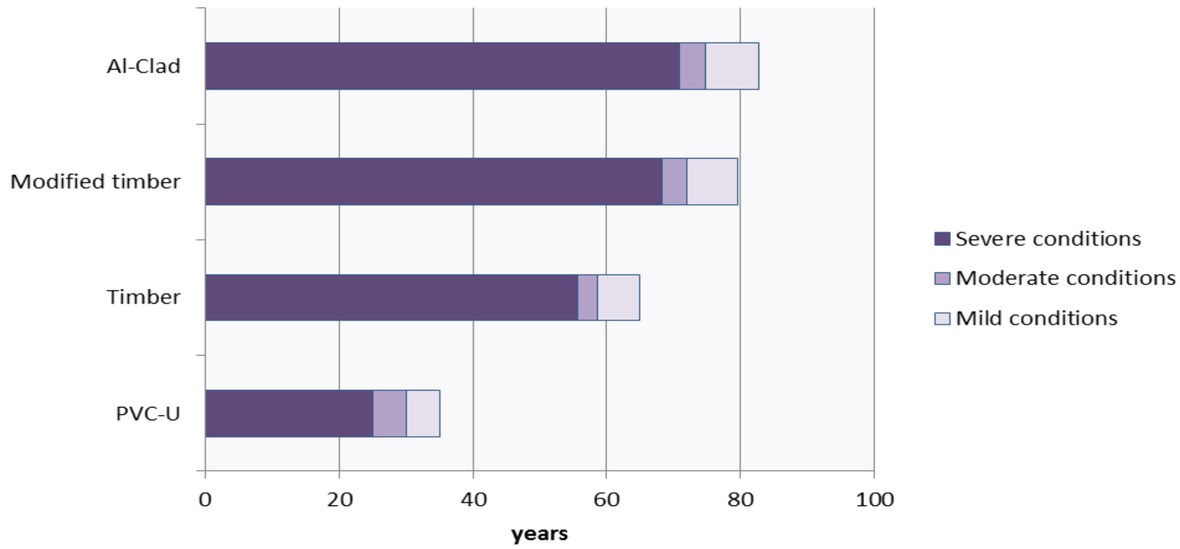

Figure 3. Estimated Service Life of options using ISO 15696:8

Table 1. Factors method (ISO 15686-8, page 16) categories

Factor	Factor category	Example
A	Inherent performance level	Improved substrate, end grain and construction joint sealing, acetylation, preservative treatment
B	Design level	Water shedding angles, rounded edges, recess installed
C	Work execution level	Factory finishes and quality standards
D	Indoor environment	Temperature, humidity
E	Outdoor environment	Sheltered, exposed, severe locations
F	Usage conditions	All assumed to be domestic
G	Maintenance level	According to manufacturer recommendation?

Table 2. Various window service lives reported in literature

Window type	Asif (2002)	Citherlet (2000)	HAPM (1996)	WCC (1990)	BRE generic window (BRE, ****)	Ref. Service Life
Aluminium	43.6	45	35+	50-60	-	**-**
PVC-U	24.1	30	25	30	25- 35*	**25**
Timber	39.6	45	35+	40+	30-35	**35**
Alu-clad timber	46.7	45	-	-	-	**35**
Modified Timber	-	-	-	-	35-60	**35**

* 25 years in the original Green Guide, subsequently amended to 35 years following a BRE Client Study commissioned by the plastics industry

Figure 4 shows the cumulative LCC for the four window frame options in a moderate exposure scenario. The full results show that, over a 60-year design life, timber windows offer the lowest cost alternative for mild scenarios, while aluminium-clad and modified timber offer lower whole life costs for moderate and severe scenarios. Despite having the lowest capital cost, PVC-U windows were shown to have the highest whole life costs over 60 years in all scenarios.

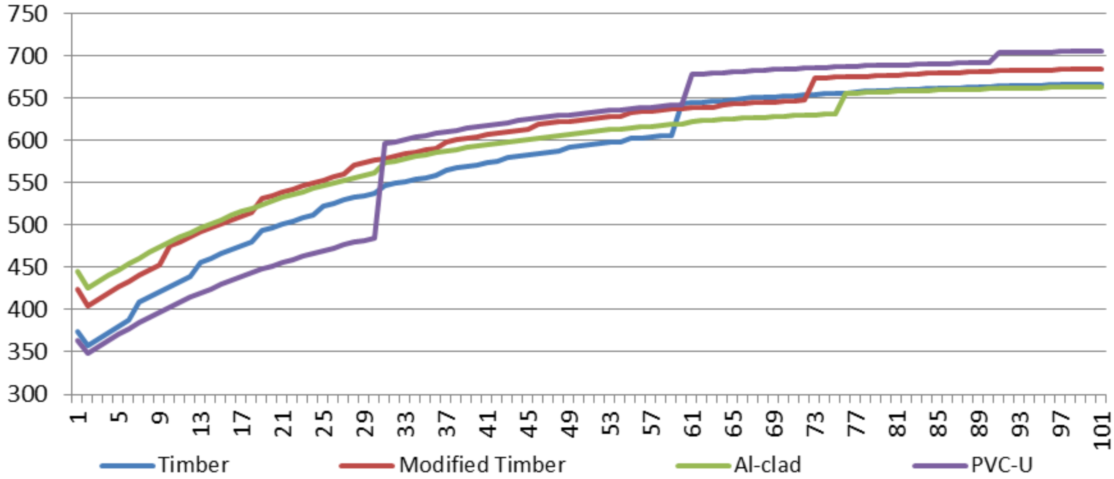

Figure 4. Cumulative Life Cycle Costs for window frame options: moderate exposure

Figure 5 shows the embodied carbon dioxide equivalent (CO2e) per window frame material over a 60 year period. CO_2e is a way of describing how much global warming a given type and amount of greenhouse gas may cause, using the functionally equivalent amount or concentration of carbon dioxide (CO_2). Put simply, if CO_2 has a Global Warming Potential (GWP) of 1, then Methane has a GWP of 25, and Nitrous Oxide a GWP of 298. It is immediately noticeable that all timber based window options have negative values while PVC-U has a strongly positive impact. This is due to the carbon storage effect of timber during its growth phase. This negative impact is affected positively or negatively in relation to EoL assumptions and treatment, and whether timber is sustainably sourced.

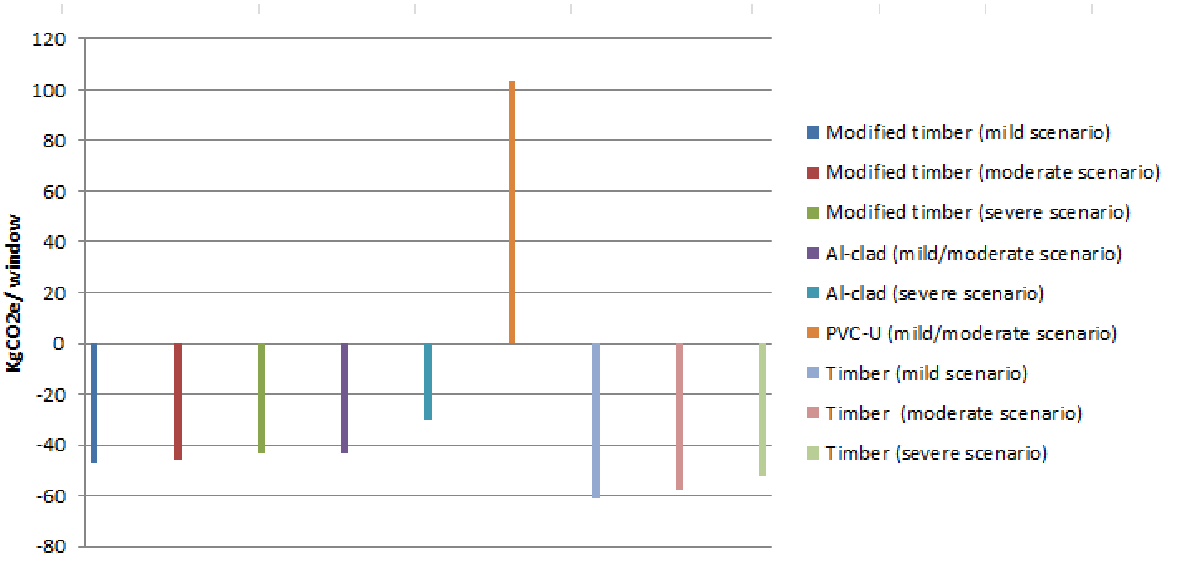

Figure 5. Global Warming Potential of various window frame materials over 60 years

Each of the timber based options has a minimum service life which would service a 60 year building design life. The various exposure scenarios considered demonstrate the application of paint in maintenance events of timber and modified timber, and the replacement of aluminium cladding in Al-clad window frames over 60 years. According to the service life planning part of this study only PVC-U windows would require complete replacement within a 60 year building life. In a mild/moderate exposure scenario there would be one complete window replacement over a 60 year building life, while in a severe exposure scenario there may be two complete window replacements.

It is stressed that rather than focusing on the absolute values of global warming potential for each frame type and scenario that the results are used comparatively.

3.2 Scenario Testing

A number of scenarios which test the sensitivity of inventory data and boundary inclusions on the GWP of frame materials were also investigated. These scenarios included the following:

1. Cradle to Grave recycling of 100% of materials at End of Life. Cradle to Grave analysis describes all the processes which a product or component goes through from raw material extraction to obsolescence and final disposal. It assumes no EoL residual value
2. Cradle to Cradle recycling of 100% of materials at End of Life. Cradle to Cradle analysis assumes that an obsolete component has a residual value at the end of its first life. It assumes that construction waste can be recycled and used to provide raw materials for re-manufacture of the same product, or new and different products
3. Incineration of 100% of materials at EoL (with production of electricity)

This research found that all timber based window frame materials are preferable to PVC-U alternatives in every scenario considered, as illustrated in Figure 6.

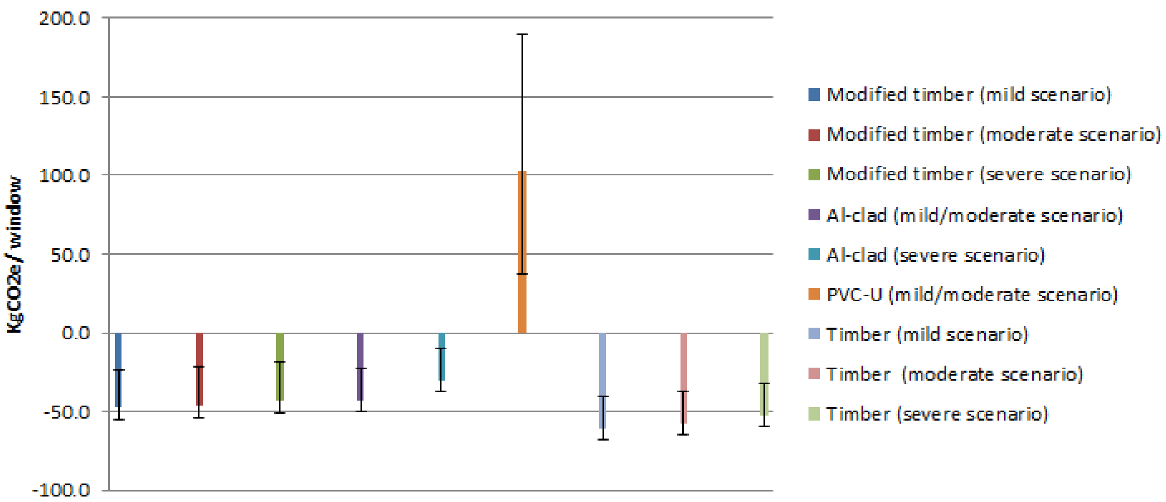

Figure 6. Scenario Analysis (black bars show differences across EoL scenarios)

4. CONCLUSIONS

A methodology to compare on an fair basis te Estimated Service Life, Life Cycle Cost and Life Cycle (environmental) Assessment of building materials and components has been described using current international standards and approaches. This approach is being recognized in a number of tools across the construction sector and will be the subject of much research and industry attention in the near future. In this paper the method has been applied to a critical building component which typically requires replacement within a building's life, incurs (often significant) maintenance costs, and which, depending on the materials chosen, can have significant environmental impact. This case study considers four window frame materials: timber, modified timber, aluminium-clad timber and PVC-U, under three exposure scenarios: mild, moderate and severe.

Applying a factor analysis, as set out in ISO 15686:8, predicts an estimated service life for timber windows of between 56 and 65 years; for modified timber windows between 68 and 80 years; and for aluminium-clad timber windows 71 and 83 years. These are set against a base case for PVC-U of between 25 and 35 years.

Using NPV analysis it is shown that for mild exposures, timber windows offer the lowest lifetime cost option. For moderate and severe exposures the more durable modified timber and aluminium-clad windows gave more favourable lifetime cost outcomes. In all exposure conditions over 60 years, PVC-U window frames were shown to have the highest whole life cost.

Where PVC-U is indexed to 100, the comparative impacts of timber frame options are 25% or less. Sourcing of timber and end of life treatments were the most influential and critical factors in this LCA study, along with the drawing of study boundaries. Recycling at end-of-life offers the most environmentally sensitive solution and supports the aims of tightening recycling initiatives (WRAP, 2012) in pursuing greater waste segregation, and possible tighter restrictions on timber waste entering landfill sites.

What is most notable is that a “one size fits all” approach to whole life appraisal is not always applicable. Factors relating to location, end of life treatment, maintenance frequency, building use, and exposure can have a significant impact on life cycle costs, environmental impact and service life of components. This emphasizes the need for tailored whole life appraisals and use, where necessary, of bespoke tools, rather than generic and box-ticking approaches.

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