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Integrating life cycle assessment with green building and product rating systems: North American perspective

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Abstract

The development of green building rating systems (GBRS) and sustainability metrics for buildings, including building products, is reviewed from a North American perspective. The Leadership in Energy and Environmental Design (LEED) system and the Living Building Challenge (LBC) are highlighted as primary examples of different levels of GBRS. Life cycle assessment (LCA) is introduced as a preferred method of quantifying sustainability, and its integration into current GBRS is examined a prominent building example. Two example applications of LCA to building products associated with GBRS – carpet and roof membranes – are provided. In the first example, conventional carpet was compared with carpet meeting the standards of the LBC's materials exclusion criteria (Red List, via the Declare product labeling system). In the second example, LCA was applied to both the manufacture and use phases of roof membrane alternatives for a building retrofit project, one of which would have aided in achieving LEED certification. The Declare-listed products did not perform better in every LCA impact category, and the GBRS-preferred roof system performed more poorly in all LCA impact categories, while suggesting the need for additional LCA categories. Both examples help to illustrate the complexity and tradeoffs encountered while integrating the quantitative perspective of LCA and the qualitative perspective of GBRS.

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1. Introduction: The social and environmental impacts of buildings

The built environment has a profound impact on the natural world as well as individuals' physical health and well-being [1, 2]. In 2010, the US building sector accounted for approximately 41% of total energy consumption, or about 7% of global energy consumption. Compared to energy consumption in 1980, the 2009 energy consumption of buildings was 48% higher [3]. Building construction and demolition account for anywhere from 25% to 65% of waste streams in the US [4-6]. For a typical building, a majority of the environmental emissions occur during the use phase, particularly due to energy use and the energy supply chain; thus, many studies have focused on energy efficiency improvements and potential cost savings [7-9].

Health concerns associated with the indoor environment, such as sick building syndrome, have given rise to studies on the effects of building design on immediate health and welfare of occupants [10, 11]. People spend 90% of their time indoors and are exposed to indoor air pollutant levels 2 to 5 times higher than outdoor values [12]. Indoor air and environmental quality (IAQ and IEQ) have been linked to worker health and productivity in multiple studies [13-17]. To better assess direct impacts to occupants, studies have analyzed metrics such as worker productivity, developing surveys or analyzing company-collected data such as employee absenteeism or sick leave [18-22].

The awareness of these environmental and direct health/productivity impacts has resulted in an increased societal demand for more sustainable structures, which utilize fewer resources to build and use increase the health and safety of its occupants. *In an attempt to address this demand, green building rating systems (GBRS) have emerged, creating a new perception of building sustainability and marketability from the stakeholders' point of view [23]. GBRS attempt to translate the knowledge base and drive the product market, making it easier for owners, designers and builders to create perceived or actual environmentally preferable structures.*

2. Green building rating systems (GBRS)

GBRS typically focus on materials, energy consumption, water consumption, indoor environmental quality, site and location, and operation and management, while also considering the design, construction, use, and waste phases of a building. Prominent GBRS include Building Research Establishment Environmental Assessment Methodology (BREEAM) in the United Kingdom [24], Leadership in Energy and Environmental Design (LEED) in the United States [25], Green Star in Australia [26], German Sustainable Building Council System (DGNB System) in Germany [27], and Estidama in the United Arab Emirates [28]. Most GBRS have different subsets that cater to specific building projects such as retrofits, schools, new construction, commercial, residential, and healthcare facilities. Another important factor of green building rating systems is the awareness of location and climate. Climate and regional issues are large factors as to why there is not one global green building rating system, as many countries develop their own rating system around the general climate [23].

LEED is a building rating system developed by the U.S. Green Building Council (USGBC). LEED has evolved through several versions, from the pilot in 1998 to the current version, LEED v4, which launched in November 2013. LEED is currently the dominant green building rating system in the United States market and is being adapted to many markets worldwide [29]. Although LEED was initiated in the US, it is now establishing its presence globally providing internationally adopted design, construction and operational guidelines and standards [30]. In 2013, 4,900 cities with green building profiles were registered in the Green Building Information Gateway (GBIG) [31]. Today there are more than 10 billion square feet of building space certified by LEED in 135 countries [32].

The Living Building Challenge (LBC) A 'newer,' more rigorous GBRS called the Living Building Challenge (LBC) was launched in 2006 by the Cascadia Green Building Council. The LBC, overseen by the International Living Future Institute (ILFI), contains building design and performance prerequisites or petals, which must all be met to achieve certification. The LBCv2.1 petals are: place, water, energy, health and happiness, materials, equity, and beauty [33]. In order to achieve LBC certification, the building must be in full operation for one year and monitored during this time to ensure it meets operational criteria, including net-zero energy and water consumption.

Each petal contains specific imperatives that must be met to achieve the petal. Under the materials petal, for example, Imperative 10, Red List, requires that manufacturers disclose the ingredients in their products to ensure that they are free of certain chemicals and materials included on the ILFI's Red List. Imperative 13, Living

Economy Sourcing, requires that manufacturer and raw material location are known to best determine how to source local products that support regional economies [33].

3. Sustainability metrics and life cycle assessment (LCA)

While the building sector has seen the development of GBRS in the past two decades, methods to assess the broader sustainability of human activities have been developed in a variety of sectors. The concept of meeting present needs without compromising the future [34], and the evaluation of needs and impacts from environmental, social and economic perspectives, have been guiding principles for developing these methods. A comprehensive method of evaluating the sustainability of products and processes is life cycle assessment (LCA). LCA is used to evaluate the resource consumption and environmental impacts of products and processes (goods and services) during their life cycle from cradle to grave [35].

LCA follows four steps established by the International Organization for Standardization (ISO) in ISO 14040 and 14044 [36, 37]. ISO describes the four main steps of an LCA as: 1) **Goal and Scope Definition** - defines the objectives of the LCA (e.g. product comparison or improvement-oriented), system boundaries and a functional unit are identified and established; 2) **Life Cycle Inventory** (LCI) - collects emission and resource use data from literature and life-cycle databases. Inventories are collected according to the system boundaries. This is a comprehensive and critical phase since LCA results rely on the quality of LCI; 3) **Life Cycle Impact Assessment** (LCIA) - presents the LCI data in terms of understandable and quantifiable environmental impacts. Three steps to conducting the LCIA include impact category definition, classification and characterization. Furthermore, the LCIA results can be normalized, grouped, weighed and analyzed to improve the real-world relevance of the results; and 4) **Interpretation and Improvement Analysis** - LCI and LCIA results are interpreted and improved to present meaningful information and to enable decision-making consistent with the defined goal and scope. Interpretation should deliver results and explain limitation to inform industries and decision makers [38].

4. Integrating LCA and GBRS

The use of LCA as an assessment tool in the building sector started around 1990 and has grown and expanded since then [39]. In the literature, some studies have explored the LCA in buildings in various parts of the world [40]. The application of LCA could be vital to sustainability and improvement of buildings and construction processes. Considering the use phase is 50-60 years for the average building, we can noticeably see that greatest environmental impact occurs during the use phase [41]. 70 to 90% of the environmental impact categories occur in the use phase. Approximately 85% and 15% of energy consumption occurs during the use and manufacturing phases, respectively [40]. Although the general LCA methodology is well-defined, its application in the building industry still suffers from a lack of sector specific standardization and use, especially in the United States. Most current buildings LCAs are quite dissimilar as they are based upon different boundaries and scopes [35].

LCA and LEED: The integration of LCA into LEED first appeared in panel discussions and working groups of the USGBC beginning in 2006 [42]. LEEDv2009 introduced a fundamental change in how LEED credits were 'weighted' (e.g., GHG emissions were given more consideration than water use). In the 2009 weighting scheme, building impacts were described with respect to 13 impact categories from TRACI (the Tool for the Reduction and Assessment of Chemical and other environmental Impacts) developed by the US EPA (US Environmental Protection Agency) and then compared to each other according to BEES (Building for Environmental and Economic Sustainability), a tool developed by NIST (the National Institute of Standards and Technology) [43-45]. In addition to weighting, LCA was integrated with LEED through an LCA pilot credit for building assemblies and materials that encouraged the use of environmentally preferable building materials and assemblies.

LCA is both explicitly and implicitly incorporated into the current version of LEED, with likely expansion in the next version given the prominence of Environmental Product Declarations. The latest version of LEED, LEED v4, incorporates LCA primarily into the Materials and Resources category with credits for building life-cycle impact reduction, building and material reuse, or whole-building life-cycle assessment [46]. LEEDv4 also issues credits for environmental product declarations, sourcing of raw materials, and material ingredients, as determined by third party

verification adhering to ISO standards 14025, 14040, 14044, 21930, and 26000 [46].

The LBC also incorporates life cycle thinking in many of its requirements, such as net-positive energy, net-positive water, materials sourcing and embodied carbon footprint (requiring projects to purchase carbon offsets equal to the embodied carbon footprint of the building's materials), although it does not require a full LCA in accordance with ISO 14040 [33]. LBC also contains a restriction on the use of certain materials - the Red List, which could potentially increase or decrease impacts in some LCIA categories by categorically excluding certain products. Materials on the Red List are not allowed to be used in a project undergoing LBC certification, except if no substitute is available.

In the following two sections, we discuss brief case studies highlighting the continuing challenges facing integration of LCA and GBRS. First, we provide a brief example of a comparative LCA focusing on conventional carpet and several LBC Red List-compliant alternative carpets. Second, we analyse an energy efficiency-related upgrade of the roof of an existing building using LCA and anticipated GBRS qualification. We discuss the need for ongoing work to integrate the highly uncertain quantitative approach of LCA with the remaining qualitative approaches used in GBRS.

5. Considering LCA, LBC and the Red List - Material

The LBC's Red List imperative is supported by the ILFI's Declare database, a new materials labeling system that aims to provide a simple to use, transparent tool designed specifically for teams working on the LBC [33]. Declare uses a nutrition label interface to list the ingredients in a building product and the state in which it was manufactured. Declare-listed products display a status of "declared", Red List compliant, or Red List free - the latter two categories are acceptable for use on LBC projects. We compared four carpets: conventional nylon carpet (standard carpet), and three Declare-listed carpets (Ecworx, Superflor, and Nexstep) as shown in Table 1, to determine the consequences of applying Red List standards to a common building material which was well-represented in the Declare dataset. All three carpets are Red List free or compliant. Manufacturing data for the conventional nylon carpet was obtained from the EPA's Waste Reduction Model [47]. Data included the material, application, percent of total weight, and weight. The data for the three Declare-listed carpets was obtained from the respective Declare ingredient list for each product. The ingredient list provides the material or chemical, the component it is part of, the CAS number for identification, the percentage by weight, and an approximation of the source location.

A functional unit of 2,026 pounds was used, which represents one ton of carpet plus manufacturing waste. Life cycle inventory was established using the Ecoinvent v2 and US LCI databases [48, 49]. Environmental impacts were calculated using the EPA tool TRACI 2 V3.0 [50]. Due to data availability, the analysis only included the material and processing inputs, excluding transportation. Nylon is the dominant material by weight and environmental impact, and it is widely recycled in the carpet industry. For this analysis, the amount of nylon per carpet was reduced by the recycled content percentage of the carpet shown in Table 1. Maintenance and end of life activities (deconstruction, disposal and material reclamation for recycling) were excluded; thus, recycled content was assumed to have no environmental impacts. Use phase emissions were also excluded.

As shown in Figure 1, Nexstep had the largest environmental impact in most categories, followed by conventional carpet, Ecworx, and Superflor. Nexstep contains 28% nylon by weight, which is a higher concentration than Ecworx and Superflor. It also contains more fiberglass and magnesium oxide than any other carpet. The combination of these material inputs results in the greatest environmental impact for Nexstep. Conversely, Superflor has the lowest impact among the four carpets. This is due to Superflor containing just 18% nylon by weight. In addition to this, it is made up of 45% calcium carbonate, or limestone, by weight. Calcium carbonate is a material which generally has some of the lowest environmental impacts compared to the other material inputs. Recycled content was incorporated into the analysis by assuming it displaced the equivalent percentage of virgin raw material required for a product, and data were not available for energy or material use in the recycling process; thus, recycled content carried no environmental burden in the manufacturing stage.

Table 1. Summary of carpets analyzed.

Product	Description
Conventional Nylon Carpet - 0% Recycled Content	Generic broadloom residential carpet
Ecoworx Carpet Tile with Ecosolution Q Face Fiber - 45% Recycled Content	Premium recycled content face fiber and 100% PVC free backing system with recyclable content for high performance environments
Nexstep - 10% Recycled Content	High performance cushion carpet tile
Superflor - 36% Recycled Content	Needlefelt plain brushed hair modular carpet on Graphlar backing designed for commercial extra heavy duty and stairs

Limitations of this analysis are exclusion of life-cycle phases such as use and end of life, including recycling energy and materials use. However, if replacement intervals are similar, the majority of the environmental impacts of building materials in traditional LCIA categories (e.g. TRACI) tend to be associated with manufacturing [41]. A major shortcoming of LCA for building products is the lack of data regarding use-phase indoor emissions due to off-gassing or product deterioration, though methods exist to incorporate the impacts of those emissions into LCA if they are known [51, 52].

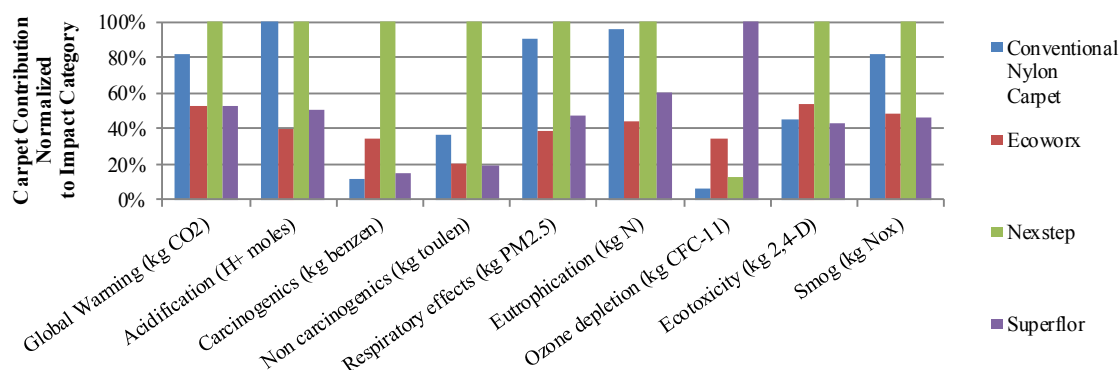


Fig. 1. Impact assessment comparison of carpet types. Ecoworx, Nexstep and Superflor are all Declare listed.

6. Considering LCA and use phase energy related to building products

The example described below presents two roof scenarios for an existing commercial building built in 1942 located in the North-eastern region of the US. The roof was selected as an illustrative case study to demonstrate the utility of life cycle assessment in the context of energy models and GBRS. Further, retrofits of existing building stock are common, approximately 85% of commercial buildings in the North East were built prior to 1990 [53].

For this case study we quantified the environmental impacts of the roof products and energy consumption of the existing building to identify which roof option is environmentally preferred. The two common options considered were a black, EPDM (*ethylene propylene diene monomer*) membrane system and a white, PVC (polyvinyl chloride) “cool roof” membrane system, shown in Figure 2. The functional unit for the study was the entire roof, 10,212 ft² and the study assumed a 20-year lifespan for the roof products and the building energy use. Data for the EPDM and PVC roof products were collected from published reports, industry data, and the ecoinvent database [48]. The EPDM and PVC membrane product information was from a published report that had detailed information on membrane composition [54]. Both membrane options used a roof section consisting of 4.72” concrete, a vapour barrier, R-30 polyisocyanurate rigid board insulation, and 0.5” Dens Deck roof board with the membrane applied on

top. The EPDM membrane required a Kraft paper backing between the Dens Deck and the membrane. The rigid board insulation data was obtained from an industry leader while the Dens Deck, vapor barrier, and Kraft paper materials were from the ecoinvent database. The data collected was then synthesized in Athena, an LCA software primarily developed for buildings and construction [55].

The environmental impacts for the building's energy consumption was also included. E-Quest was used to analyze the energy consumption of case study building. The energy consumption was divided into cooling and heating loads; the cooling load adjusted for electric window units with a 3.4 coefficient of performance and the heating load is natural gas. Considering the 20-year life span of the roof materials, the energy consumption for the building also accounted for 20 years.

The LCA results show that the energy consumption, especially the cooling loads, dominated all environmental impact categories (Figure 2). Utilizing a PVC membrane resulted in a lower cooling load by approximately 1% over the EPDM membrane, while heating loads were about equal. However, manufacturing impacts from PVC production more than offset the gains from the reduced cooling load in all environmental impact categories. The manufacturing of PVC includes chlorine, vinyl chloride monomer (a carcinogen), and toxic additives [56-59]. Additionally, PVC generates large quantities of waste. Although the building could have received 2 LEED points for urban heat island reduction, the LCA indicates that EPDM would be the better choice.

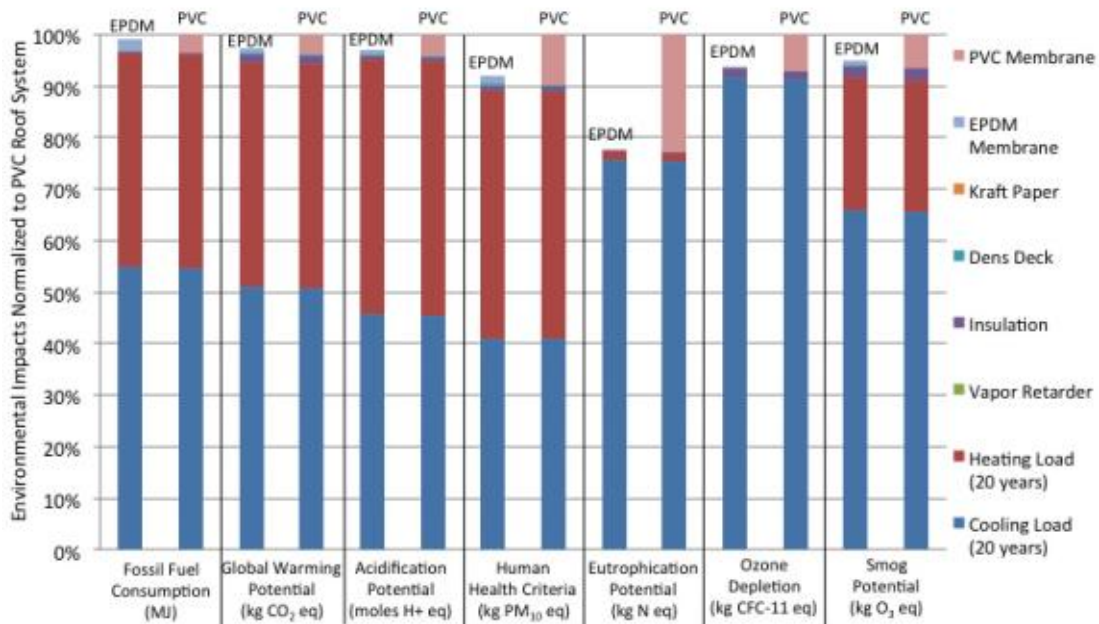


Fig. 2. Materials breakdown of roof membrane options.

7. Conclusion

LCA is widely regarded as an important tool for the quantitative assessment of sustainability, while GBRS continue to arguably push the green building market. However, shortcomings of both methods are evident, and the confluence of the two approaches is important ground for future work. In this article we have reviewed the development of these parallel methods, and provided two brief examples of LCA evaluations of a GBRS-related building material. In the first example, the GBRS-certified (Declare listed) building materials did not necessarily score better than the conventional alternative in every impact category. In the second example, a cool roof material

that would have received GBRS approval (e.g. earned LEED points) scored worse in every LCA impact category. However there was not an LCA category associated with urban heat island reduction, a potential shortcoming. Since materials selection and energy analyses are large components of potential points earned, tying use phase energy consumption into LCA of products within GBRS should attract a broader group of building owners by aligning the environmental and financial implications of products as much as possible. Evaluating energy savings associated with product choice can also increase the scientific merit behind GBRS credits. It appears that a greater incorporation of LCA into GBRS would help with quantitative comparisons, while GBRS may be able to inform the development of a more complete set of LCA indicators or impact categories.

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