LIFE CYCLE ASSESSMENT (LCA) AND THE BUILDING ENVELOPE: BALANCING DURABILITY AND ENVIRONMENTAL IMPACT

An Examination of LCA in Low-Slope Roofing

By
James L. Hoff, DBA

ABSTRACT

When selecting among alternative materials and systems, two methodologies are available to the building envelope designer. Life Cycle Cost (LCC) is a scientific approach that evaluates the economic impact of a product throughout its life cycle. Life Cycle Assessment (LCA) is also a scientific approach to evaluate a product over its life cycle; but LCA targets *environmental* rather than economic impact as the primary measure. LCA is frequently referred to as a "cradle-to-grave" approach that tracks the impact of a product from initial extraction of raw materials to the eventual recycling or disposal of the finished product. LCA is also a key element in the ISO 14000 standards for environmental management; and many global manufacturers now use LCA to evaluate and compare their products against competitive materials. With the 2007 announcement by the U.S. Green Building Council that LCA will be integrated into the LEED Green Building Rating System, it is anticipated that all manufacturers of building materials in North America will soon be required to provide product LCA information in order for their materials to be considered for inclusion in LEED projects.

Because the materials that make up the building envelope are constantly exposed to harsh weather conditions and are expected to perform without failure for many decades, the construction industry has traditionally relied upon LCC, with its emphasis on product durability, as the best measure of long-term value. As the construction industry moves from LCC to LCA, however, some members of the industry are concerned that the new LCA approach may place too little emphasis on product durability. After a brief review of the history of this new approach to evaluating products over their life cycle, this paper will discuss the basic concepts of LCA and review the relationship between LCA and product durability. Examples of roofing and other building envelope materials that have previously been analyzed using LCA will be reviewed, and the implications of the findings will be discussed. Finally, the paper will offer suggestions for best industry practices in implementing LCA as an integral part of building envelope design.

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INTRODUCTION: THE EMERGENCE OF LIFE CYCLE ASSESSMENT (LCA)

With the growing emphasis on “green” or sustainable construction, building designers are increasingly turning to Life Cycle Assessment (LCA) to select building materials and systems with optimal environmental benefits. Similar to Life Cycle Cost (LCC), LCA may be used to evaluate a product over its life cycle; but LCA targets *environmental impact* rather than economic value as its primary measure. With the recent announcement by the U.S. Green Building Council that LCA will be integrated into the LEED Green Building Rating System (USGBC, 2007), it is likely that the use of LCA will rapidly accelerate.

Because the materials that make up the building envelope are constantly exposed to harsh weather conditions and expected to perform without failure for many decades, the construction industry traditionally has relied upon LCC, with its emphasis on product durability, as the best method to determine long-term value. However, as the construction industry moves from LCC to LCA, some researchers have expressed concern that the new LCA approach may place too little emphasis on product durability (Hoff, 2007; McKay, 2007). After a brief review of the history of this approach to evaluating products over their life cycle, this paper will review the relationship between LCA and durability and offer suggestions for implementing LCA as an integral part of the design of durable, sustainable low-slope roofing systems.

WHAT IS LIFE CYCLE ASSESSMENT?

LCA is a scientific approach to evaluating the environmental impact of a product throughout its life cycle. LCA is frequently referred to as a “cradle-to-grave” approach, although with the addition of comprehensive recycling programs, it may also be called a “cradle-to-cradle” approach that tracks the impact of a product from the initial extraction raw materials to the final recycling of these materials into new products.

The Product Life Cycle

The term “life cycle” refers to the major activities in the course of the service life of a product, from its manufacture, use, maintenance, and up to its final disposal. Figure 1 illustrates the life cycle stages in a typical LCA along with the inputs and outputs to be considered:

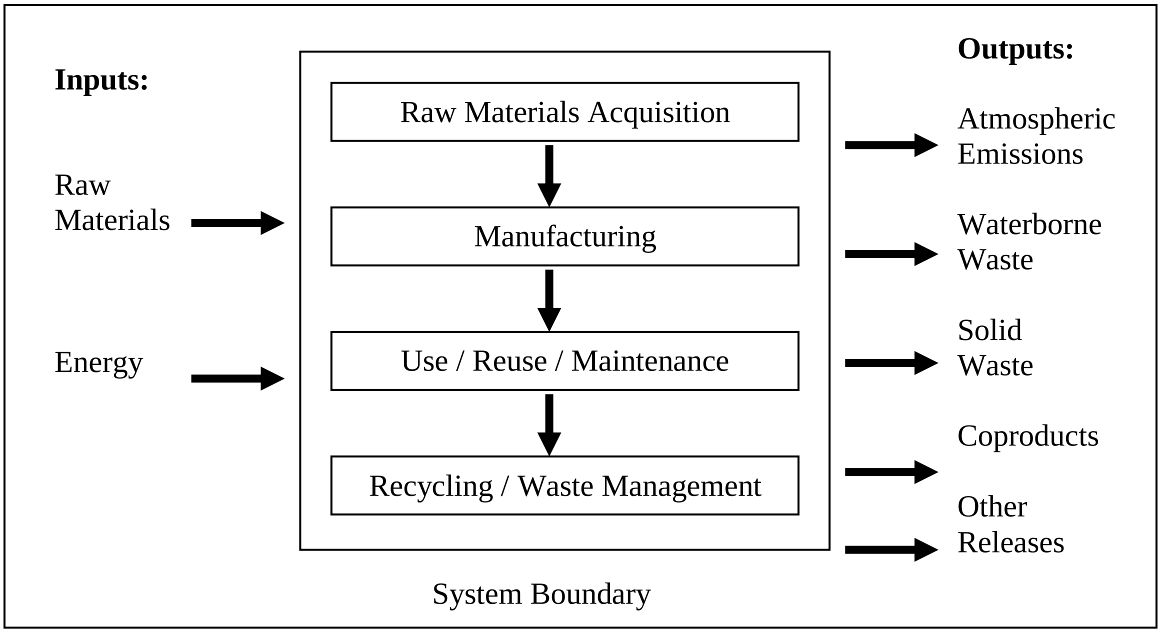

Figure 1: Life Cycle Stages
(Source: Scientific Applications International Corporation, 2006, p.1.)

Environmental Impacts

Environmental impacts are the result of the inputs and outputs over a product's life cycle. Inputs such as raw materials and energy carry environmental impacts just as much as obvious environmental outputs such as atmospheric emissions, and solid wastes. Although the total number of different potential environmental impacts may be very large, the U.S. Environmental Protection Agency has identified the most critical impact categories in its widely-used TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) tool. These impact categories along with the measures employed for each category are listed in Table 1.

Table 1: TRACI Impact Categories and Measures

TRACI Impact Category:	**Impact Measure:**
Global Warming Potential (GWP)	kg CO^2 Equivalent
Ozone Depletion Potential (ODP)	kg CFC Equivalent
Photochemical Oxidant Potential (PCOP)	kg NOX Equivalent
Acidification Potential	H+ Moles Equivalent
Eutrification	kg Nitrogen Equivalent
Health Toxicity (Cancer)	kg Benzene Equivalent
Health Toxicity (Non-Cancer)	kg Toluene Equivalent
Health Toxicity (Air Pollutants)	kg: DALYs Equivalent
Eco-Toxicity Potential	kg 2,4-D Equivalent
Fossil Fuel Use	mJ Surplus Energy / mJ Extracted Energy

Source: Bare, Norris, Pennington, & McKone, 2003, p.55.

In addition to identifying the major threats that impact the long-term viability of the environment and human health, the TRACI methodology also identifies specific measures to apply to each impact. As an example, although many hazardous chemicals may contribute to cancer, the TRACI scale measures all of these threats in terms of their equivalency to Benzene, a well-documented carcinogen.

The LCA Process

Once relevant inputs and outputs have been identified and a measurable scale has been developed for each impact, LCA provides a methodology to apply this information to decision-making. According to the U.S. Environmental Protection Agency (EPA, 2008), an effective LCA process may be divided into three basic steps:

1. Compiling an inventory of relevant energy and material inputs and environmental releases.
2. Evaluating the potential environmental impacts associated with identified inputs and releases.
3. Interpreting the results to help in making an informed decision.

Because the LCA process involves a final step of interpreting the results, it is employed frequently as a comparative method to make decisions among alternatives. For example, one of the first applications of LCA was conducted in the 1970s by the Coca-Cola Company regarding the packaging of soft drinks (Duda & Shaw, 1997). At the time, Coke was considering replacing its returnable glass bottles with disposable cans or plastic bottles. Because of emerging public concern regarding the potential environmental damage of disposable containers, the company wanted to fully explore comparative environmental impacts before making a decision. To the surprise of many at the time, the LCA demonstrated that plastic bottles were the best environmental choice, because each plastic bottle consumed and emitted fewer hydrocarbons than the alternatives.

Benefits of LCA

By focusing on the totality of environmental impacts, LCA may help avoid the shifting of impacts from one place to another. Looking at the Coca-Cola example discussed previously, the continued use of glass bottles in lieu of plastic bottles would not have reduced overall environmental impact. Rather, it would shift the environmental burden from the hydrocarbons required to produce plastic bottles to the energy required and the waste water generated to collect, clean and re-use glass bottles.

LCA also allows analysis of trade-offs to promote the best possible decisions for any particular situation or local condition. As an example, even though the use of plastic bottles in the United States may be a lower impact alternative compared to glass bottles, the use of glass bottles might be the better choice in less-developed regions of the world, especially if imports of plastics are relatively expensive and recycling efforts involve fewer mechanized (and energy-intensive) processes.

The benefits of LCA first discovered by the soft-drink industry are now beginning to influence building construction. An example from the concrete industry may help illustrate this trend. Prior to the advent of LCA, it was assumed by many construction engineers and environmentalists that concrete with a high level of “natural” limestone aggregate was more environmentally beneficial than concrete with a high level of fly ash, a potentially hazardous waste product from coke and steel production. Although limestone itself is less environmentally hazardous than fly ash, limestone concrete requires higher levels of Portland cement to achieve required compressive strength. In 2004, a life cycle assessment conducted by Lippiatt and Ahmad revealed that this increased amount of Portland cement and the energy impacts associated with this increase actually made the overall environmental impact of limestone concrete higher than fly ash concrete. In this example, the use of LCA allowed the best environmental alternative to be identified even when this alternative appeared to contradict established consensus regarding environmental “friendliness.”

Limitations of LCA

Although LCA may help reduce total resource use, the method itself requires considerable resources. Calculating the environmental impact of single product using TRACI or a similar methodology may require hundreds of hours of research and thousands of dollars of investment. However, investment in LCA may be viewed as accumulative, similar to investments in fire and wind-uplift testing. Each fire and wind-uplift test on a construction product provides information that adds to the overall body of knowledge and reduces the need for additional testing. In a similar manner, the start-up cost to obtain an LCA for the first products reviewed may be relatively high, but costs for additional materials should decline once a critical mass of impact data is established.

In addition to the potential for high testing costs, LCA alone cannot determine which product is the most cost-effective or will work the best. As a result, LCA still requires value judgments to be made about the suitability of the product analyzed and the validity of the LCA measure. This limitation will be discussed in later in this paper, especially in regard to its relation to durability.

WHAT IS DURABILITY?

According to most dictionaries, the broad definition of durability is the ability to exist for a long time without significant deterioration. When applied to buildings and building components, durability is typically defined in a similar manner, but with several important distinctions. The Canadian Standards Association *Guideline on Durability in Buildings* (CSA, 2001) provides one of the most recognized definitions of building durability in North America. According to this standard, durability is defined as the ability of a building or any of its components to perform its required functions in its service environment over a period of time without unforeseen cost for maintenance or repair. In contrast to the simpler dictionary definition, durability as applied to buildings must offer more than mere survival: it must also be capable of performing required functions. In addition, these functions must be performed not only for a long time, but for a specified period of time. And finally, although normal deterioration will obviously occur, there should be no unforeseen cost associated with this normal deterioration. Given the importance of these distinctions, each of these concepts should be carefully examined in order to fully integrate durability into the overall LCA process.

Required Functions

While many building components and systems may have a single required function, modern low-slope roofs must fulfill many roles. As a major contributor to the water-tightness of the building envelope, a low-slope roof must serve as a water-proofing layer to block the intrusion of moisture in many forms, including rain, snow, hail, ice, and vapor. In addition to resisting moisture, the roof plays an important role in storm water drainage from the rooftop. And as an equally significant contributor to the building's thermal envelope, modern roof systems must resist the movement of heat and cold at ever-increasing levels as energy costs continue to rise. Finally, the roof system must serve as an important work platform for the building, housing critical mechanical equipment that must be serviced periodically. And with the development of "green" (vegetated) roofs and photo-voltaic roof systems, the requirements of the roof as a service platform continue to expand. Each of these important functions must be addressed within life cycle assessment of every roofing system in order to assure that the most sustainable roof is indeed selected. And if any of these required functions is omitted or ignored, the usefulness of the assessment may be significantly compromised.

Without Unforeseen Costs

The use of the word "unforeseen" reveals several key concepts that must be taken into consideration in order to fully integrate durability into LCA. First, the possibility of unforeseen costs suggests that planning is required to assure that no costs are unforeseen. In addition, there is an equally strong suggestion that some level of cost should be expected (or foreseen) for the building component or system to achieve meaningful durability. As a consequence, the lack of a detailed plan regarding ongoing monitoring and maintenance or the lack of a realistic budget for these activities may compromise the usefulness of any LCA.

Over a Period of Time

The period of time in the CSA definition of durability is commonly referred to as the service life of the building component or system. Obviously, any failure for a roofing system to achieve its intended service life will seriously compromise the effectiveness of LCA in directing design choices and materials selection. Expectations regarding service life and its importance in LCA will be discussed in detail later in this paper.

LIFE CYCLE ASSESSMENT AND DURABILITY

Based on the importance of durability as it relates to LCA, the potential for overemphasis on immediate environmental benefit without equal concern for long-term durability should be a concern for every major construction sector including low-slope roofing. As stated in a paper presented at the 11th Canadian Conference on Building Science and Technology by Jamie McKay, a LEED™ Accredited Professional:

> "The majority of green building assessment systems focus on the design to the constructed building, with little focus on the effect of the building system's life during operation. This tendency has resulted in a failure of many rating systems to properly consider durability, lifecycle cost, and the effects of premature building envelope failures." (McKay, 2007, p.1.)

The concern articulated by McKay and other researchers appears to be shared by the majority of construction professionals who design, specify and manage today's buildings.

According to a recent *Building Design & Construction* survey of over 70,000 building designers and owners, the strongest opinion regarding sustainable construction was that building materials should be evaluated on the basis of life cycle cost, long-term durability, and maintenance, and not just environmental impact and energy savings ("White Paper on Sustainability", 2003, p. 17).

LCA and Value Judgments

Although LCA may be very useful in determining the general environmental impact of a construction product or system, LCA cannot determine which product will best perform the required service functions. As a result, LCA still requires value judgments to be made regarding the suitability of the product analyzed and the validity of the LCA measure. An example of critical value judgments associated with LCA in roofing system design may be illustrated by the roofing industry's best-practice recommendation for the use of a cover board over all foam roofing insulation materials (NRCA, 2007, p.46). As mentioned previously, resistance to thermal transmission and accommodation of traffic loads are two of the key required functions of a roofing assembly . By reducing the potential for crushing of foam insulation under traffic loads, a cover board may help to extend the thermal efficiency and useful service of the underlying insulation, and even facilitate its recycling or re-use. However, if an LCA comparing roof assemblies with and without a cover board is conducted without any differentiation in the useful service life of the two assemblies, the LCA may indicate that foam insulation without a cover board offers a lower environmental impact. This apparent contradiction will result because the inclusion of a cover board (and all of the related manufacturing, installation and disposal inputs) merely adds to the total environmental impact of the roofing assembly without contributing any benefit for the potential increase in service life of the insulation.

LCA and Service Life Expectations

The accuracy of any LCA will be highly dependent on the validity of the service life assigned to the products and systems being evaluated. To the greatest extent possible, the assignment of a service life period should be based on reliable and reproducible data developed from rigorous scientific or empirical research. Unfortunately, little such service life data is available for modern low-slope roofing systems, and what data is available appears to contain limitations and contradictions.

Two of the most comprehensive studies of modern low-slope roof system service life were conducted by Cash (1997) and Schneider and Keenan (1997). Cash's study included an exhaustive review of the average service life of a wide variety of low-slope roofing systems, but the data was based not on actual field reports, but rather on an opinion survey of estimated service life. In addition, the return rate for the survey was relatively low and many of the respondents were unfamiliar with all of the roofing systems rated. Schneider and Keenan also published a comprehensive review of the service life of similar low-slope roofing systems. But unlike the survey data in Cash's study, Schneider and Keenan's data were based on verified reports of actual roofing systems as they were removed from service. However, many of the roofs in Schneider and Keenan's study were located in a single geographic region (Tennessee), and some of the roof system classifications may have included roofs that differed significantly in initial quality and durability.

In addition to general studies of low-slope roof systems, information about service life can be obtained from the evaluation reports of roofing systems submitted for approval and certification to various governing authorities and review agencies. As an example, the British Board of Agrément (BBA), which reviews and certifies roofing systems for conformity to a variety of European building standards, provides a minimum estimate of useful service life for every product it evaluates. As an example, the certificate for non-reinforced EPDM roofing systems manufactured and marketed by Carlisle Syntec Systems (BBA Certificate No. 92/2791) states in part that, “All evidence available suggests that the Carlisle SureSeal Reinforced FR EPDM Roof Waterproofing System should have a life in excess of 20 years.” In a similar manner, the certificate for a reinforced plastisol-coated PVC roofing system manufactured and marketed by Sarnafil Ltd. (BBA Certificate No. 08/4532) states in part that, “All available evidence indicates that a Sarnafil roofing system, used in the context of this Certificate, should have a life in excess of 35 years.” The BBA evaluation protocol is relatively comprehensive, including evaluations of inherent material properties as well as field performance data. However, much of the information evaluated by the BBA is based on an anecdotal data as submitted by individual manufacturers that may not meet the objective standards of a scientific or empirical approach to service life estimation.

Finally, information regarding service life may be derived from the warranty offerings of roof system manufacturers. Although the length of product and system warranties may not be considered a scientific measure of service life, there is a growing body of research across several industrial sectors suggesting that manufacturers’ warranties do tend to serve as an indicator of relative service life (Wiener, 1985; Kelley, 1988). In addition, modern accounting practices place a significant burden on manufacturers to accurately account for the warranted service life of their products (FASB, 1990) and publically disclose this information as part of their annual financial statements (FASB, 2002). Some of the rigor applied by manufacturers in analyzing the service life of their products to meet these accounting standards also may be demonstrated in several warranty database studies conducted within the roofing industry (Hoff, 1997; Hoff, 2003). Although these studies are limited in scope to the contractual warranty period, the data from this research suggest that the average service life of any particular roofing system is likely no less than the maximum warranty period offered by the manufacturer of the roofing system.

When the service life estimates from all of these potential sources are compiled together, the differences and contradictions become apparent. Table 2 summarizes the service life estimates from all of these data sources for a variety of different low-slope roofing system types:

Table 2: Estimated Low-Slope Roof System Service Life (Years)

	Data Source:			
System Type:	Cash[a]	Schneider[b]	BBA[c]	Manufacturer Warranty[d]
Asphalt BUR	16.6	13.6	20	20
SBS Modified	16.6	17.3	20	20

PVC	n/a[e]	n/a[e]	35	15
EPDM	14.1	16.8-18.4	20	30
TPO	no data	no data	20	30

Notes:

a. Mean service life from Cash (1997).

b. Mean service life from Schneider & Keenan (1997).

c. British Board of Agrément (BBA) Certificates (Available www.bbacerts.co.uk).
   1) Asphalt BUR: BBA Certificate 94/3062 Chesterfield Roof Waterproofing Systems
   2) SBS Modified: BBA Certificate 91/2618 Icopal HT Roof Waterproofing Systems
   3) PVC: BBA Certificate 08/4532 Sarnafil PVC Roof Covering System
   4) EPDM: BBA Certificate 92/2791 Carlisle Syntec Systems
   5) TPO: BBA Certificate 87/1849 Anderson SureWeld Systems

d. *NRCA Low Slope Roofing Materials Guide*, 2006-07, Vol. 2, Section 5 Roof Membrane Warranties.
   1) Asphalt BUR: GAF Materials Corp. "Diamond Pledge™ Roof Guarantee."
   2) SBS Modified: GAF Materials Corp. "Diamond Pledge™ Roof Guarantee."
   3) PVC: Johns Manville International, Inc. "UltraGard Roofing System Guarantee."
   4) EPDM: Firestone Building Products Co. "Platinum Roofing System Limited Warranty."
   5) TPO: Firestone Building Products Co. "Platinum Roofing System Limited Warranty."

e. Data from the Cash & Schneider studies included discontinued formulations of PVC that do not allow the data to be meaningful.

As illustrated in Table 2, estimates for the service life of modern low-slope roofing systems vary from slightly more than a decade to well over three decades, depending on data source and methodology, Given this sizeable variation, how can an appropriate service life be established to conduct meaningful life cycle assessment? The best answer to this question may lie in several important distinctions among these estimates.

One of the most apparent differences among these estimates is their temporal perspective. The relatively low Cash and Schneider service life estimates may be considered "backward looking" because the estimates are based on the performance of previously-installed roofs and roof populations that include the many material and installation errors that have contributed to the previously-discussed industry learning curve. In contrast, the relatively higher BBA and manufacturer warranty service life estimates may be considered more "forward-looking" because the estimates are based on the expected future performance of roofing systems utilizing the most recent improvements in materials and installation methods.

These estimates of roof service life may also be differentiated based on the quality level they assume. The quality level assumed by Cash and Schneider may be relatively low since their service life estimates assume that the roofs will be composed of "average" materials installed using "average" installation precision. In contrast, the quality level assumed by the BBA and manufacturer warranty estimates may be much higher since these estimates assume that both materials and installation will meet or exceed important minimum standards as established by the roofing manufacturer and the building code and standard community.

DURABILITY TOOLS FOR A SUSTAINABLE FUTURE

The contrast between forward-looking versus backward-looking service life estimates and average versus high quality levels may help identify a critical decision point for the low-slope roofing industry. Should the industry move forward with the assumption that the roofs installed on the green, sustainable buildings of the future will be average in performance, or should the expectation be set higher? And if the industry decides to move forward with higher expectations, how does it develop and implement processes and controls to assure this higher level of performance is attained? Although current understanding of long-term durability and service life of low-slope roofing systems may be limited, there are several tools that may be used and promoted by the roofing industry to improve the durability of roofing systems and effectively integrate roof system durability into LCA.

Failure Analysis / Best Practice Guidelines

One area of research that appears to have yielded significant results concerns the evaluation of important failure mechanisms within modern low-slope roofing systems. And although the relationship between these failure mechanisms and overall roof service life is not fully quantified, understanding of these failure mechanisms has fostered the development of effective counter-measures to prevent, mitigate, or quickly repair these failure locations. One of the most comprehensive examinations of roof system failure mechanisms was conducted by Bailey and Bradford in 2005. This study of over 24 million square feet of asphalt and single-ply roof systems managed by the US Army identified critical defects ranging from initial material selection to long-term maintenance activities that accounted for approximately 75% of all observed roof performance problems. In turn, the identification of these key defects was used by the authors to develop best practice recommendations for all stages of roof system asset management.

Although little research is available to correlate failure analysis to roof service life, it is likely that the defects observed by Bailey and Bradford contribute to the unusually wide variation in roof service life estimates previously discussed in this paper. And if the defects observed in this study as well as other studies were effectively addressed using the countermeasures identified in these studies, it is also likely that roof service life would quickly start to climb toward the high end of current estimates.

It is also important to note that almost all the recommendations from the Bailey & Bradford study already appear in current roofing industry best practice guidelines for roof system design, installation, maintenance and repair. Most noteworthy for the building designer interested in integrating these important best practices into the design of long-term sustainable roofing systems is the sizeable library of consensus documents developed by the National Roofing Contractors Association. These documents, including comprehensive technical manuals, quality control guidelines, repair manuals, and inspection / maintenance manuals, establish far-reaching best practice guidelines for the roofing industry. In addition, these documents also contain detailed drawings, instructions and photos to assist the building designer, as well as detailed references to source research data to support their recommendations.

Durability Planning

Roofing industry research in failure analysis combined with proven best practice guidelines may set the stage for the effective use of planning to maximize roof service life and minimize environmental impacts. In addition to providing a useful definition of building durability as discussed previously, the Canadian Standards Association *Guideline on Durability in Buildings* (CSA, 2001) also provides a comprehensive methodology and framework to make decisions on durability. The guideline addresses important elements of durability planning, including quality assurance, methods to predict service life, design and construction considerations, and operating and maintenance programs. The guideline also provides helpful overall procedures and sample project formats that can be utilized to develop and implement an effective durability plan for any building or building system.

Although durability planning is not formally included in the USGBC LEED-NC program for new construction, the Canadian version of this program (LEED Canada-NC 1.0) explicitly includes durability planning as a credit under the Materials and Resources section. Under the Canadian version of LEED, one point may be earned for developing and implementing a building durability plan in accordance with the previously-discussed CSA *Guideline on Durability in Buildings*.

Generalizing from the durability planning recommendations in the CSA standard, the following processes appear to be the most important steps in developing an effective durability plan for a roofing system:

1. <u>Identity the critical durability determinants</u>. Failure analysis from studies such as Bailey & Bradford (2005) will help building designers identify which design, material, installation and service factors hold the most value in optimizing the service life of the roof system.
2. <u>Identify the critical durability interventions</u>. Using the recommendations derived from failure analysis research and industry best practice guidelines, the building designer can identify specific interventions our countermeasures to prevent or mitigate degradation of roof service life due to critical durability determinants. These countermeasures may take a number of forms, including initial design enhancements, ongoing inspection and maintenance procedures, and major renewal or repair initiatives of key roof system components and details.
3. <u>Develop an action plan and timetable</u>. Using the recommendations and the suggested formats of the CSA durability guideline, the building designer can develop a long-term actionable plan that can be incorporated into ongoing building maintenance activities.

These key steps in effective durability planning may appear obvious. But the wide variation in service life data of roofing systems as previously discussed suggests that what may be obvious has never been seriously implemented on a large scale by building designers and owners. And if life cycle assessment of buildings and roofing systems is to fulfill its long-term potential to reduce environmental impact, durability planning must become a vital and integrated part of all LCA activities.

In addition, because these steps may provide an effective way to evaluate different combinations of material, design and service options to determine what combination will provide the lowest overall environmental impact, durability planning may contribute both to the identification of viable sustainable roofing options as well as the efficient evaluation and selection of the most suitable options for a particular building application. The use of key durability determinants and durability interventions may also facilitate rigorous evaluation of the trade-offs between increasing roof system durability (and perhaps increased roof system cost and environmental impact) in the initial design and installation of the roof system as compared to periodic increments of durability (at perhaps a lower overall cost and impact) provided by system maintenance and repair interventions.

RECOMMENDATIONS GOING FORWARD

Reach Agreement on Service Life Standards

Given the variation in current estimates of roof service life and their mixture of backward-looking / forward-looking and low quality / high quality perspectives, the roofing industry should seriously consider reaching a consensus that any truly sustainable low-slope roofing system should be designed, manufactured, installed and serviced to achieve a minimum acceptable service life. Based on current code agency evaluations and roofing manufacture warranty periods, this minimum acceptable service life would appear to be at least 20 years, and perhaps up to 30 years or more for some low-slope roofing system designs and strategies. The adaptation of common minimum service life standards would also prevent the “mixing and matching” of service life estimates that might bias a life cycle assessment toward a particular roofing system type.

Embrace and Promote Durability Planning

Because the lack of meaningful consideration for durability within life cycle assessment may fatally compromise the results of LCA, the roofing industry should insist that every roof system LCA contain a detailed durability plan that identifies and addresses key failure mechanisms, either through enhanced robustness or redundancy, planned maintenance and repair, or a combination of both. Given the head start the current CSA *Guideline on Durability in Buildings* offers in establishing a meaningful approach to consistent durability planning, the industry should thoroughly familiarize itself with this standard and be prepared to promote it and advance it as a best practice model.

Address Critical LCA “Value Judgments” with New Research

As mentioned previously, there are a number of important industry best practice standards that may require value judgments when a life cycle assessment is conducted. As an example, the use of cover boards appears to offer long-term sustainable value, but little scientific research has been conducted to quantify this value or relate this value to the opportunity for reduced environmental impact. In a similar manner, industry best practice guidelines for the use of multiple layers of roof insulation, the staggering of insulation joints, and the elimination of through-fastening “thermal shorts” also appear to provide long-term value in regard to energy efficiency, but this value also lacks definitive research evidence to quantify its contribution to reducing environmental impact. Addition industry research in these and similar areas may be very helpful in assuring that the increasing use of LCA as a design tool will also increase the long-term durability and environmental benefit of modern low-slope roofing systems.

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