A Review of Resources on Life Cycle Assessment and Embodied Energy and Carbon in Building Materials

A reference document for
Life Cycle Assessment (LCA) and Buildings Research for WA State

University of Washington (UW) and Washington State University (WSU)

Research in Support of SB 5485

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A Review of Resources on Life Cycle Assessment and Embodied Energy and Carbon in Building Materials

Overview

This document is a compilation of the background research generated in developing the recommendations included in the Final Report of Life Cycle Assessment and Buildings Research for Washington State. The majority of the background research contained herein was completed in the Fall of 2011 and Winter of 2012. As LCA practice continually changes, we recognize that this document is already out of date. The research team does not have the resources to update and review all of the items included within this resource and thus recommends users to reference this resource with caution.

We have included our analysis of all items identified by either the research team or stakeholders, even when we have concluded that these items are either out of date or not relevant. This information is compiled into this reference document so that stakeholders can recognize the scope of our background research and as a reference for future LCA researchers.

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X1 ESSB 5485

X1.1 Introduction

Washington Senate Bill 5485 (ESSB 5485) was signed by Governor Gregoire in May of 2011. It authorizes the University of Washington (UW) and Washington State University (WSU) to conduct a study into possible opportunities to employ life cycle assessment methodologies to evaluate the environmental impacts embodied within building materials and products, as well as to explore the potential of integrating life cycle assessment methods, data, and/or standards into the state building code.

The full text of the bill was obtained through the LCA for WA website (http://courses.washington.edu/lcaforwa/wordpress/) and is directly accessible online at http://apps.leg.wa.gov/documents/billdocs/2011-12/Pdf/Bills/Session%20Law%202011/5485-S.SL.pdf

This section contains copies of the documents created by the state:

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X1.2 Signed Legislation

CERTIFICATION OF ENROLLMENT

ENGROSSED SUBSTITUTE SENATE BILL 5485

Chapter 341, Laws of 2011

62nd Legislature
2011 Regular Session

STATE BUILDINGS--ENERGY CONSERVATION--LIFE-CYCLE ASSESSMENT

EFFECTIVE DATE: 07/22/11

Passed by the Senate April 18, 2011
YEAS 47 NAYS 0

BRAD OWEN

President of the Senate

Passed by the House April 7, 2011
YEAS 91 NAYS 1

FRANK CHOPP

Speaker of the House of Representatives

Approved May 12, 2011, 2:30 p.m.

CHRISTINE GREGOIRE

Governor of the State of Washington

CERTIFICATE

I, Thomas Hoemann, Secretary of the Senate of the State of Washington, do hereby certify that the attached is **ENGROSSED SUBSTITUTE SENATE BILL 5485** as passed by the Senate and the House of Representatives on the dates hereon set forth.

THOMAS HOEMANN

Secretary

FILED

May 13, 2011

Secretary of State
State of Washington

ENGROSSED SUBSTITUTE SENATE BILL 5485

AS AMENDED BY THE HOUSE

Passed Legislature - 2011 Regular Session

State of Washington **62nd Legislature** **2011 Regular Session**

By Senate Environment, Water & Energy (originally sponsored by Senators Hargrove and Ranker)

READ FIRST TIME 02/16/11.

AN ACT Relating to maximizing the use of our state's natural resources; and creating new sections.

BE IT ENACTED BY THE LEGISLATURE OF THE STATE OF WASHINGTON:

NEW SECTION. **Sec. 1.** (1)(a) The University of Washington, led by the college of built environments, and Washington State University, led by the college of engineering and architecture, shall conduct a review of other states' existing building codes, international standards, peer-reviewed research, and models and tools of life-cycle assessment, embodied energy, and embodied carbon in building materials.

(b) This review must identify:

(i) If the standards and models are developed according to a recognized consensus-based process;

(ii) If the standards and models could be implemented as part of building standards or building codes; and

(iii) The scope of life-cycle accounting that the standards and models address.

(2)(a) By September 1, 2012, the University of Washington and Washington State University shall submit a report to the legislature

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consistent with RCW 43.01.036. In addition to providing the data required in subsection (1) of this section, the report must include recommendations to the legislature for methodologies to:

(i) Determine if a standard, model, or tool using life-cycle assessment can be sufficiently developed to be incorporated into the state building code;

(ii) Develop a comprehensive guideline using common and consistent metrics for the embodied energy, carbon, and life-cycle accounting of building materials; and

(iii) Incorporate into every project the ongoing monitoring, verification, and reporting of a high performance public building's actual performance over its life cycle.

(b) The report must include a list of any journal articles, study summaries, and other scientific information reviewed by the University of Washington and Washington State University in the development of the report and the information relied upon by the University of Washington and Washington State University in finalizing the report required under (a) of this subsection.

(c) When developing its recommendations under this section, the University of Washington and Washington State University shall seek input from organizations representing design and construction professionals, academics, building materials industries, and life-cycle assessment experts.

(3) For the purposes of this section, "life-cycle assessment" means manufacturing, construction, operation, and disposal of products used in the construction of buildings from cradle to grave.

<u>NEW SECTION.</u> **Sec. 2.** (1)(a) By December 1, 2012, the department of general administration shall make recommendations to the legislature, consistent with RCW 43.01.036, for streamlining current statutory requirements for life-cycle cost analysis, energy conservation in design, and high performance of public buildings.

(b) The department of general administration shall make recommendations on what statutory revisions, if any, are needed to the state's energy life-cycle cost analysis to account for comprehensive life-cycle impacts of carbon emissions.

(2) In making its recommendations to the legislature under

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subsection (1) of this section, the department of general administration shall use the report prepared by the University of Washington and Washington State University under section 1 of this act.

<u>NEW SECTION.</u> **Sec. 3.** If specific funding for the purposes of this act, referencing this act by bill or chapter number, is not provided by June 30, 2011, in the omnibus appropriations act, this act is null and void.

Passed by the Senate April 18, 2011.
Passed by the House April 7, 2011.
Approved by the Governor May 12, 2011.
Filed in Office of Secretary of State May 13, 2011.

X1.3 Senate Bill Report

SENATE BILL REPORT
ESSB 5485

As Amended by House, April 7, 2011

Title: An act relating to maximizing the use of our state's natural resources.

Brief Description: Maximizing the use of our state's natural resources.

Sponsors: Senate Committee on Environment, Water & Energy (originally sponsored by Senators Hargrove and Ranker).

Brief History:
Committee Activity: Environment, Water & Energy: 2/08/11, 2/15/11 [DPS, w/oRec].
Passed Senate: 3/07/11, 44-5.
Passed House: 4/07/11, 91-1.

SENATE COMMITTEE ON ENVIRONMENT, WATER & ENERGY

Majority Report: That Substitute Senate Bill No. 5485 be substituted therefor, and the substitute bill do pass.
Signed by Senators Rockefeller, Chair; Nelson, Vice Chair; Honeyford, Ranking Minority Member; Chase, Fraser, Morton and Ranker.

Minority Report: That it be referred without recommendation.
Signed by Senator Delvin.

Staff: Jan Odano (786-7486)

Background: It is the policy of the state to ensure that energy conservation practices and renewable energy systems are used in the design of major publicly owned or leased facilities. Whenever a public agency determines that a major facility should be constructed or renovated, the agency must conduct a life-cycle cost analysis that includes energy costs as well as all operating costs. In addition, all major public facility projects receiving capital funding must be designed, constructed, and certified to Leadership in Energy and Environmental Design (LEED) silver standard.

Life-cycle assessments review every impact associated with all stages of a process from extracting raw materials through manufacturing, distributing, using, repairing, maintaining, recycling, or disposing. Life-cycle assessment can provide a broader review on the environmental, social, and economic concerns related to a product.

This analysis was prepared by non-partisan legislative staff for the use of legislative members in their deliberations. This analysis is not a part of the legislation nor does it constitute a statement of legislative intent.

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Embodied energy is the amount of energy needed to extract, transport, manufacture, install, and recycle or dispose of a product or service. Methodologies to determine embodied energy vary as to the scale and scope of the use and type of embodied energy.

The State Building Code Council (SBCC) is authorized to adopt and amend uniform building and energy codes. It establishes the minimum building code to protect the health and safety of building occupants. The SBCC advises the Legislature and Governor on issues relating to the building codes.

Summary of Engrossed Substitute Bill: The University of Washington (UW), in conjunction with a nonprofit consortium involved in research on renewable industrial materials, and in consultation with the SBCC, must review other states' codes, international standards, and literature on life-cycle assessment and embodied energy and embodied carbon in building materials. The UW, in conjunction with a nonprofit consortium, must make recommendations to the Legislature for methodologies to assess and determine the amount of embodied energy in building materials or greenhouse gas emission avoided by using building materials with low embodied energy; and develop a comprehensive guideline for measuring embodied energy and carbon in building materials. General Administration must make recommendations for streamlining energy conservation, life-cycle cost analysis and high performance codes for public buildings.

Appropriation: None.

Fiscal Note: Available.

Committee/Commission/Task Force Created: No.

Effective Date: Ninety days after adjournment of session in which bill is passed.

Staff Summary of Public Testimony on Original Bill: PRO: We need to align the state building codes with our climate change policy and sustainability. Wood and wood products are very sustainable especially compared to other building materials and are part of the global solution. Wood sinks carbon, and trees replacing those cut for wood are carbon sinks. Gravel and steel do not sink carbon. The amount of energy used to make concrete and steel could require much more than the energy savings of a building built to LEED standards. We should address the inconsistent and inefficient processes that allow industries to take advantage of the current building code to sustain businesses that are not consistent with existing environmental policy. A lifecycle assessment of building materials needs to be part of the equation. The amount of energy it takes to produce wood products is far less than other materials. Using wood materials will reduce our carbon emissions and restart the mills across the state. Wood and forest products are a big part of the state's economy representing the second largest manufacturing sector. Using more wood is good for the environment and good for the economy. Stimulating the economy will help to bring more revenue and jobs to the state. California has adopted its own green code, which is something to look at.

CON: This adopts a new code without review by the SBCC. The SBCC has promised to review green codes and green plumbing codes. The IGCC impacts every aspect of building including electrical, mechanical, plumbing codes and land use. The IGCC is not final and adoption now is premature. It is a false premise that wood is disadvantaged in the building code, many architects use it in their building designs. The idea of measuring embodied energy is worthy, but there is no common metric for embodied energy. The metric should be developed at the national level. Using the SBC to promote wood is inappropriate, the purpose of the SBC is to protect life and safety of the occupants of the building. Architects and builders should be the ones to determine the materials for a building based on safety and use of the building. Architects and building officials carry the liability for building codes. Wood products organizations or other groups should not determine building construction or materials. Embodied energy is about the life of the building. The best buildings are the ones that have the longest life. Lifecycle assessments are subjective.

OTHER: The SBCC is in the process of reviewing all green codes. The IGCC is very broad covering more than materials such as land use, grey-water, and plumbing code. Embodied energy is not an easy fit with a life-cycle assessment. Isolating fossil fuels will require a special effort to isolate in the life-cycle assessments.

Persons Testifying: PRO: Elaine Oneil, Consortium for Research on Renewable Industrial Materials; Dwight Yochim, Wood Products Council; Dave Nunes, Pope Resources; Debora Munguia, WA Forest Protection Assn.

CON: Tonia Neal, WA State Conference of Mason Construction; Pete Crow, International Assn. of Plumbing & Mechanical Office; Randy Scott, WA State Assn. of Plumbers and Pipefitters; Stan Bowman, Marc Jenessky, American Institute of Architects; Bruce Chatkin, WA Aggregates & Concrete.

OTHER: Tim Nogler, State Building Code Council; John Lynch, General Administration; Nancy Hirsch, NW Energy Coalition; Mo McBroom, WA Environmental Council.

House Amendment(s):

- Requires the Washington State University (WSU), College of Engineering and Architecture along with the University of Washington College of Built Environments to conduct a review of other states' existing building codes, international standards, peer-reviewed research and models of life-cycle assessment, embodied energy and embodied carbon in building materials and develop a report and recommendations;
- Removes the requirement for a nonprofit consortium to conduct the review in consultation with the State Building Code Council;
- Modifies the review and reporting requirements;
- Includes developing recommendations for ongoing monitoring, verification, and report of the actual performance of high performance public buildings;
- Removes the intent section; and
- Adds a null and void clause.

X1.4 House Bill Report

HOUSE BILL REPORT
ESSB 5485

As Passed House - Amended:
April 7, 2011

Title: An act relating to maximizing the use of our state's natural resources.

Brief Description: Maximizing the use of our state's natural resources.

Sponsors: Senate Committee on Environment, Water & Energy (originally sponsored by Senators Hargrove and Ranker).

Brief History:
Committee Activity:
Environment: 3/17/11, 3/24/11 [DPA];
Capital Budget: 3/28/11, 3/29/11 [DPA(CB w/o ENVI)].
Floor Activity:
Passed House - Amended: 4/7/11, 91-1.

Brief Summary of Engrossed Substitute Bill
(As Amended by House)

- Requires the University of Washington and Washington State University to conduct a review of other states' building codes, international standards, peer-reviewed research, and models and tools of life-cycle assessment, embodied energy, and embodied carbon in building materials and make certain recommendations to the Legislature.
- Requires the Department of General Administration to make recommendations to the Legislature for streamlining statutory requirements related to life-cycle cost analysis, energy conservation in design, and high performance of public buildings and make recommendations concerning the state's energy life-cycle cost analysis.

HOUSE COMMITTEE ON ENVIRONMENT

Majority Report: Do pass as amended. Signed by 13 members: Representatives Upthegrove, Chair; Rolfes, Vice Chair; Short, Ranking Minority Member; Harris, Assistant Ranking Minority Member; Fitzgibbon, Jinkins, Morris, Moscoso, Nealey, Pearson, Takko, Taylor and Tharinger.

This analysis was prepared by non-partisan legislative staff for the use of legislative members in their deliberations. This analysis is not a part of the legislation nor does it constitute a statement of legislative intent.

Staff: Courtney Barnes (786-7194).

HOUSE COMMITTEE ON CAPITAL BUDGET

Majority Report: Do pass as amended by Committee on Capital Budget and without amendment by Committee on Environment. Signed by 10 members: Representatives Dunshee, Chair; Ormsby, Vice Chair; Zeiger, Assistant Ranking Minority Member; Asay, Jinkins, Lytton, Moeller, Pearson, Smith and Tharinger.

Staff: Steve Masse (786-7115).

Background:

Washington State Building Code Council.

The Washington State Building Code Council (SBCC) establishes the minimum building, mechanical, fire, plumbing, and energy code requirements necessary to promote the health, safety, and welfare of the state's residents, by reviewing, developing, and adopting the State Building Code (SBC). The SBC establishes the minimum construction requirements for Washington. The SBC is comprised of various building, residential, fire, and other model codes adopted by the Legislature.

Under the State Energy Code, "embodied energy" means the total amount of fossil fuel energy consumed to extract raw materials and to manufacture, assemble, transport, and install the materials in a building and the life-cycle cost benefits including the recyclability and energy efficiencies with respect to building materials. The total sum of current values for the costs of investment, capital, installation, operating, maintenance, and replacement as estimated for the lifetime of the product or project is taken into account.

Life-cycle Cost Analysis of Public Facilities.

When a public agency determines that a major new facility should be built or renovated, a life-cycle cost analysis must be completed at the design phase of the project. A life-cycle cost analysis must conform to guidelines established by the Department of General Administration (GA). A "life-cycle cost" is the initial cost and cost of operation of a major facility over its economic life. "Economic life" means the projected or anticipated useful life of a major facility as expressed by a term of years. A life-cycle cost analysis includes, but is not limited to, the following:

- the coordination and positioning of a major facility on its physical site;
- the amount and type of fenestration employed in a major facility;
- the amount of insulation incorporated into the design of a major facility;
- the variable occupancy and operating conditions of a major facility; and
- an energy-consumption analysis of a major facility.

Summary of Amended Bill:

The University of Washington (UW), led by the College of Built Environments, and Washington State University (WSU), led by the College of Engineering and Architecture, are

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required to conduct a review of other states' existing building codes, international standards, peer-reviewed research, and models and tools of life-cycle assessment, embodied energy, and embodied carbon in building materials.

This review must identify:

- if the standards and models are developed according to a recognized consensus-based process;
- if the standards and models could be implemented as part of building standards or building codes; and
- the scope of life-cycle accounting that the standards and models address.

By September 1, 2012, the UW and WSU are required to submit their review to the Legislature and make recommendations to the Legislature for methodologies to:

- determine if a standard, model, or tool using life-cycle assessment can be sufficiently developed to be incorporated into the SBC;
- develop a comprehensive guideline using common and consistent metrics for the embodied energy, carbon, and life-cycle accounting of building materials; and
- incorporate into every project the ongoing monitoring, verification, and reporting of a high performance public building's actual performance over its life cycle.

In developing its recommendations, the UW and WSU must seek input from organizations representing design and construction professionals, academics, building materials industries, and life-cycle assessment experts.

By December 1, 2012, the GA is required to make recommendations to the Legislature for streamlining current statutory requirements for life-cycle cost analysis, energy conservation in design, and high performance of public buildings. The GA must make recommendations on what statutory revisions, if any, are needed to the state's energy life-cycle cost analysis to account for comprehensive life-cycle impacts of carbon emissions. In making its recommendations to the Legislature, the GA is required to use the report prepared by the UW and WSU.

Appropriation: None.

Fiscal Note: Available. New fiscal note requested on March 29, 2011.

Effective Date of Amended Bill: The bill takes effect 90 days after adjournment of the session in which the bill is passed. However, the bill is null and void unless funded in the budget.

Staff Summary of Public Testimony (Environment):

(In support) The bill addresses important environmental issues, especially greenhouse gas emissions. The built environment has a significant impact on greenhouse gas emissions. The bill would require recommendations on embodied energy in primary building materials. The bill takes a scientific approach to provide information on the impact of building materials on the environment. The bill does not mandate the use of wood in buildings, but ultimately the hope is that more wood and other local materials would be used in constructing new buildings. The CBE is willing to conduct the study required by the bill and could undertake the work without creating an advantage or preference for certain materials.

(With concerns) The direction of the bill has improved as it has been amended, but the bill still needs some revisions. The study on embodied energy is a good idea, but there is concern about the cost of requiring a study given the state's current financial challenges. The bill's intent section is biased towards wood, and this bias should be removed. The bill should be amended to address the study standards for embodied energy, instead of presuming that there is a common and consistent metric for embodied energy in building materials. In addition to embodied energy, the study should also account for life-cycle impacts.

(Opposed) The bill is clearly written to promote the use of wood. The bill selectively considers only a small percentage of a project's total environmental impacts over the life of the building. The bill does not account for the operational and use phases of a building's life. The bill gives preferential treatment for wood. Embodied energy is being studied at the federal level, and the state should wait for the federal study to be completed. The bill is not timely given the current budget situation. If a life-cycle study is going to be conducted, all building materials should be evaluated fairly without prescribing an outcome.

Staff Summary of Public Testimony (Capital Budget):

(In support) The life-cycle assessment is a good tool to compare the total costs of products from cradle to grave. The CBE currently does life-cycle costs assessments on wood products, from which the UW can use existing information.

(Opposed) If this is done by the UW, most of their work is related to wood products and discriminates against other building materials, like concrete. The life-cycle cost assessment should use any objective information, and the review results should be considered carefully before being implemented.

Persons Testifying (Environment): (In support) Jim Fridley, University of Washington; and Debra Munguia, Washington Forest Protection Association.

(With concerns) Stan Bowman, American Institute of Architects Washington Council.

(Opposed) Bruce Chattin, Washington Aggregates and Concrete Association; and Tonia Sorrell-Neal, Washington State Conference of Mason Contractors.

Persons Testifying (Capital Budget): (In support) Stan Bowman, American Institute of Architects Washington Council; Debora Mungia, Washington Forest Protection Association; and Elaine Oneil, Univesity of Washington.

(Opposed) Bruce Chattin, Washington Aggregates and Concrete Association.

Persons Signed In To Testify But Not Testifying (Environment): None.

Persons Signed In To Testify But Not Testifying (Capital Budget): None.

A1.5 Committee on the Environment Bill Report

Washington State
House of Representatives
Office of Program Research

BILL ANALYSIS

Environment Committee

ESSB 5485

Brief Description: Maximizing the use of our state's natural resources.

Sponsors: Senate Committee on Environment, Water & Energy (originally sponsored by Senators Hargrove and Ranker).

Brief Summary of Engrossed Substitute Bill

- Requires the University of Washington (UW) to conduct a review of other states' codes, international standards, and literature on life-cycle assessment, embodied energy, and embodied carbon in building materials.
- Requires the UW to make recommendation to the Legislature for methodologies to: (1) conduct an assessment and determine the amount of embodied energy and carbon in building materials or greenhouse gas emissions avoided by using building materials with low-embodied energy or carbon; and (2) develop a comprehensive guideline using a common and consistent metric for the embodied energy and carbon in building materials.
- Requires the Department of General Administration to make recommendations for streamlining current statutory requirements for life-cycle cost analysis, energy conservation in design, and high performance of public buildings.

Hearing Date: 3/17/11

Staff: Courtney Barnes (786-7194).

Background:

Washington State Building Code Council.

The Washington State Building Code Council (SBCC) establishes the minimum building, mechanical, fire, plumbing, and energy code requirements necessary to promote the health, safety, and welfare of the state's residents, by reviewing, developing, and adopting the State Building Code (SBC). The SBC establishes the minimum construction requirements for

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House Bill Analysis - 1 - ESSB 5485

1

Washington. The SBC is comprised of various building, residential, fire and other model codes adopted by the Legislature.

Under the State Energy Code, "embodied energy" means the total amount of fossil fuel energy consumed to extract raw materials and to manufacture, assemble, transport, and install the materials in a building and the life-cycle cost benefits including the recyclability and energy efficiencies with respect to building materials. The total sum of current values for the costs of investment, capital, installation, operating, maintenance, and replacement as estimated for the lifetime of the product or project is taken into account.

Life-cycle Cost Analysis of Public Facilities.

When a public agency determines that a major new facility should be built or renovated, a life-cycle cost analysis must be completed at the design phase of the project. A life-cycle cost analysis must conform to guidelines established by the Department of General Administration (GA). A "life-cycle cost" is the initial cost and cost of operation of a major facility over its economic life. "Economic life" means the projected or anticipated useful life of a major facility as expressed by a term of years. A life-cycle cost analysis includes, but is not limited to, the following:

- the coordination and positioning of a major facility on its physical site;
- the amount and type of fenestration employed in a major facility;
- the amount of insulation incorporated into the design of a major facility;
- the variable occupancy and operating conditions of a major facility; and
- an energy-consumption analysis of a major facility.

Summary of Bill:

The University of Washington (UW) is required conduct a review of other states' existing codes, international standards, and literature on life-cycle assessment, embodied energy, and embodied carbon in building materials. This review must be conducted in conjunction with a nonprofit consortium involved in research on renewable industrial materials and in consultation with the SBCC.

By July 2012, the UW, in conjunction with a nonprofit consortium involved in research on renewable industrial materials, is required to make recommendations to the Legislature for methodologies to:

- conduct an assessment and determine the amount of embodied energy and carbon in building materials or greenhouse gas emissions avoided by using building materials with low-embodied energy or carbon; and
- develop a comprehensive guideline using a common and consistent metric for the embodied energy and carbon in building materials.

In developing its recommendations, the UW and nonprofit consortium must seek input from building materials industries and other interested parties.

The GA is required to make recommendations for streamlining current statutory requirements for life-cycle cost analysis, energy conservation in design, and high performance of public buildings.

Appropriation: None.

Fiscal Note: Available.

Effective Date: The bill takes effect 90 days after adjournment of the session in which the bill is passed.

X1.6 Final Bill Report

FINAL BILL REPORT
ESSB 5485

C 341 L 11
Synopsis as Enacted

Brief Description: Maximizing the use of our state's natural resources.

Sponsors: Senate Committee on Environment, Water & Energy (originally sponsored by Senators Hargrove and Ranker).

Senate Committee on Environment, Water & Energy
House Committee on Environment
House Committee on Capital Budget

Background: It is the policy of the state to ensure that energy conservation practices and renewable energy systems are used in the design of major publicly owned or leased facilities. Whenever a public agency determines that a major facility should be constructed or renovated, the agency must conduct a life-cycle cost analysis that includes energy costs as well as all operating costs. A life-cycle analysis must conform to guidelines established by the Department of General Administration (GA). In addition, all major public facility projects receiving capital funding must be designed, constructed, and certified to Leadership in Energy and Environmental Design (LEED) silver standard.

Life-cycle assessments review every impact associated with all stages of a process from extracting raw materials through manufacturing, distributing, using, repairing, maintaining, recycling, or disposing. Life-cycle assessment can provide a broader review on the environmental, social, and economic concerns related to a product.

Embodied energy is the amount of energy needed to extract, transport, manufacture, install, and recycle or dispose of a product or service. Methodologies to determine embodied energy vary as to the scale and scope of the use and type of embodied energy.

Summary: The University of Washington (UW) College of Built Environments and the Washington State University (WSU) College of Engineering and Architecture must complete a review of other states' existing building codes, international standards, peer-reviewed research and models of life-cycle assessment, embodied energy and embodied carbon in building materials. The review must identify:

- if standards and models are developed according to recognized consensus-based process, and could be implemented as part of building standards or building codes; and
- the scope of life-cycle impacts addressed in the standards and models.

This analysis was prepared by non-partisan legislative staff for the use of legislative members in their deliberations. This analysis is not a part of the legislation nor does it constitute a statement of legislative intent.

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The UW and WSU must report to the Legislature recommendations for methodologies to:

- determine if a standard, model, or tool using life-cycle assessment can be sufficiently developed to be incorporated into the state Building Code;
- develop a comprehensive guideline using common and consistent metrics for embodied energy, carbon, and life-cycle accounting of building materials; and
- incorporate ongoing monitoring, verification, and reporting of a high performance public building over its life cycle.

UW and WSU must seek input from design representatives, construction professionals, academics, building materials industries, and life-cycle assessment experts.

GA must make recommendations for streamlining statutory requirements of life-cycle cost analysis, energy conservation in design, and high performance buildings using the report from UW and WSU.

If specific funding is not included in the Omnibus Appropriations Act, this bill is null and void.

Votes on Final Passage:

Senate	44	5	
House	91	1	(House amended)
Senate	47	0	(Senate concurred)

Effective: July 22, 2011.

X2 Codes & Legislation

X2.1 Introduction

Life cycle assessment data and methods are influencing code development and being integrated into building codes and legislation at many scales (city, state, national and international). In this section, we have identified relevant codes and legislation (both proposed and adopted) that explicitly utilize LCA either as part of an integrated analysis or as the justification for prescriptive requirements.

Currently, few laws (none known in US) mandate that LCA reports be submitted as a part of the official review process for building permitting. This is not to say that characteristics of life cycle assessment are not explicitly stated. In fact, all of the reviewed items are written from a foundation of LCA or have benchmark-gathering portions to supplement future LCA study.

X2.2 Summary of Studied Items

Pg	Name	Description	Location	Consensus Based Process?	Relative Importance*	LCA Scope Addressed, A--D**
4	ANSI/ASHRAE/USGBC/IES 189.1-2009	Standard for the Design of High Performance Green Buildings	U.S.	Y	1A	A,B,C,D
5	BC Wood First Initiative	Bill 9-2009 Wood First Act	CA	N	3	A
6	CalGreen	California Building Standards Commission	U.S.	N	1	A,B,C,D
7	CA Assembly Bill 32	California Global Warming Solutions Act	U.S.	N	3	A,B,C varies
8	EPBD	EU European Energy Performance and Building Directive	DE	N	2	A,B,C,D
9	Exec. Order 13423	Good environmental practice for purchasing	U.S.	N	1B	A,B,C,D
12	Exec. Order 13514 Sec. 13	EPA/GSA joint task force Report with recommendations for green purchasing	U.S.	N	1B	TBD
13	French EPD Mandate	French law mandating product EPDs	FR	N	1B	A,B,C
14	IgCC	International Green Construction Code	U.S.	Y	1A	A,B,C,D
16	NYC INT 0577-2011	NY City Code: limiting cement content	U.S.	N	2	A
17	Oregon Wood First (proposed)	Proposed House Bill 3429-2011	U.S.	N	3	A
18	Various EU Legislation	See summary table	EU	?	2	Varies

*1 being highest importance, 3 being lowest

** A: Production/Manufacturing and Construction stages (cradle to gate)
B: Use stage
C: End of Life stage
D: Reuse, Recovery, and Recycling stage

X2.3 Evaluation

Of the instances of LCA integrated into building codes or legislation, the following are evaluated to be of the highest relevance and a priority for closer evaluation:

1. ASHRAE 189.1: Model code with diverse industry involvement.
2. IgCC: Already being adopted by some municipalities.
3. CalGreen: Voluntary LCA section.
4. French EPD: Demonstrating how legislation can advance the use of LCA in practice.
5. Executive Order 13514: Pending guidance from Federal Government on green procurement practices.
6. Dutch LCA Analysis (pending): worthy of following/future evaluation.

These and other instances are analyzed in more detail on the following pages.

ANSI/ASHRAE/USGBC/IES 189.1-2009 Standard for the Design of High-Performance Green Buildings (Except Low-Rise Residential Buildings)

Organization: ANSI et al/IgCC
Date: 2011 by ASHRAE
Reference: http://www.ashrae.org/resources--publications/bookstore/standard-189-1

Consensus: Yes
Implementation: Possible
LCA Scope: A, B, C, D

Description

This standard was created through collaboration between ASHRAE, The US Green Building Council and the Illuminating Engineering Society of North America. It is co-published with the International Green Construction Code (IgCC) and is an alternative compliance option. It is commonly called ASHRAE 189.1. Users of the IgCC can either comply with ALL of the requirements of the IgCC or ALL of the requirements of ASHRAE189.1 (not selectively choose sections from each).

In Chapter 9, 'The Building's Impact on the Atmosphere, Materials and Resources', users have an option of 'prescriptive' or 'performance'-based compliance. Section 9.5 outlines a performance-based option that requires the completion of a LCA in accordance with ISO 14044 for at least two building alternatives comparing a 'common design' and the 'high performance' option. The code requires the alternative to have a minimum of 5% of improvement over the other alternative in a minimum of two impact categories. The impact categories listed are land use (or habitat alteration), resource use, climate change, ozone layer depletion, human health effects, ecotoxicity, smog, acidification and eutrophication. The standard outlines a basic procedure and requires an ISO-compliant critical review.

Analysis

This method, although similar to the IgCC method (reviewed later in this section), has some key differences. First, the 5% improvement on only two impacts is a relatively small percentage improvement. Given the inherent variability and uncertainty in most LCI data, this may be too small to be statistically relevant. However, this difference will be significantly easier to achieve than the 20% outlined by the IgCC. This standard does not presume a specific LCA tool but rather outlines a standard LCA methodology. It appears to permit a focused study of specific options and presumes a more detailed LCA study using project-specific data. The requirement of attaining a third party critical review would alleviate the responsibility of the code official to understand and verify the results of an LCA study and place the costs of LCA evaluation directly onto the building team.

BC Wood First Initiative

Organization: Provincial Legislature of British Columbia
Date: 12.16.2011
Reference: http://www.jti.gov.bc.ca/woodfirst/

Consensus: No
Implementation: Possibly
LCA Scope: A

Description

Bill 9, British Columbia Wood First Act. Provincial bill passed in October of 2009.

As written, the bill is very short and not wholly descriptive. It is divided into five parts. First, the responsible parties (local and provincial governments) and sources of funding for public buildings are defined. The purpose of the act is then stated: "to facilitate a culture of wood by requiring the use of wood as the primary building material in all new provincial buildings." To that purpose, three directives, called "Best Practices," are given: 1) the minister has the jurisdiction to recommend the best practices for wood use in their buildings; 2) the minister can advise on the design and construction contracts of said projects; 3) the minister can carry out his/her prescribed responsibilities. The depth of the bill seems to come in the fourth part under the "power to make regulations." This power is given to the Lt. Governor under the Interpretation Act to create laws and other rules as needed that were otherwise not originally stipulated by the bill. The Lt. Governor can essentially interpret the bill and create laws to guide it. This power comes through various committees of which the Lt. Governor is the head.

Analysis

The Wood First Act has spread through most of British Columbia, where it has been adopted by thirty-seven communities and municipalities as of October 2011 (Kootenay Advertiser, Oct. 14 2011). It is supported by an initiative of the Canadian Wood Council called Wood Works! and has locations across Canada working to get the BC Wood First Act into other provinces. Its proponents used economic and environmental stands to justify the legislation. The latter used LCA data to support the position (personal communication with Werner Hofstatter). The act specifies that buildings that are built primarily of wood still must fit within the BC building code. This code, however, has to be and is being amended to create allowances to expand the scale of buildings that can be built of wood. Most model building codes are more restrictive of wooden buildings for both structural and fire-related issues.

CalGreen

Organization: State of California
Date: Initiated 2007 by Gov. Schwarzenegger, Enacted January 1, 2011.
Reference: http://www.documents.dgs.ca.gov/bsc/CALGreen/2010_CA_Green_Bldg.pdf

Consensus: No
Implementation: Possibly
LCA Scope: A3, A5, B1, B6-7, C1, C4, D

Description

The California Green Building Standards Code (CalGreen) is a mandatory code, effective January 1st, 2011, which is enforced in all new construction. CalGreen represents the first minimum standards code of its kind in the US. It requires a minimum level of sustainable practice including water reduction by 20%, diversion of waste from landfills by 50% and installation of low pollutant-emitting materials. In addition, it requires separate metering of indoor and outdoor water and periodic efficiency inspections of energy systems.

The minimum code requirements are mandatory. There are additional optional tiers that practitioners can choose to meet. The next step is to understand the code requirements for the jurisdiction where the project is located. CalGreen has mandatory requirements that must be adopted by all code jurisdictions in the State; however, the local jurisdiction has the option to amend the code in some ways to customize it to their needs. They can choose to adopt the "Tier 1 or Tier 2" in addition to the minimum mandatory code. These are referred to as "reach codes."

Analysis

Although there are numerous other "code" frameworks (i.e. Build it Green, CHPS, LEED), this is the first mandatory 'green' building code. It touches on all lifecycle phases. Within the mandatory framework, CalGreen has a voluntary component addressing LCA that can be adopted by municipalities as mandatory. LCA is addressed in a similar manner as that of ASHRAE 189.1, whereby LCA can be used as a performance path in lieu of prescriptive requirements such as recycled content, bio-based content inclusion, regional material selection, etc. The requirement is to perform two whole building LCAs, one as a base building and one as an alternative showing at least a 10% improvement over the base. This improvement must come in at least three of the five impact categories stipulated (global warming potential, ozone depletion potential, acidification potential, eutrophication potential, smog potential) of which global warming must be one. (Although not an "impact category," fossil fuel depletion is also a recognized area of potential savings.) An alternative route for practitioners wishing to not perform these LCAs is to select at least 50% of the building's materials and assemblies with an approved LCA tool showing their performance in global warming potential and at least two other impact categories.

California Assembly Bill 32

Organization: State of California
Date: Signed 2006, Effective 2013
Reference: http://www.arb.ca.gov/cc/ab32/ab32.htm

Consensus: No
Implementation: Possibly
LCA Scope: A

Description

AB 32 is a law passed in California focused on reducing greenhouse gas emissions. It puts a statewide limit on the amount of greenhouse gas emissions that are allowed to come out of industry smoke stacks, commuter tailpipes and all other sources of emissions. It was signed into law in 2006, and the first layer of restrictions takes effect in January of 2013. It is being developed by the Air Resources Board (ARB), which will also administer the law's enforcement. The basic framework is beginning greenhouse gas emissions reductions by constricting the cap year after year, so that by 2020, the emission levels have returned to 1990 levels. AB 32 is a "cap and trade" system that will allow polluters to transition into cleaner and more efficient processes by not forcing them to replace heavy pollution machinery or systems all at once. This would be extremely costly, so these companies are allowed to purchase carbon offsets from other companies that can more easily fit under the cap. Their excess "cap space" will become a secondary market as a commodity.

Analysis

AB 32 fits into a long-term vision to lower greenhouse gas emissions. It can affect the construction industry in several ways. The effects will mostly be indirect, affecting the upstream production of materials and the transportation sector the most. It will certainly affect manufacturing plants responsible for building products and their transportation, a cycle which includes both inputs from materials and the output to distributors and then to customers. Provisions in the law to track all emissions for filing will bolster data for lifecycle assessment reports, as most of this data is currently not made publically available. Although it doesn't explicitly reference LCA, LCA methods are typically used to track and report greenhouse gas emissions. Cement plants have been identified as one of the industries that must participate in this program, and thus AB32 may impact construction prices or cement plant locations.

(EU) European Energy Performance of Buildings Directive (EPBD)

Organization: European Union, Directive implementation Advisory Group (DIAG)
Date: 2000, 2010
Reference: http://www.epbd-ca.eu/

Consensus: No
Implementation: Possibly
LCA Scope: A, B, C, D

Description

The EPBD is a very complex, multi-layer system of reductions across Member States of the European Union. In 2002, the EU set forth the first directive mandating energy conservation, energy efficiency standards and greenhouse gas emissions. In 2010, a recasting of these directives has improved upon the levels originally targeted. The targets are now to reduce greenhouse gas emissions to 80-95% below 1990 levels by 2050 and to save 20% of all energy used by 2020.

Analysis

As a part of the recasting of the directives, the European Commission that oversees these directives issued “The Roadmap to 2050.” The map lays out specifics on the established goals and benchmarks for achieving them. The roadmap keys in on saving energy through efficiency and relies heavily upon decarbonization.

In light of these directives, many companies specializing in low-carbon building consulting have developed tools for analyzing the global warming potential of buildings in both operations and the embodied impacts of materials. These tools are being used and developed in a variety of ways with different goals and levels of implementation. Parts of the EPBD have to do with the permitting and taxing of buildings. The permitting phases are early in the design process, having to do with development, construction, renovation, etc. Taxing can deal with these same buildings but also with existing structures in relationship to how they preform functionally. These tools are meant to be a way of interfacing with officials, to give users, designers and owners common data from which to work.

Executive Order 13423

Reference: Executive Order 13423: Strengthening Federal Environmental, Energy, and Transportation Management, Signed January 24, 2007, INSTRUCTIONS FOR IMPLEMENTING EXECUTIVEORDER 13423.
Date: Finalization Pending
Reference: http://www.fedcenter.gov/_kd/Items/actions.cfm?action=Show&item_id=6825&destination=ShowItem

Consensus: No
Implementation: Possibly
LCA Scope: A, B, C, D

Description:

Section 2 of the E.O. directs Federal agencies to implement sustainable practices for:

- Energy efficiency and reductions in greenhouse gas emissions,
- Use of renewable energy,
- Reduction in water consumption intensity,
- Acquisition of green products and services,
- Pollution prevention, including reduction or elimination of the use of toxic and hazardous chemicals and materials,
- Cost-effective waste prevention and recycling programs,
- Increased diversion of solid waste,
- Sustainable design/high performance buildings,
- Vehicle fleet management, including the use of alternative fuel vehicles and alternative fuels and the further reduction of petroleum consumption, and
- Electronics stewardship.

Analysis:

The instructions provided by the federal center (see website link above) give the following summary, listed in Table X2.1, with applicable sections included only. These apply to federal agencies, but might represent a matrix of considerations that the state might also strive to meet within the LCA structure.

Table X2.1: Executive Order 13423 Summary of Applicable Sections (2 pages)

Requirements	Responsible Agency	Deliverable
Environmental Management Systems*: not applicable*		
Energy and Water Management		
Issue renewable energy-related guidance	DOE	Guidance on achieving the renewable energy goal, use of renewable energy credits, use of alternatively finance projects, use of and investment in renewable energy generation, and retention of funds
Issue water conservation-related guidance	DOE	Guidance on FY 2007 baseline and meeting water conservation goal
Implement energy efficiency goals: Reduce energy intensity by 3% annually OR 30% relative to FY 2003 baseline	Agencies	Reduced energy intensity at Federal buildings; improved energy efficiency; and reduced greenhouse gas emissions
Implement energy goals: Meet at least half of EPAct 2005 renewable energy goals from new sources	Agencies	Implement energy goals: Meet at least half of EPAct 2005 renewable energy
Implement energy goals: Implement on-site renewable energy projects	Agencies	Where feasible
Implement water reduction goals: Reduce water consumption intensity by 2% annually through end of FY 2015 OR 16% by end of FY 2015	Agencies	Reduce water consumption intensity
Green Purchasing		
Prepare and issue E.O. implementing instructions	OMB/OFPP	Proposed OFPP Policy Letter for implementing the acquisition requirements of the E.O. Consultation with CEQ and the Steering Committee
Prepare and issue E.O. implementing instructions	OMB/OFPP	Federal Acquisition Regulation revisions, as necessary to implement the E.O. Consultation with CEQ and the Steering Committee
Review CPG	EPA	
Program coordination	EPA, DOE, USDA	Coordinated product designations and guidance
Model green purchasing programs	EPA, DOE, USDA	Model programs for implementing the green purchasing program components for which each respective agency is the technical lead
Purchase green products and services	Agencies	Acquisition of products and services requiring the supply or use of green products Recycled content products, Energy efficient products, Renewable energy, Water efficient products, Biobased products, Environmentally preferable products and services, Non-ozone depleting substances, Products with low or no toxic or hazardous constituents
Purchase printing and writing paper containing 30% postconsumer fiber	Agencies	
Contracts for operation of government facilities or fleet require compliance with E.O. requirements	Agencies	Contracts requiring contractor to comply with the E.O. requirements to the same extent as the agency

Agreements, permits, leases, licenses, or other legally-binding obligations require tenant or concessionaire to take actions facilitating agency's compliance with E.O. requirements	Agencies	Requirements are added to the extent the head of the agency determines appropriate
Management of Toxic and Hazardous Chemicals and Materials		
Develop toxics and hazardous chemicals and materials reduction plan	Agencies	Written plan
Reduce the quantity of toxic and hazardous chemicals and materials acquired, used, or disposed	Agencies	Purchase and use of no or low toxic or hazardous chemicals, including products containing toxic or hazardous constituents
Reduce the quantity of toxic and hazardous chemicals and materials acquired, used, or disposed	Agencies	Purchase and use of no or low toxic or hazardous chemicals, including products containing toxic or hazardous constituents
Waste Diversion/Recycling		
Establish and report to FEE solid waste diversion goals	Agencies	Waste diversion goal to be achieved by December 31, 2010
Designate facility recycling coordinators	Agencies	Facility recycling coordinators
Increase diversion of solid waste	Agencies	Reduce solid waste sent to landfills or incineration
Maintain waste prevention and recycling programs at agency facilities, including leased facilities, in cost-effective manner	Agencies	Reduce or eliminate product purchases (waste prevention) and increase recycling, donation, reuse, repair
Justification for use of recycling revenue	Senior officials	Justification to OFEE, for resolution with OMB, of uses of recycling revenue other than those listed in statute
Sustainable Design/High Performance Buildings		
Issue guidance for sustainable design/high performance buildings plans	OMB	Identification of required components of the plans
Develop and implement sustainable design/high performance buildings implementation plan	Agencies	Sustainable design/high performance buildings plan
Review Guidance Principles and Technical Guidance	Interagency Sustainability Working Group	Update, expand, and/or revise guiding principles and technical guidance
Report projects to High Performance Federal Buildings Database	Agencies	Expanded and updated database
Ensure that new construction and major renovation of buildings comply with *Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings*	Agencies	Sustainable design incorporated into new Federal building construction and renovation
Ensure that 15% of existing capital asset building inventory incorporates the sustainable practices in the *Guiding Principles*	Agencies	Sustainable design principles incorporated into existing Federal buildings
Fleet Management: ***not applicable***		
Other requirements: ***not applicable***		

Executive Order 13514 Section 13

Reference: Talk given by Alison Bennett of the EPA at the ASTM E60 meeting in West Conshohocken, PA in October 2011, and a report by the General Services Administration (GSA) entitled: *Executive Order 13514 Section 13: Recommendations for Vendor and Contractor Emissions*, http://www.fedcenter.gov/_kd/Items/actions.cfm?action=Show&item_id=15392&destination=ShowItem

Date: April 2010 and October 2011 (final draft in progress/pending)

Consensus: No for the Executive Order, Some for the report

Implementation: Possibly

LCA Scope: TBD

Description:

This section of the US Executive Order 13514 is summarized in the report by the GSA as:

> 'On October 5, 2009, the President of the United States signed Executive Order (EO) 13514 calling on Federal agencies to "establish an integrated strategy towards sustainability in the Federal Government and to make reduction of greenhouse gas emissions a priority for federal agencies." Among other initiatives, the EO requires agencies to set baselines and targets for their scope 1, 2, and 3 greenhouse gas (GHG) emissions. Scope 3 emissions are emissions from indirect sources related to agency activities, including supply chain emissions. Section 13 of the EO specifically directs the General Services Administration (GSA), in coordination with other key agencies, to assess the feasibility of working with the Federal supplier community (comprised of vendors and contractors that serve federal agencies) to measure and reduce supply chain GHG emissions, while encouraging sustainable supplier operations.'

Analysis:

There is an Executive Order 13514 Section 13 Interagency Workgroup with a subgroup led by Alison Bennett and Libby Sommer of the EPA and Brennan Conaway and Joni Teter of GAS. The objectives of the workgroup are to get more agencies of the federal government to purchase more green-friendly products and specifically to ensure that the product-related acquisition goals of Executive Order 13514 Section 13 are met. They are currently mainly focusing on greenhouse gases. The subgroup working on it has GSA and EPA co-chairs, and its members include representatives of DOD, DLA, USDA, NIST, NIOSH, VA, NASA, DOC, DOI, etc. The intent of the subgroup is to look at the hundreds of current 'ecolabels' and provide a format for choosing amongst them by purchasers based on certain criteria such as whether they are consensus-based, third party certified, etc. The Interagency Workgroup is hoping to have a draft ready by late 2012. The product is expected to be accepted by all the aforementioned agencies of the federal government. They also intend the product to be a template that might be adopted by states, municipalities and other groups. The original schedule to release the report for public comment has been delayed at least two times and is now expected to be published some time in 2012.

French EPD Regulation

Organization: France (Federal Government)
Date: Initiated 2009, Implementation 2013 and 2017
Reference: http://www.inies.fr/

Consensus: No
Implementation: Yes
LCA Scope: varies

Description

Originally envisioned as a regulation to mandate the use of EPDs on all products sold in France, the regulation has changed to require EPDs by 2013 on all products that make environmental performance claims. These EPDs are not required to be third party verified until 2017. In addition to developing the regulations, the French government has funded a research organization, the Centre Scientifique et Technique du Batiment (CSTB), to support the development of building industry specific EPDs and the creation of an EPD database, INIES (www.inies.fr).

Analysis

As of July 2012, the French EPD database INIES contains at least 700 individual or joint EPDs that cover at least 5,000 commercial products on the French market. The French government developed a standard guide permitting EPDs with a reduced (and simplified) set of environmental impacts to be reported (AFNOR French Standard NFP01-010, 2004. Environmental quality of construction products - Environmental and health declaration of construction products, France). The INIES database is providing additional LCI data to be used in whole building LCA analysis and is providing data to help researchers evaluate the validity of using industry average LCI data in whole building analysis (Hodkova, J, & Lasvauz, S., 2012). The majority of EPDs in the French database are not third party verified. Starting in 2017, all EPDs will be required to be verified in France (per presentation at LCA and Construction Symposium, Nantes France, 2012).

It appears that this legislation has been effective in motivating industry to develop LCA data on their manufacturing processes and products. Informal evaluation by those with experience with the program indicates that the current impact is focused on increasing awareness by manufacturers and users and recognizing that the anticipated benefit of reducing impacts

IgCC 2012: International Green Construction Code

Reference: http://www.iccsafe.org/cs/IGCC/Pages/default.aspx Accessed July 16, 2012
Date: Finalized 2012

Consensus: Yes
Implementation: Possibly
LCA Scope: A, B, C

Description:

The IgCC is a newly developed 'model code that includes sustainability measures for the entire construction project and its site — from design through construction, certificate of occupancy and beyond. The new code is expected to make buildings more efficient, reduce waste, and have a positive impact on health, safety and community welfare' (from IgCC website). The code aims to provide a minimum green standard for buildings and additional voluntary rating systems that can be adopted in a customized manner by individual jurisdictions.

Section 303 of the code provides a provision for a whole building LCA that requires the execution of an analysis of a proposed project to demonstrate that the building has no less than a 20% improvement in environmental performance for global warming potential and at least two other listed environmental impacts (primary energy use, acidification potential, eutrophication potential, ozone depletion potential and smog potential). The code assumes the user will create an LCA of both the new building and a reference building and requires the inclusion of operations, maintenance, transportation and the impacts from resource extraction to demolition and disposal. Impacts from electrical and mechanical equipment need not be included. The LCA should conform with ISO 14044 and includes a clause that links the scope of elements included in the LCA to the LCA tool that is being used.

As of May 2012, five states and seven municipalities have adopted the IgCC. Rhode Island, Maryland, Oregon and Florida have adopted it in full. North Carolina has adopted the water portion only. Richland, WA, Keene, NH, Ft. Collins, CO, Boyton Beach, FL, Phoenix, AZ, Scottsdale, AZ are the adopting cities.

Analysis:

As performing this LCA is an alternative to following straightforward mandatory measures related to material manufacturing (e.g. recycled content, bio-based materials and indigenous/local materials as outlined in Section 505 of the code), the effort to complete the LCA will need to be relatively low in order to encourage users to adopt it.

The requirement calls for the use of a LCA tool as approved by the code official. Currently there are limited, readily accessible LCA tools in the US, such as the Athena Impact Estimator. (Tools to comply with whole building LCA code requirements have been developed for other markets such as France and Germany. Understanding the effort and effectiveness of these tools will be critical to evaluation of this code standard.)

As no pilot studies have been performed to test this regulation, it is not clear how difficult the 20% improvement will be to achieve. Requirements for defining the baseline building include meeting the minimum energy requirements of the IgCC and the structural requirements of the International Building Code.

New York City Initiative 0577-2011

Organization: NYC
Reference: http://www.urbangreencouncil.org/greencodes/introductions/int0577-2011.pdf
Date: 11.30.2011

Consensus: No
Implementation: Possibly
LCA Scope: A

Description

This is a prescriptive requirement that limits the cement content in concrete for all mixes less than 14,000 psi to no more than 400 pounds of Portland cement per cubic yard of concrete.

Analysis

The justifications for this legislation are the high carbon emissions related to cement manufacture and the aim of reducing the embodied carbon in concrete through the use of alternate, supplementary cementitious materials (SCMs). These SCMs usually meet two different sustainability objectives. The first is that the manufacture of ordinary Portland cement emits carbon dioxide both from energy use in the kilns and from the chemical reaction that produces cement from the raw materials (particularly limestone). Supplementing the concrete mix with many SCMs balances some of these emissions, although the Portland cement-based components of concrete do have the capacity to re-sequester some of these emissions during its primary and secondary lives. However, LCA information on the extent of this is not currently established. The second objective is that many SCMs are considered wastes or byproducts from other industries, so this represents pre-consumer recycling. Examples are fly ash from coal energy production or slag from the steel industry. The EPA requested that the concrete industry evaluate the use of fly ash as an SCM approximately 20 years ago.

This initiative is a prescriptive example of using LCA data in attempt to reduce a specific set of environmental impact factors within a local building code. This does not provide flexibility for the design and manufacturing team to optimize all concrete performance requirements in design and thus does not enable a comprehensive life cycle approach to the design of concrete mixes.

Oregon Wood First (proposed, not enacted)

Organization: State of Oregon Legislature
Date: 12.16.2011
Reference: gov.oregonlive.com/bill/2011/HB3429/

Consensus: No
Implementation: No
LCA Scope: A,B

Description

House Bill 3429, Oregon Wood First Act.

Built upon the same lines of thinking as the BC Wood First Act of 2009, this proposed bill was to be the first of its kind in the US to stipulate a specific material use in building construction. It was additionally similar in that it did not prescribe any mechanisms for how wood would be integrated into the construction industry.

Analysis

This bill is no longer under consideration as the current version was killed in the House in 2011 (per verbal conversations with bill sponsors). It is therefore not applicable to this work at this time.

Various EU Legislation requiring full building LCA

Organization: Varies
Date: Varies
Reference: Per LCA and Construction Conference, Nantes France, July 2012

Consensus: No
Implementation: Varies
LCA Scope: Varies

Description

During the LCA and construction conference held in July 2012, in Nantes, France, the research team became aware of multiple different local and national EU governmental requirements for full building LCA as part of the building approval project.

Although we have not been able to review these legislative requirements in detail in time for the final report publication, we have included our summary notes attained based on presentations and verbal discussions at the conference. (K. Simonen, personal notes).

Location	***Item***	***Type***	***Notes***
France	Name Unknown	Legislation	Regional mandate (Bourgogne) focused on reducing 'grey' energy (embodied energy) requires whole building LCA as part of permitting process. No benchmarks or reductions required- just reporting of the data.
Netherlands	Name Unknown	Potential legislation	Possible requirement to include whole building LCA as mandate for country specific building code. (no direct confirmation of this)

X3 Rating Systems and Metrics

X3.1 Introduction

Life Cycle Assessment is beginning to be used in green building rating systems and is used as a metric to evaluate materials, products and systems. In this section, we have identified national and international rating systems and provide a brief overview of many of them. Some are starting to incorporate LCA, while in others it is optional. Most have been developed as lists of prescriptive or performance criteria that should be attained to achieve goals which may have been developed from a partial LCA viewpoint.

Over the past few years, there has been an increasing movement to integrate LCA into rating systems worldwide. The individual bodies that administer the rating systems have taken on these efforts. For instance, the Green Building Initiative worked with the Athena Institute for Sustainable Materials to develop a free, deployable software out of their LCA tool: Impact Estimator. The new tool, the EcoCalculator, is now a part of the Green Globes assessment. Similar initiatives have been piloted in the USGBC LEED system.

John Carmody of the University of Minnesota's Center for Sustainable Building Research and Wayne Trusty of the Athena Institute assert in the UMN publication, Informedesign (vol. 5, issue 3), that

> *"The adoption of LCA tools into Green Globes, LEED, and other regional rating systems represents a major step forward in what will likely be an ongoing integration of LCA into the sustainable design process. Over time, this process should strengthen the link between rating system scores and actual environmental benefits. The ultimate goal is to model the environmental impacts of whole buildings, so that rating systems can abandon the checklist approach and rate buildings based on a comprehensive model of their environmental performance, similar to the way energy modeling is done today."*

X3.2 Summary of Studied Items

Pg.	Name	Description	Location	Consensus Based Process?	Implement to bldg std or code?	LCA Scope Addressed, A-D*
3	Architecture 2030	2030 Challenge for Products	U.S.	N	1	A1-3
5	BREEAM	Certification system in Europe	U.K.	N	2	A,B,C
7	Environmental Product Declarations (EPDs)	National and International Efforts ISO, ASTM, CEN Green Standard, UL Environment, Earthsure	Int.	?	1B	A,B,C
8	Envision	Infrastructural Rating System	U.S.	N	2	A
9	Green Globes	Assessment Rating System	CA/U.S.	Y	2	A
10	LEED V4	USGBC LEED V4 \Draft (three MR credits reference LCA)	U.S.	N	1A	A
12	ILBI	Living Building Challenge	U.S.	N	2	A
13	Pharos	Building Materials Evaluation Tool	U.S.	Y	1B	A,B,C,D
14	TSC	The Sustainability Consortium (Walmart et al)	U.S.	Y	1B	A,B,C,D
n/a	USGBC	LEED Pilot Credit 43	U.S.	N	2	A,B,C varies
15	Various EU Systems	Regional Rating Systems Overview	EU	?	1B	Varies

* A: Production/Manufacturing and Construction stages (cradle to gate)
B: Use stage
C: End of Life stage
D: Reuse, Recovery, and Recycling stage

X3.3 Evaluation

The items noted 1A or 1B are worthy of further review/study.

2030 Challenge for Products

Organization: Architecture 2030
Date: 02.14.2011
Reference: www.architecture2030.org/2030_challenge/products

Consensus: No
Implementation: Possibly
LCA Scope: A1-3 (although could be expanded)

Description

Architecture 2030 is an independent non-profit organization focused on addressing climate change through targeting building industry improvements. The 2030 Challenge for Products is literally a challenge to all in the building industry (designers, builders, manufacturers and owners) to adopt the following targets (as extracted from the Architecture 2030 website, Nov. 10, 2010):

> *Products for new buildings, developments, and renovations shall immediately be specified to meet a maximum carbon-equivalent footprint of 30% below the product category average. The embodied carbon-equivalent footprint reduction shall be increased to:*
>
> - *35% or better in 2015*
> - *40% or better in 2020*
> - *45% or better in 2025*
> - *50% or better in 2030*

Along with this challenge, Architecture 2030 has developed resources to explain their methodology and strategy which are being published online at the Building Green Information Hub: http://www2.buildinggreen.com/topic/2030-challenge (accessed Nov 10, 2011). The 2030 Challenge for Products complements the original 2030 Challenge that calls for a stepped reduction in the operational impacts of buildings from current levels to carbon neutral (using no fossil fuel, GHG-emitting energy to operate) in 2030.

Analysis

Since being issued by Architecture 2030 in 2006, the 2030 Challenge for Buildings has been adopted by 73% of the top 30 Architecture firms – and 41% of all firms total – in the United States. Additionally, the initiative has been adopted and is being implemented by numerous states, cities, universities, businesses, professional offices and organizations nationwide. This support from individuals, firms, organizations and local and state governments has culminated in bi-partisan federal legislation in both the U.S. House of Representatives and Senate.

The recently launched 2030 Challenge for Products has been adopted by "leading organizations within the green building products industry, LCA and EPD experts, and many architecture firms and product manufacturers" (personal communication with Francesca Desmarais November 14, 2011). The widespread adoption of the 2030 Challenge provides a strong base for promoting the 2030 Challenge for Products. As currently structured, the 2030 Challenge for Products is expected to help spur demand for EPDs. Many industry PCRs and product benchmarks must be developed before the objectives of being able to evaluate and specify 'low carbon' products will be possible. See the EPD section (p. X3-7) for more information on the current status of these efforts.

Building Research Establishment Environmental Assessment Method (BREEAM)

Organization: BREEAM
Date: 12.17.2011
Reference: http://www.breeam.org/

Consensus: No
Implementation: Possibly
LCA Scope: A,B,C,D

Description

BREEAM is a method of environmental certification in the UK, which was established prior to LEED. It started as a 26-page memo from BRE in 1990 and has grown to a 350-page technical guide. BREEAM and LEED are two major green building certification systems in the world today with many similar characteristics. Assessors (or a single assessor) that are certified through BREEAM's training systems audit building projects for compliance. Unlike a LEED Accredited Professional (AP), the assessor is the one that determines the level of compliance and reports it to the organizational body. A LEED AP's role is to gather the project documentation for submittal to USGBC where ratings are determined. Although BREEAM is not owned or operated by the government, a good portion of the national model building codes and BREEAM guidelines are aligned to help eliminate confusion. It bases compliance upon benchmarks established by UK model codes.

> *BREEAM assesses the performance of buildings in the following areas:*
>
> ***Management****: overall management policy, commissioning site management and procedural issues.*
>
> ***Energy use****: operational energy and carbon dioxide (CO2) issues.*
>
> ***Health and well-being****: indoor and external issues affecting health and well-being.*
>
> ***Pollution****: air and water pollution issues.*
>
> ***Transport****: transport-related CO2 and location-related factors.*
>
> ***Land use****: greenfield and brownfield sites.*
>
> ***Ecology****: ecological value conservation and enhancement of the site.*
>
> ***Materials****: environmental implication of building materials, including life-cycle impacts.*
>
> ***Water****: consumption and water efficiency.*

The areas listed above are the areas of the project where points can be gained. An assessor tallies the points to establish where the project will comply. The levels of rating range from Pass to Outstanding. BREEAM 2008 represented an update to their systems. Now there is a mandatory post-construction assessment that must be carried out before the building is rated. This has resulted in more strenuous assessment ratings.

Analysis

BREEAM was and is still built for the UK policy climate. Its checklists mirror several pieces of code in the building permitting process. The developers of BREEAM have aligned its directives with UK model codes to further promote its adoption through the removal of administrative barriers by attempting to alleviate redundant paperwork. Other green building councils (e.g. the Dutch Green Building Council) have translated and adopted BREEAM, and there are other versions of its system. For example, some buildings in the US are being dually certified through BREEAM and LEED.

As to BREEAM's applicability to lifecycle assessment, it gives credit for using products with low environmental impacts listed in their Green Guide. 1,500 listed items have been assessed through BRE's 2008 LCA Methodology. BREEAM-certified assessors have access to the "Green Guide Calculator" to *"quickly and efficiently generate Green Guide ratings for a significant proportion of specifications not listed in the Green Guide Online."* According to BRE's website, this online calculator is a digital version of the Green Guides database, allowing easier, quicker, remote access to assessors. The calculator contains all of the current material data with others to be added when available. As of now, it is not available to the public.

Environmental Product Declarations (EPDs)

Organization: Standards: ISO, CEN, ASTM
Date: Varies
Reference: ISO 14025, CEN 15804, ISO 21930

Consensus: Yes and Now
Implementation: Possibly
LCA Scope: Varies

Description

EN Standard 15804 characterizes EPDs as:

> "An EPD communicates verifiable, accurate, non-misleading environmental information for products and their applications, thereby supporting scientifically based, fair choices and stimulating the potential for market- driven continuous environmental improvement. EPD information is expressed in information modules, which allow easy organization and expression of data packages throughout the life cycle of the product. The approach requires that the underlying data should be consistent, reproducible and comparable. The EPD is expressed in a form that allows aggregation (addition) to provide complete information for buildings."

All EPDs are based upon Product Category Rules (PCRs). EPDs can be self declared or third party verified by an EPD operator. In Europe, each country typically sponsors an EPD Program. In the US, multiple EPD programs are developed/under development.

Analysis

EPDs provide frameworks for compiling and reporting LCA data in such a way that comparisons can be made between LCA results. Additionally, EPDs provide a format that encourages transparency of multiple environmental impacts. The LEED 2012/Version 4 proposed credit to reward products that report environmental impacts with an EPD, as well as the 2030 Challenge for Products have provided motivation for industry leaders to peruse development of PCRs and EPDs.

In order to develop a PCR, the industrial sector/product category group must have a comprehensive LCA to begin with. The PCR should be harmonized with other PCRs in similar sectors and regions. As multiple efforts are currently underway to develop building product PCRs, the creation of US specific standards that complement and clarify European and international standards (CEN 15804, ISO 21930) is of particular value.

Motivating the use of EPDs shows potential to help spur the generation of product specific LCA data as has been demonstrated through the French EPD program evaluated in the building code section (X2).

Envision

Organization: Institute for Sustainable Infrastructure
Date: 12.16.2011
Reference: http://sustainableinfrastructure.org/

Consensus: No
Implementation: Possibly
LCA Scope: A1-3 (although could be expanded)

Description

Envision is designed to be implemented within the world of civil infrastructural projects. Per their website:

> *Envision™ is an objective and comprehensive framework that describes the elements of a civil infrastructure project that should be considered from a sustainability perspective as well as the improving levels of performance that could be achieved through additional investment or negotiation. Additional investment can also produce higher levels of functionality or performance that can far exceed initial costs — they can also lead to expedite regulatory review and approval processes and higher levels of community and political support.*

Analysis

The Envision Rating system has just been released. It represents a comprehensive system dedicated to roads and other infrastructure. Pilot case studies are currently being performed and evaluated. The Institute for Sustainable Infrastructure (ISI) hopes to move forward with regional implementation in 2012. Since it focuses on infrastructure and not buildings, it will not be further detailed herein.

Green Globes

Organization: The Green Building Initiative (GBI) (US license holder, backed by ANSI)
Date: 02.20.2012
Reference: http://www.greenglobes.com/

Consensus: Yes
Implementation: Possibly
LCA Scope: A1-3

Description

Green Globes is a Canadian-born building rating/certification system. It is an outgrowth of BREEAM, which was brought to Canada in the 1990s for use as an energy assessment program for a subsidiary of the British energy company, ECD Consultants, Ltd. When ECD first began using it, they referred to it as BREEAM Green Leaf, and it was a system of self-assessment. Several groups (Canadian government, universities, research institutions) got involved to expand the system, changing its name in 2002 to Green Globes (GG) and putting it entirely online to speed its adoption across Canada.

Green Globes was seen as a less expensive alternative to LEED. The Canadian government recommended its use for buildings with budgets between one and ten million dollars while recommending LEED for those over ten million. Similar to LEED in terms of its structure, Green Globes gives credit to projects in seven areas: Energy, Indoor Environment, Site, Water, Resources, Emissions, and Project/Environmental Management.

Like BREEAM, the assessment is carried out by a third party consultant that interfaces with the design team throughout the project. Assessors can be individuals or companies who have received training and certification under Green Globes training courses.

Analysis

The Green Building Initiative holds the rights to promote and further develop GG in the US and is an American National Standards Institute (ANSI) accredited standards developing organization in the US. Green Globes continues to grow in the US with its 100th certification in 2010.

Among the few unique aspects of Green Globes compared to other rating systems is a credit section devoted to LCA. Currently, education credits are given if the designers use LCA while making decisions on building assemblies and materials. GBI is investigating how to bring LCA further into Green Globes through tools of environmental impact assessment. The tool used in Green Globes is the Athena EcoCalculator, which is further reviewed in Section X6.3.

LEED Version 4

Organization: U.S. Green Building Council
Date: 08.23.2012
Reference: http://www.usgbc.org/ShowFile.aspx?DocumentID=9541

Consensus: No (Yes with regard to internal standards development)
Implementation: Possibly
LCA Scope: A1-3 (although could be expanded)

Description

The U.S. Green Building Council is a non-profit NGO focused on advancing sustainable building design and construction and is the developer of the LEED building rating system. Regional USGBC chapters are often the focus of the sustainable building community of a region. LEED is the dominant green rating system in the US commercial construction market with over 10,000 buildings certified. Over the past few years, several 'pilot credits' have been proposed enabling users to test the integration of LCA into the LEED rating system. Recently, the LEED 2012 draft went through a round of public comment in January of 2012, from which it was determined that it would not be ready in 2012. Another round of public comment is scheduled for Winter 2012. It is now referred to as LEED V4 and might be ready in 2013 or 2014. Based on the previous draft, three areas for linking LCA are proposed: (1) Environmentally Preferable Structure and Enclosure, which provides points for systems that either use low environmental impact structures or enclosures or re-use an existing structure; (2) Non-Structural Materials Transparency, which provides points for use of products with EPD data; and (3) Avoidance of Chemicals of Concern in Building Materials, which prioritize materials and products that declare a list of ingredients used and which do not contain any substances identified as causing cancer or reproductive toxicity [25].

Analysis

Based on the 2nd round drafting of the new document, the use of LCA and LCA related products (EPDs, tools, etc.) could yield credits in three areas, two of which are pilot credits, while the other is a shift within Materials and Resources.

Pilot credit 01 is for creating a LCA of building assemblies and materials and is available in the New Construction and Healthcare categories. Using Athena's EcoCalculator, the designer will enter the impact results for various assemblies into USGBC's LEED Credit Calculator as documentation. During the pilot period, all buildings completing this step receive the credit under Innovation and Design; no benchmarks must be reached. The aspiration is this will eventually earn up to 7 credits based on performance.

Pilot Credit 43 Certified Products is available to all building type categories. It highlights the use of EPDs as a manner of bringing transparency to a project's material supply chain and to the material's composition with regards to its environmental, economic and societal profile. The requirement is to specify at least 10% of the total cost of non-structural material with EPDs (Type III labels) and/or Type I Eco Labels.

Changes to the Materials and Resources credit section are broader than the two pilot credit sections. Multiple previous sections have been deleted and/or re-organized into new credit areas. Four of the new or adapted credit sections contain LCA-related efforts including whole building LCAs, EPDs and other transparency measures. All of them have a specific focus on creating a building with more transparency materials and reducing overall environmental impact. The proposed MR Credit: Material Disclosure and Optimization provides points for using structural and/or nonstructural products that report their environmental footprint with an EPD. Product-specific EPDs are given preference over industry-wide/generic EPDs. The MR Credit: Material Ingredient Reporting rewards the use of products that report the chemical compounds on a Chemicals of High Concern list. Third party verification of the reporting is required. The MR Credit: Avoidance of Chemicals of Concern rewards to use of products that can certify that they do not included specific potentially hazardous substances.

The MR Credit: Building Life Cycle Impact Reduction section contains a provision for the designer to perform a whole building LCA. This whole building LCA is one of the four optional paths to securing up to three credits. The new building design must show at least a 10% improvement over a reference building in at least 3 of 6 impact categories (global warming potential, ozone depletion potential, acidification potential, eutrophication potential, smog potential and depletion of nonrenewable resources), one of which must be global warming potential. Additionally, no impact category can increase more than 5% over the reference. The reference building is defined loosely as a building "of comparable size, function, orientation and operating energy performance as defined in EA Prerequisite Minimum Energy Performance. The Service life of the reference buildings must be the same and at least 60 years to fully account for maintenance and replacement" (USGBC, LEED Rating System v4, 4th Public Comment Draft, 2012). The buildings must also be compared using the same LCA tool and datasets, must report all impact categories and use data compliant with ISO 14044.

Living Building Challenge

Organization: International Living Future Institute
Date: April 2010
Reference: https://ilbi.org/lbc/standard

Consensus: No
Implementation: Possibly
LCA Scope: A1-3 (for the LCA component only-other life cycle phases included in other aspects of the program)

Description

The Living Building Challenge is a forward-looking building certification standard developed by a non-profit NGO, the International Living Future Institute, and is closely allied with the Cascadia Green Building Council, which integrates USGBC and Canadian Green Building Council members in Oregon, Washington, British Columbia and Alaska. The stated purpose of the Living Building Challenge is to 'define the most advanced measure of sustainability in the built environment possible today and act to diminish the gap between current limits and ideal solutions' (International Living Future Institute. 2009. The Living Building Challenge 2.0. p.5). In order to be certified as a 'living building,' both prescriptive and performance criteria in several different areas, known as 'petals,' must be met.

Within the Materials 'petal', LCA is addressed in two components. First, the total embodied impacts of the building must be estimated and carbon offsets purchased from a list of approved sources. Additionally, there is a 'red list' of materials identified that should not be ingredients of any of the building products. Materials included must either be 'red list free' or the design team must document that significant effort has been made to identify alternate products. Manufacturers that demonstrate transparency and share the product ingredients are to be prioritized in final decision-making.

Analysis

Many of the petal imperatives within the LBC touch on aspects of LCA. As stated above, the Materials petal is the most directly applicable. The mechanism employed to account for the embodied carbon, however, is not a life cycle assessment report. Without specifying a certain tool, the use of online assessment tools such as Athena EcoCalculator or BEES 4.0 are accepted. The LBC asks for a one-time purchase of carbon offset credits to achieve carbon neutrality. Among the stated goals under the Materials petal is the goal to promote transparency within the materials products industry. The ILFI therefore promotes the Pharos Project (see below, p. X3-13) as a manner of vetting green products more fully. This is in keeping with social and economic aspects of LCA.

The Pharos Project

Organization: The Pharos Project from Healthy Building Networks
Date: 03.23.2012
Reference: http://www.pharosproject.net/

Consensus: Yes, if considering that it is open source software
Implementation: Possibly
LCA Scope: A,B,C,D

Description

As described by Paul Bogart, director of the Healthy Building Network at Greenbuild 09, "the Pharos Project is a building materials evaluation tool that looks across a range of impacts from environmental to human health (users) to impacts in the communities where these products are produced and disposed." The Pharos Project is an open-source, downloadable tool that is continuously updated and maintained as a non-profit organization. It is designed as an easy search engine to seek materials to best fit "needs and values." Possibly the most interesting aspect of this is that Pharos has a social agenda, meaning that it wants to be a forum where material selectors can discuss openly the merits of the materials and what values they are looking for in their selection, as well as serving as a place to communicate these principles to the manufacturers and producers. The transparency goal is admirable given the rapid spread of "green" nomenclature in everyday society.

Analysis

The use of the Pharos software is subscription-based and on an annual basis. The subscription fee goes to support their Chemical and Material Library. Because it is a part of the Health Building Network, it has the advantage of being partnered with other similar programs as a means of supporting the Pharos indicators. For instance, many architects use GreenSpec as a means of specifying project materials based on LCA approaches for energy use, water use, etc. Pharos lends its scoring system to effectively rank these projects based on the user's selected category. It also exceeds some LCA reporting with its focus on material toxicity and human health.

Because Pharos works as a search engine, the aim is that a designer can easily use it to find materials to fit a design need, including those for LEED credits and Living Building Challenge non-red listed items. Per their website, there is a continual open call to manufacturers to have their projects evaluated and listed in the database. Because this is a free evaluation service with an available evaluation framework, and given the newness of the program, the volume of materials in the database should continue to grow.

The Sustainability Consortium

Organization: The Sustainability Consortium
Date: 03.23.2012
Reference: http://www.sustainabilityconsortium.org

Consensus: Yes for members
Implementation: Possibly
LCA Scope: A, B, C, D

Description

The Sustainability Consortium (TSC) began in August of 2009 and is led by Walmart and other national retailers. According to TSC's website, these founding members were feeling pressure to "reduce the environmental and social impacts associated with global consumption." These retailers joined forces with their suppliers, university researchers, NGOs and manufacturers to "more accurately quantify and communicate the sustainability of products." Their stated challenge was to strive for a better understanding of sustainability, standardization and more informed decision-making. Since launching with fifteen founding partners, membership has grown to seventy-five as of the middle of 2011. "Consume and produce smartly" is a tagline of TSC.

Part of the deliverables for TSC was to be a "Sustainable Products Index," which was given a timetable for development of five years. Although that duration has not passed, TSC has now shifted its approach. Through the progress of the research, it has been found that the complexity of gathering and understanding all the associated data is extreme. The focus has now shifted to creating "Eco-Rules" for different consumer product categories. These categories are essentially umbrellas containing numerous individual products. These "eco-rules" will help establish a common way to calculate the environmental footprint of products.

Analysis

The realization by TSC of the complexity and enormity of standards creation is not uncommon among LCA researchers. The complexity is difficult to overcome, especially when a single indicator number is what is required as the product. This, however, should not dissuade TSC from continuing along this path of discovery. Their "eco-rules" are essentially the same as the Product Category Rules (PCRs) that are being developed for products in the construction industry such as concrete or steel. A large benefit from TSC's work is in the nature of communication. It is a powerful step to see many of the United States' largest and best-known retailers pushing the envelope of sustainable product creation and delivery. This is an encouragement to other retailers, suppliers, and manufacturers to also value their commitments to the environment and their customers' well-being.

Various EU Rating Systems with LCA

Organization: Varies
Date: Varies
Reference: Per LCA and Construction Conference, Nantes France, July 2012

Consensus: No
Implementation: Varies
LCA Scope: Varies

Description

During the LCA and construction conference held in July 2012, in Nantes, France, the research team became aware of multiple different local and national EU rating systems that integrate LCA as part of the building assessment.

Although we have not been able to review these programs in detail in time for the final report publication, we have included our summary notes attained based on presentations and verbal discussions at the conference (K. Simonen, personal notes). *See Section A of the Final Report for more detailed information.*

Location	***Item***	***Type***	***Notes***
Germany	BNB	Rating System	All government buildings must comply. Similar to LEED.
Germany	DGNB	Rating System	Voluntary system to assess buildings. Alternate method.
Switzerland	Minergie-eco	Rating System	Rating system that is evolving to include whole building LCA.

X4 Standards

X4.1 Introduction

LCA is beginning to be addressed in the development of various national and international standards. In this section, we have identified national and international standards that are currently available or are being developed which address various aspects of LCA. Some of the standards are more applicable to this research project than others. Section X4.2 lists the items which were reviewed, with a summary of their status and relative importance to this effort. An importance rating of 1 indicates additional information is given in Section X4.3. An importance rating of 3 indicates that the item will not be considered further at this time.

Some of the items are currently being developed, and as such, the draft scope and synopsis have been provided when available.

Note, that with respect to the ASTM standards listed, there is a difference between a Standard Practice (SP) and a Standard Guide (SG). According to the **ASTM Form and Style for ASTM Standards Manual** [2011] the difference is as follows:

> ‘A *standard practice* is an accepted procedure for the performance of one or more operations or functions. In certain cases, practices may include one or more test methods necessary for full use of the practice. Examples of practices include selection, preparation, application, inspection, necessary precautions for use or disposal, installation, maintenance, and operation of testing apparatus.’

> ‘A *standard guide* is a compendium of information or series of options that does not recommend a specific course of action. Guides are intended to increase the awareness of information and approaches in a given subject area. Guides may propose a series of options or instructions that offer direction without recommending a definite course of action. The purpose of this type of standard is to offer guidance based on a consensus of viewpoints but not to establish a standard practice to follow in all cases.’

X4.2 Summary of Evaluated Items

Pg.	Name	Description*	Location	Status	Consensus Based Process?	Importance for bldg std or code?**	LCA Stage Addressed, A-D***
na	ASTM A1068-10	SP for Life-Cycle Cost Analysis of Corrosion Protection Systems on Iron and Steel	U.S.	Current	Y	3	na
7	ASTM D7075-04	SP for Evaluating and Reporting Environmental Performance of Biobased Products	U.S.	Current	Y	1B	A,B,C
na	ASTM E1971-05	SG for Stewardship for the Cleaning of Commercial and Institutional Buildings	U.S.	Current	Y	3	B
na	ASTM E1991-05	SG for Environmental Life Cycle Assessment (LCA) of Building Materials/Products	U.S.	Not to be updated	Y	3	na
8	ASTM E2114-08	Standard Terminology for Sustainability Relative to the Performance of Buildings	U.S.	Current	Y	3	A,B,C
9	ASTM E2129-10	SP for Data Collection for Sustainability Assessment of Building Products	U.S.	Current	Y	2	A,B,C
na	ASTM E2365-05	SG for Environmental Compliance Performance Assessment	U.S.	Current	Y	3	na
na	ASTM E2725-10	SG for Basic Assessment and Management of Greenhouse Gases	U.S.	Current	Y	3	na
10	ASTM WK23356	Proposed New *Practice* for PCRs for Use in Development of Environmental Declarations for Building Products and Systems	U.S.	Being Developed	Y	1B	A,B,C varies

na	ASTM WK26696	Proposed New Practice for Roof System Life Cycle Assessment	U.S.	Being Developed	Y	2	?
11	ASTM WK28938	Proposed New *Guide* or *Practice* for Whole Building LCA *(title under development)*	U.S.	Being Developed	Y	1B	A,B,C
12	ASTM WK31993	Proposed New Practice for Communication of Sustainable Attributes of Products	U.S.	Being Developed	Y	1B	A
13	EN 15643-1: 2010	Scw-Ab - Part 1: General framework	Europe	Current	Y	1B	A,B,C,D
14	EN 15643-2: 2011	Scw-Ab - Part 2: Framework for the assessment of environmental performance	Europe	Current	Y	1B	A,B,C,D
15	EN 15643-3: 2012	Scw-Ab - Part 3: Framework for the assessment of social performance	Europe	Current	Y	2	A,B,C,D
16	EN 15643-4: 2012	Scw-Ab - Part 4: Framework for the assessment of economic performance	Europe	Current	Y	2	A,B,C,D
17	EN 15804: 2011	Scw-Epd - Core rules for the product category of construction products (Product Category Rules)	Europe	Current	Y	1B	A,B,C,D
18	EN 15942: 2011	Scw-Epd - Communication Format - Business To Business	Europe	Current	Y	1B	A,B,C,D
19	EN 15978: 2011	Scw- Assessment of environmental performance of buildings - Calculation method	Europe	Current	Y	1B	A,B,C,D
na	EN 16309	Scw - Assessment of social performance of buildings - Methods	Europe	Current	Y	2	?
20	ISO 14020: 2000	Eld – General principles	Int’l	Current	Y	1B	A,B,C,D

na	ISO 14021: 1999	Eld – Self-declared environmental claims (Type II environmental labelling)	Int'l	Current	Y	1B	?
21	ISO 14025: 2006	Eld – Type III environmental labeling- Principles and procedures	Int'l	Current	Y	1B	A,B,C,D
22	ISO 14040: 2006	Em – Life cycle assessment -- Principles and framework	Int'l	Current	Y	1B	A,B,C
23	ISO 14044: 2006	Em -Life cycle assessment -- Requirements and Guidelines	Int'l	Current	Y	1B	A,B,C
na	ISO 15392: 2008	Sbc -- General principles	Int'l	Current	Y	1B	?
24	ISO 15686-6: 2004	Buildings and constructed assets -- Service life planning -- Part 6: Procedures for considering environmental impacts	Int'l	Current	Y	1B	B
25	ISO 21930: 2007	Sbc -- Environmental declaration of building products	Int'l	Current	Y	1B	?
26	ISO/DIS 13315-1	Em for concrete and concrete structures--Part 1: General principles	Int'l	Being developed	Y	2	A,B,C
27	ISO/DIS 14067	Carbon footprint of products-Requirements and guidelines for quantification and communication	Int'l	DES	Y	1B	A,B, C
na	ISO/DTR 14047	Em – LCA - Examples of application of ISO 14044 to impact assessment situations	Int'l	Current	Y	3	na
na	ISO/DTR 14049	Em – LCA – Ex. of application of ISO 14044 to goal and scope definition & inventory	Int'l	Current	Y	3	na
na	ISO/TR 14047	Em – LCA - Examples of application of ISO 14042	Int'l	Current	Y	3	na
na	ISO/TR	Em – LCA - Data	Int'l	Current	Y	3	na

	14048	documentation format					
na	ISO/TS 15686-9:2008	Buildings and constructed assets -- Service-life planning -- Part 9: Guidance on assessment of service-life data	Int'l	Current	Y	3	na
28	PD CEN/TR 15941:2010	Sustainability of Construction Works – Environmental Product Declarations - Methodology for selection & use	Europe	Current	Y	1B	A,B,C,D
29	PAS 2050	SG for assessing life cycle emissions for goods and services	UK	Current	Y/ Partial	1	A,B
30	SCS-002	(draft) Life Cycle Impact Assessment Framework and Guidance for Establishing Public Declarations and Claims	US	In Development	Y	2	A
na	PD CEN/TRUL-880E	Standard for sustainability, manufacturing	US	Current	Y	3	?
31	WRI/WBCSD	Product Carbon Footprint Standard	Int'l	Current	P	1B	V

*Nomenclature:

SG	Standard Guide
SP	Standard Practice
PCR	Product Category Rules
Scw	Sustainability of construction works
Ab	Assessment of buildings
Epd	Environmental product declarations
Eld	Environmental labels and declarations
Em	Environmental management
LCA	Life cycle assessment
Sbc	Sustainability in building construction
PAS	British Standards Institution's (BSI) Publicly Available Specification

** 1 being highest importance, 3 being lowest

*** A: Production/Manufacturing and Construction stages (cradle to gate)
B: Use stage
C: End of Life stage
D: Reuse, Recovery, and Recycling stage

X4.3 Evaluation

ISO standards remain the internationally recognized bases for standards of LCA. CEN15804 is now a European 'consensus standard' meaning that it will be adopted by all European states and thus is becoming a dominant standard for production of EPDs for building products. This document is well written and flexible enough to be customized for US use.

Of the standards noted in Section X4.2, items noted "na"(not applicable) in the page field were determined by the research team to not be relevant to this research project. Thus, although assessed during our research phase, they are not evaluated within this report. The remaining items are further evaluated on the following pages collated by the standardization organization in this format:

ASTM Standard	ASTM Work Group Draft
EN Standard	
ISO Standard	ISO/DIS – Work Group Draft
PAS	
SCS	

ASTM D7075-2004: Standard Practice for Evaluating and Reporting Environmental Performance of Biobased Products

Reference: http://www.astm.org
Date: 11.25.2011

Consensus: Yes
Implementation: Possibly
LCA Scope: A, B, C

Description

This standard provides recommended guidance and procedures for using a LCA approach to demonstrate the environmental impact of bio-based and fossil resource-based products. It references ISO 14040 Environmental Management—Life Cycle Assessment—Principles and Framework for its basis. The steps of the LCA process are described and include defining the goal, scope, functional unit, reference flow, unit processes, and product system boundaries. The life cycle inventory is discussed with respect to the simplification of input and output flows to include only those pertinent to the study. The life cycle assessment is addressed and based on the U.S. EPA TRACI methodology. These results are evaluated for completeness, consistency, and identification of most environmental impact issues. The reporting of the LCA completed for the bio-based or fossil resource-based product in question is outlined to provide guidance for producing a fully defined and transparent explanation of the assessment.

Analysis

The use of this document is most applicable to technical professionals who do not perform LCA but desire a reference. The document is also most applicable to the assessment of bio-based products. The deliverable of this standard's guidance may be applicable to the industry or governmental institutions for environmental impact evaluation during decision making processes involving bio-based or fossil resource-based products.

ASTM E2114-08: Standard Terminology for Sustainability Relative to the Performance of Buildings

Reference: http://www.astm.org
Date: 11.25.2011

Consensus: Yes
Implementation: Possibly
LCA Scope: A, B, C

Description

This standard defines terms relating to sustainable development with respect to building performance and is commonly referenced by other standards within the sustainable building performance scope.

Analysis

The terminology identified and defined by this standard extends to the entire building life cycle with potential to extend beyond to supplementary building information beyond the life cycle.

ASTM E2129-10: Standard Practice for Data Collection for Sustainability Assessment of Building Products

Reference: http://www.astm.org
Date: 11.25.2011

Consensus: Yes
Implementation: Possibly
LCA Scope: A, B, C

Description

This standard addresses the collection of data for sustainability evaluation relating to building products only and does not provide guidance for the interpretation of the data. The Construction Specifications Institute 1995 Master Format is used for the organization of this standard to convey a list of both general questions and questions relating to building-specific products which have the potential to aid in the collection of data appropriate for sustainability considerations. The standard explicitly notes that the information provided is for guidance and should be considered in correlation with professional judgment and other guidance. The divisions addressed include general requirements, site construction, concrete, masonry, metals, wood and plastics, thermal and moisture protection, windows and doors, finishes, specialties, equipment, furnishings, conveying systems, mechanical, and electrical.

Analysis

The guidance, explicitly stated as questions divided amongst the divisions of the Construction Specifications Institute, extends to the entire building life cycle with potential to extend beyond to supplementary building information.

ASTM WK23356: New Practice for Development of Product Category Rules for Use in Development of Environmental Declarations for Building Products and Systems

Reference: http://www.astm.org/search/site-search.html?query=WK23356&cartname =mystore And attendance by Liv Haselbach at ASTM E60 meetings, October 2011 and April 2012.

Consensus: Yes
Implementation: Possibly
LCA Scope: A (information) or A-C (comparable type)

Description

A draft introduction and scope of this proposed new practice is as follows:

> 'Every building product and system has environmental impacts. These impacts occur during all life-cycle stages of the product in multiple ways and on local, regional, and global scales. By understanding the nature of and quantifying these impacts, effective measures can be taken to modify impacts positively. ---- This practice is for the development of consistent product category rules (PCRs) that can be used by Type III environmental declarations program operators to develop business-to-business (cradle-to-gate) and business-to-consumer Type III environmental product declarations (EPD) for building products and systems. Product category rules provide a set of specific rules, requirements, and guidelines for developing EPD and specify the underlying requirements of the lifecycle assessment (LCA). ---- Only environmental aspects of sustainability are addressed in this practice. The social and economic aspects of sustainability are not addressed in this practice. Environmental aspects determined in accordance with this practice are intended to be combined with economic and societal aspects. ---- *This standard does not purport to address all of the safety concerns, if any, or other product related concerns covered by product legislation associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*'

Analysis

The environmental impacts currently being addressed in the proposed draft *only* include the following: climate change (greenhouse gases), formation of tropospheric ozone, acidification, eutrophication, and stratospheric ozone depletion. Resource uses include energy, consumptive water, and waste. However, toxic, hazardous and some other types of materials/chemicals must also be listed in the LCA modeling. A sensitivity analysis shall be performed on primary data. Two types of EPDs are addressed: an Information Module EPD (cradle to gate of a building product) and a Comparable Type III EPD (cradle to grave of a building product or system life cycle, which must have third party certification). Note that this standard duplicates the intent of CEN15804 and care should be taken to avoid unnecessarily conflicting with this emerging standard.

ASTM WK28938: New Guide or Practice for Whole Building LCA (title under development)

Reference: http://www.astm.org/DATABASE.CART/WORKITEMS/WK28938.htm
And attendance by Liv Haselbach at ASTM E60 meetings, October 2011 and April 2012.

Consensus: Yes
Implementation: May be a guide or may be a practice.
LCA Scope: A-C

Description

Based on the current revision being balloted in August 2012, a draft scope of this proposed standard is as follows:

'**1.1** The purpose of this Standard Practice is to support the use of whole building Life Cycle Assessment (LCA) in codes and rating systems by ensuring that comparative assessments of final whole building designs relative to reference building designs take account of relevant building features, life cycle stages, and related activities for both the reference and final building designs.

1.2 This Standard Practice provides criteria that shall be taken into account and applied irrespective of the assessment tool that is used when LCA is undertaken at the whole building level to compare a final design to a reference building design.

1.3 The criteria do not deal with building occupant behavior, possible future changes in building function, building rehabilitation or retrofit, or other matters that cannot be foreseen or reasonably estimated at the design and/or permitting stage where this Standard Practice applies.

1.4 Only environmental aspects of sustainability are addressed in this practice. The social and economic aspects of sustainability are not addressed in this practice.

1.5 This standard does not deal with basic LCA methodology, calculation methods or related matters that are covered in cited international standards.

1.6 This standard does not supersede or modify existing ISO standards for the application of LCA at the product level, nor does it deal with address the aggregation of building product Environmental Product Declarations (EPDs) at the whole building level.

1.7 This standard does not specify the impact categories or sustainability aspects to be addressed in building codes or rating systems and users of this standard shall conform to impact category requirements specified in the applicable code or rating system.

1.8 The text of this standard contains notes that provide explanatory material. These notes shall not be considered as requirements of the standard.'

ASTM WK31993: New Practice for Communication of Sustainable Attributes of Products

Reference: http://www.astm.org/search/site-search.html?query=WK31993&cartname =mystore

Consensus: Yes
Implementation: Uncertain.
LCA Scope: A

Description

Currently, based on the webpage, the draft scope of this proposed new guide is as follows:

'**1.1** This standard sets forth requirements for communicating product data related to the sustainability of a product. It identifies the attributes that must be reported. It specifies the unit reporting requirements associated with each attribute.

1.1.1 Attributes to be reported are environmental aspects and environmental impacts associated with the acquisition and manufacture of a product. This standard does not address the environmental aspects and impacts associated with a products use or end of life.

1.1.2 This Standard does not set forth requirements for communication of social aspects and impacts other than sustainability certifications.

1.1.3 This Standard does not set forth requirements for communication of economic aspects and impacts other than sustainability certifications.

1.2 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.'

EN 15643-1: 2010 - Sustainability of Construction Works- Sustainability Assessment of Buildings

Part 1: General framework

Reference: http://shop.bsigroup.com/ProductDetail/?pid=000000000030192734
Date: 06.05.2012

Consensus: Yes
Implementation: Yes
LCA Scope: A,B,C,D

Description

The series of standards beginning with EN 15643 were developed in 2009 and 2010 by a technical committee of the European Committee for Standardization with the purpose of enabling the comparability of the results from assessments to environmental, social and economic impacts of buildings. Methods of characterization assessment are themselves also outlined within, while methods of how to perform the assessments are not. This first section of the series provides an umbrella framework with principles, requirements and guidelines to which the next three sections go into more detail about their "legs" of sustainability: the environmental, the societal, and the economic.

Analysis

EN 15643-1 combines at a high level all of the guiding principles for the assessment of buildings that are outlined further in later sections. It is clearly stated that benchmarks to be achieved in sustainable design and performance schemes are to be dictated by the client and/or other regulations and not by this standard. However, in compliance to those mandates, this standard gives guidance for organizing, characterizing the impacts of decisions and communicating the results of LCAs.

Similarly to ISO standards, 15643-1 begins with establishing a functional unit and setting system boundaries to which the assessment will adhere. Unlike the ISO standards, it goes on to emphasize using scenario planning to indicate different directions and different potential ranges of impacts. It speaks to the need for transparency in reporting and in communication. Another mixed point relating to the comparison to ISO 14040 specifically speaks to the impacts on the site (land) and to mechanisms to account for "operational" uses in the building.

EN 15643-2: 2011- Sustainability of Construction Works- Sustainability Assessment of Buildings

Part 2: Framework for the assessment of environmental performance

Reference: http://www.techstreet.com/standards/bs_en/15643_2_2011?product_id =1780421
Date: 03.29.2012

Consensus: Yes
Implementation: Yes
LCA Scope: A,B,C,D

Description

EN 15643 is part 2 of a general framework created to establish a consistent and repeatable way to evaluate buildings for environmental performance. The core concept behind the four part series of which this is part is to create an updated framework for the environmental, social and economic impact of buildings. Like the ISO standards, it is concerned with the use of indicators that are functionally equivalent and can be compared directly. The intent is that this manner of assessment is deeply embedded within the design intention of the building. It states that the technical and functional requirements are to be included in the owner's brief to the designers from the outset of the project. These requirements could also be in the form of regulations such as jurisdictional code or project electives.

Analysis

EN 15643-2 does not set measurement or benchmarking standards; it only constructs a framework in which to view and disseminate the data once collected. In section 5.4.2, it recognizes EN 15978 is the standard to follow for data gathering and analysis. EN 15978 is reviewed below.

This standard, EN 15643-2, is useful in that it helps to create an even playing field from which all building performances can be judged. It sets up a baseline matrix that can be followed by all stakeholders from municipal entities to private developers concerning the judgment and communication of what is "green" about any building's performance.

EN 15643-3: 2012- Sustainability of Construction Works - Sustainability Assessment of Buildings

Part 3: Framework for the assessment of social performance

Reference: http://shop.bsigroup.com/ProductDetail/?pid=000000000030259777
Date: 06.05.2012

Consensus: Yes
Implementation: Yes
LCA Scope: A,B,C,D

Description

In this section of the EN 15643 series, the assessment of the social performance of buildings is considered. Taken into account are technical characteristics and functionalities of buildings. How "social performance" is defined is an important factor in understanding the scope of this standard. The keywords given in defining "social performance" are: accessibility, adaptability, health and comfort, loadings on the neighborhood, maintenance, safety / security, sourcing of materials and services and stakeholder involvement. These are considered to be the "quantifiable indicators" of social involvement with buildings. It does not expound on other associated or qualitative factors that could also be involved.

Analysis

EN 15643-3 sets up an assessment for social performance in much the same way as for environmental performance. It specifically mentions that two types of data are needed: building-related data and user and control systems-related data. Both of these adhere to another standard for guidance, "Sustainability of Construction Works – Methods." Transparency and scenario planning are again keys to providing the owner and design team with information to support good decision-making. The performance categories listed above are further defined in the standard. These definitions should give a user freedom to find information relative to the investigation without being mired down with the limited specifics of a narrow scope.

As with environmental LCAs, social quantification is limited to the social aspects that are quantifiable. Social qualities of buildings such as beauty, cultural and historic relevance, etc. are not captured by these metrics. Care should be taken in interpreting these limited impacts as capturing all social impacts.

EN 15643-4: 2012- Sustainability of Construction Works - Sustainability Assessment of Buildings

Part 4: Framework for the assessment of economic performance

Reference: http://shop.bsigroup.com/ProductDetail/?pid=000000000030186110
Date: 06.05.2012

Consensus: Yes
Implementation: Yes
LCA Scope: A,B,C,D

Description

In this section of the EN 15643 series, the assessment of the economic performance of buildings is considered. This is a departure under most conventional views of LCA. Lifecycle costing is generally considered to be a separate pursuit and is usually not included in an LCA. This standard considers two types of values within a building: the cost and financial value. These indicators are represented in two approaches to the economic assessment: the economic performance expressed in terms of costs over time and the economic performance in terms of financial value over time. In terms of proprietary non-disclosure, there does not seem to be any direct provisions. However, like other portions of this series, it is not a legally binding dictation of procedures, only a guide for uniformity of reporting. Disclosures are left to the client's brief and other regulations.

Analysis

EN 15643-4 is precise in its definition of what costing values are needed in order to evaluate economic performance. Section 5.4.2 lists and describes where and when those values are to be tracked and listed. In the spirit of transparency, verification is required to ascertain the validity of the analysis. In the annex, there is a list of additional documentation that should accompany this assessment.

This section of the standard seems to be very complimentary to its other parts in that it boldly provides a substantial base for economic sustainability. Whereas lifecycle costing is not normally included in LCA work, it plays a vital role in how buildings are brought into existence and the course of action for reusing, recycling or demolishing them. This standard could be used as a tool to enable better decision-making.

EN 15804: Sustainability of Construction Works - Environmental product declarations - Core rules for the product category of construction products

Reference: http://www.techstreet.com/cgi-bin/detail?doc_no=bs_en|15804_2012;product_id=1826556
Date: 03.24.2012

Consensus: Yes
Implementation: Yes
LCA Scope: Specifically covers A1-3 but has options within to cover groups B,C, and D

Description

This standard is a framework for writing Product Category Rules (PCRs) establishing Environmental Product Declarations (EPDs) for construction products. It "provides a structure to ensure that all EPDs of construction products, construction services and construction processes are derived, verified and presented in a harmonized way." It defines EPDs as "verifiable, accurate, non-misleading environmental information for products and their applications (that) support scientifically-based, fair choices and (therefore) stimulate the potential for market-driven continuous environmental improvement." In this, it provides a framework for the consistent creation and evaluation of EPDs. It is part of a suite of standards dedicated to construction works along with EN 15643 1 and 2, which are also dedicated to LCA principles. *Quotations taken from the standard, EN 15804.*

Analysis

This document is clearly written and provides both sufficient detail to enable consistent building industry-specific EPDs and flexibility as required to adopt to specific regional environmental and policy conditions. This is now adopted as a European consensus standard, and thus must be implemented by all EU states. Given the need for international harmonization of EPDs, this document is likely to become a core standard for building industry EPDs. Some customization is needed to ensure consistent interpretation within a region or country or by a specific EPD operator.

EN 15942: 2011- Sustainability of Construction Works - Environmental Product Declarations - Communication format business to business

Reference: http://shop.bsigroup.com/en/ProductDetail/?pid=000000000030200469
Date: 04.01.2012

Consensus: Yes
Implementation: Yes
LCA Scope: A,B,C,D

Description

EN 15942 is expressly meant to help facilitate the communication of EDPs and lays out a format to present EPD results in a standard format to display the information. It specifies what information is required to be included as to not advantage one product over another. It does allow, per EN 15804, some voluntary additional information to be disclosed in a given format.

Analysis

Standardizing the data and presentation method of EPDs will be valuable to help users navigate and compare these documents that contain significant technical information and that can be quite complex.

EN 15978: 2011- Sustainability of Construction Works -Assessment of environmental performance of buildings - Calculation Method

Reference: http://www.techstreet.com/cgi-bin/detail?doc_no=bs_en|15804_2012; product_id=1826556
Date: 03.29.2012

Consensus: Yes
Implementation: Yes
LCA Scope: A,B,C,D

Description

Continuing the standard series on construction works, EN 15978 addresses the methods of calculation to ensure standardization of account practice with regard to environmental, economic and social impact indicators. It communicates through flow charts the procedural evolution of steps to take, indicating clauses that are dedicated to explain each step along the way. This standard is very specific in its method, explaining any allowable variation and dictating how to address all areas of the study (i.e. the goal and scope of the study, the building's probable service life, the duration and quality of the study, etc.), as well as the calculation methods to be followed.

EN 15978 also associates environmental impacts with scenarios. Scenarios would be planned potential deviations from one pattern that could be exhibited by a building over time. The alternate scenario planning can take into account multiple factors such as material durability and replacement patterns, reuse patterns of replaced components, energy use by occupant, and a host of others at each stage of the building's life cycle. These scenarios are important to help understand that even the best initial assessments cannot predict the future and uncertainties should be "built in." Therefore the range of possibilities should be accounted for.

Analysis

Although this standard is narrow in its prescription of what is needed to provide a well calculated environmental assessment of a building's design, at every point it allows for variations from the norm. However, these variations are to be contextualized and documented. This enables any building to be subjected to the standard's structure and thus made comparable. The goal of this, and the other standards in this series, is to create a transparent account of the impacts associated with a building's total life cycle.

ISO 14020: 2000 - Environmental labels and declarations - General Principles

Reference: http://www.iso.org/iso/iso_catalogue.htm
Date: 04.01.2012

Consensus: Yes
Implementation: Yes
LCA Scope: A,B,C,D (generally discussed)

Description

Environmental labels and declarations provide purchasers or specifiers information about a product's environmental characteristics. They are provided to give the purchaser the best indicators of environmental impacts as known. This concept gives hope that markets, and therefore manufacturers, will respond to the demand of products that have lesser impacts and spur on this type of innovation. ISO 14020 is a framework that is meant to encourage the creation of better products. The means of doing so is through nine principles and is the foundation document for other ISO standards. Life cycle scope is only specifically discussed in Principle 5.

> ***Principle 1****: Environmental labels and declarations shall be accurate, verifiable, relevant and not misleading.*
>
> ***Principle 2:*** *Procedures and requirements for environmental labels and declarations shall not be prepared, adopted, or applied with a view to, or with the effect of, creating unnecessary obstacles to international trade.*
>
> ***Principle 3:*** *Environmental labels and declarations shall be based on scientific methodology that is sufficiently thorough and comprehensive to support the claim and that produces results that are accurate and reproducible.*
>
> ***Principle 4:*** *Information concerning the procedure, methodology, and any criteria used to support environmental labels and declarations shall be available and provided upon request to all interested parties.*
>
> ***Principle 5:*** *The development of environmental labels and declarations shall take into consideration all relevant aspects of the life cycle of the product.*
>
> ***Principle 6:*** *Environmental labels and declarations shall not inhibit innovation which maintains or has the potential to improve environmental performance.*
>
> ***Principle 7:*** *Any administrative requirements or information demands related to environmental labels and declarations shall be limited to those necessary to establish conformance with applicable criteria and standards of the labels and declarations.*
>
> ***Principle 8:*** *The process of developing environmental labels and declarations should include an open, participatory consultation with interested parties. Reasonable efforts should be made to achieve a consensus throughout the process.*
>
> ***Principle 9:*** *Information on the environmental aspects of products and services relevant to an environmental label or declaration shall be available to purchasers and potential purchasers from the party making the environmental label or declaration.*

ISO 14025: Environmental labels and declarations - Type III environmental labeling – Principles and Procedures

Reference: http://www.iso.org/iso/iso_catalogue.htm
Date: 03.31.2012

Consensus: Yes
Implementation: Yes
LCA Scope: A,B,C,D

Description

Like EN 15942, this standard sets formatting for the communication of Environmental Product Declarations (EPDs). It recognizes that different audiences need different amounts of information based on awareness levels and begins to set up standards to address this. Type III EPDs are specifically targeted at business-to-business communications. The need for harmonization of the rules used by EPD program operators (program instructions) and product category rules (PCRs) is emphasized. This standard provides organizational and technical requirements for development of PCRs and EPDs

In addition, this standard is a continuation of ISO 14020. It has the same objectives including market encouragement of more sustainable and less impactful products.

Analysis

This standard outlines the procedures for EPDs. It follows ISO 14040 in that the EPDs must evaluate and report the product's entire life cycle. It establishes the relationships of third party program operators and other interested parties through a regulation of transparency, repeatability, consistency, and other similar metrics.

This standard is internationally recognized as the primary standard for developing EPDs and PCRs.

ISO 14040:2006(E) Environmental management – Life cycle assessment – Principles and framework

Reference: http://www.iso.org/iso/iso_catalogue.htm
Date: 11.25.2011

Consensus: Yes
Implementation: Yes
LCA Scope: ALL

Description

Standard 14040 provides a methodological framework for defining the general requirements of performing an LCA study. Frameworks for each of the four phases of an LCA – goal and scope definition, inventory analysis, impact assessment and interpretation – are discussed. Emphasis and guidance within these phases are placed on enhancing credibility and transparency by defining all units, flows, references, and boundaries, and by providing clarity and consistency within reporting and review processes.

Analysis

Standard 14040 (together with ISO 14044) is commonly referred to by other LCA related standards, practices, and guidance as a basis for methodological principles and procedures and is an internationally recognized primary LCA standard.

ISO 14044:2006 Environmental management - Life cycle assessment - Requirements and guidelines

Reference: http://www.iso.org/iso/iso_catalogue.htm
Date: 07.11.2006

Consensus: Yes
Implementation: Yes
LCA Scope: ALL

Description

Standard 14044 complements ISO 14040 to provide more detailed requirements and guidelines for preparation of an LCA. Of note is the inclusion of more detail on data quality, allocation assumptions and impact categorization methods.

Analysis

Standard 14044 (together with ISO 14040) is commonly referred to by other LCA related standards, practices, and guidance as a basis for defining LCA practice and is an internationally recognized primary LCA standard.

ISO 15686-6:2004(E) Buildings and constructed assets – Service life planning – Part 6: Procedures for considering environmental impacts

Reference: http://www.iso.org/iso/iso_catalogue.htm
Date: 11.25.2011

Consensus: Yes
Implementation: Yes
LCA Scope: B

Description

Standard 15686-6 describes the procedure for considering environmental impacts pertaining to constructed assets during the lengthier site to cradle phase dictated by performance and use. The standard identifies that these impacts are best addressed during the initial product planning stage for an integrated design approach and that service life should be strongly considered in the LCA for more accurate results. LCA data should be appropriate, and if an underlying basis for information cannot be obtained, existing data sets that follow an LCA routine conforming to ISO 14040 and ISO/TR 14025 should be used. Decisions should be made that meet the requirements for technical, economic, and environmental performance or show preference to the areas of concern. Clear documentation, definition, and consideration of environmental concerns are encouraged for verifiability, to show the design is within some set of environmental parameters.

Analysis

This standard would support regulations requiring an environmental impact consideration and aid in the service life planning portion of the planning and design phases with respect to design options and their technical, economic, and environmental satisfaction of the requirements.

ISO 21930:2007 Sustainability in building construction – Environmental declaration of building products

Reference: http://www.iso.org/iso/iso_catalogue.htm
Date: 10.01.2007

Consensus: Yes
Implementation: Yes
LCA Scope: ALL

Description

Standard 21930 provides guidance for preparing Environmental Product Declarations (EPDs) for building products. The standard was developed to help ensure that the information presented in EPDs is uniformly expressed. The standard references other ISO standards, most importantly ISO 14025. Similar to CEN 15804, this standard outlines different modules to define the specific life cycle phases and additional clarification to ISO 14025. The standard explicitly states which environmental impacts (at a minimum) must be included in an EPD (climate change, depletion of the stratospheric ozone layer, acidification of land and water sources, eutrophication and formation of tropospheric ozone (photochemical oxidants)) and what LCI data should be reported (depletion of non-renewable energy resources, depletion of non-renewable material resources, use of renewable material resources, use of renewable primary energy and consumption of freshwater), as well as the reporting of hazardous and non-hazardous waste.

Analysis

ISO 21930 and CEN 15804 are good foundations for developing standards for PCRs and EPDs of building products. Additional regionally-specific clarification is still required in order to ensure consistency of reporting. Areas that require additional clarification include: allocation procedures, energy modeling assumptions, impact characterization factors and treatment of biogenic carbon.

ISO/DIS 13315-1 Environmental management for concrete and concrete structures - Part 1: General principles

Reference: http://www.jsce.or.jp/committee/concrete/e/newsletter/newsletter14/ SAKAI.pdf
Date: 12/30/11

Consensus: Yes
Implementation: Possibly
LCA Scope: A, B, C

Description

The environmental management for concrete and concrete structures suite of standards is currently under development by ISO Technical Committee 71, Subcommittee 8 (ISO/TC71/SC8), Environmental Management of Concrete and Concrete Structures. Part 1 (General Principles), proposed by working group 1 (WG1), has been accepted as a standard. Part 2 is under development in WG2. Per the introduction by the subcommittee chair, the objectives are to:

> 'The aim is to take the existing ISO framework environmental standards and provide concrete specific standards and information. The consistence with the existing ISO environmental standards, such as the ISO 14000 family, ISO 15686-6 and ISO 21930 is thoroughly kept in the same way that the standards developed in ISO/TC71 aligned with those developed in ISO/TC59 and ISO/TC98. In other words, ISO/TC71/SC8 will develop the standards from the point of view on how the existing ISO environmental standards are specialized to concrete and concrete structures, how to consider the concrete-related environmental aspects in selection of raw materials, concrete production, execution, maintenance and demolition of concrete structures, reuse and recycling of concrete and also how to incorporate the environmental design into the concrete industry.'

Analysis

Liv Haselbach has participated in both current working groups. It will take many years to develop the entire suite of standards, but based on Part 1, the effort is very comprehensive with respect to the stage of a product or process and also the environmental impacts being evaluated.

ISO/DIS 14067 - Carbon footprint of products - Requirements and guidelines for quantification and communication (draft)

Reference: http://www.iso.org/iso/iso_catalogue.htm
Date: 06.06.2012

Consensus: Yes (still in draft form)
Implementation: Pending
LCA Scope: Varies

Description

Standard ISO/DIS 14067 details principles, requirements and guidelines for calculating and reporting the carbon footprint of products (CFPs). The standard is based upon the principles of LCA and references other ISO standards. Additionally, it provides guidance on requirements for reporting and verifying CFPs of both comprehensive (all life cycle phases) or partial (select life cycle phases) LCAs. This standard provides more detail than ISO 14025 or ISO 21930 regarding calculation procedures for tracking greenhouse gas emissions and sequestering.

Analysis

This standard has the potential to bridge the WRI/WBCSD greenhouse gas protocol product carbon footprint standard and the ISO LCA standards to help enable consistent reporting of greenhouse gas emissions related to products.

PD CEN/TR 15941: 2010 - Sustainability of Construction Works - Environmental Product Declarations - Methodology for selection and use of generic data

Reference: http://shop.bsigroup.com/ProductDetail/?pid=000000000030200467
Date: 06.05.2012

Consensus: Yes
Implementation: Yes
LCA Scope: A,B,C,D

Description

PD CEN/TR 15941 supports the development of EPDs and provides direction for the selection and use of generic data by practitioners involved in preparing EPDs to improve consistency and comparability. It introduces pre-verification to help with data selection and indicates the types and potential sources of data. It gives guidance on how to judge this data as well. 15941 gives explanations of quality requirements for data and the aggregation of some of the components and assemblies that are part of any building.

This standard is a referenced part of EN 15804, which is reviewed above.

Analysis

Generic data is used in place of systems-specific data to describe environmental impacts to a product's life cycle while in an LCA. Specific data is often unavailable or would not describe a more holistic system as well as generic numbers could. In addition, generic data is often more useful in scenario planning to project away from a baseline.

This standard describes what the generic data is and where it can come from, i.e. trade organizations, manufacturers, etc. It demonstrates how generic data can be adapted more easily to regional and local conditions to better describe specific situations.

Data quality is of course a concern. Measures are taken in the standard to vet, verify and judge the data quality, hence the concept of pre-verification. Pre-verification could save a substantial amount of time in research in that it is a pre-qualifier based on prescribed merits. All data quality is subject to the same criteria as that of the data quality judgment laid out in ISO 14040.

Publicly Available Specification (PAS) 2050

Reference: http://www.bsigroup.com/Standards-and-Publications/How-we-can-help-you/Professional-Standards-Service/PAS-2050
Date: 2008 & 2011

Consensus: Yes/Partial
Implementation: Possibly
LCA Scope: A, B ?

Description

PAS 2050 is a publically available specification (PAS) developed by the British Standards Institute (BSI Group). A "PAS" is a specification that is somewhere between an in-house spec and a national standard. It allows BSI to create an industry-wide standard without having to garner a full consensus and therefore makes for faster development. PAS 2050 was developed in response to community and industry desires for a consistent method for assessing the life cycle greenhouse gas emissions (carbon footprint) of goods and services (products). Life cycle greenhouse gas emissions are defined as "the emissions that are released as part of the processes of creating, modifying, transporting, storing, using, providing, recycling or disposing of such goods and services." PAS 2050 offers organizations a method to deliver improved understanding of the greenhouse gas emissions arising from their supply chains, but the primary objective of this PAS is to provide a common basis for GHG emission quantification that will inform and enable meaningful greenhouse gas emission reduction programs.

Originally published in 2008, PAS 2050 has since been updated and revised. The updated version was released in 2011. Its focus to set standards for companies and products to evaluate their carbon footprints. PAS 2050 aims to set a standard of how to achieve carbon neutrality.

Analysis

The terminology identified and defined by this standard extends to the entire building life cycle with potential to extend beyond to supplementary building information beyond the life cycle. PAS 2050 differs from ISO and WRI LCA standards in that it is written to be specific to products, their supply chains and processes in manufacturing. ISO and WRI have embarked on updating their own standards to include a focus specific to products.

SCS-002: Life Cycle Impact Assessment Framework and Guidance for Establishing Public Declarations and Claims (draft)

Reference: http://www.leonardoacademy.org/programs/standards/life-cycle.html
Date: Draft for public comment Issued 2/2012

Consensus: Yes
Implementation: Possibly
LCA Scope: A,B,C,D

Description

This standard is currently under development by the Leonardo Academy Standards Committee on Type III Life-Cycle Impact Profile Declarations for Products, Services and Systems. The objective of the standard (from the Leonardo Academy web site accessed June 2012) is:

> 'to specify the life-cycle impact assessment (LCIA) methods, scope, metrics and format for declarations. The LEO-SCS-002 standard will comply with the requirements of ISO 14044 and ASTM draft standard E06.71.10. LEO-SCS-002 is intended to develop a uniform and standardized format for properly reporting the environmental life-cycle impacts of any system studied and explicitly excludes weighting factors and interpretation of LCIA results.'

Analysis

This standards process is being led by a relatively new ANSI standards body, The Leonardo Academy. The standard aims to standardize methodology for reporting environmental impacts using unique environmental performance metrics that were originally developed by an environmental consulting firm, Scientific Certification Systems (SCS). The draft issued in early 2012 was fairly controversial. We have received many comments from stakeholders questioning the early 2012 draft (see enclosed copy of stakeholder comments for more detailed items of concern).

WRI/WBCSD Greenhouse Gas Protocol: Product Life Cycle Accounting and Reporting Standard.

Reference: http://www.ghgprotocol.org/standards/product-standard
Date: September 2011

Consensus: Partial (multi-stakeholder process)
Implementation: Possibly
LCA Scope: Varies

Description

The World Resource Institute and the World Business Council for Sustainable Development (WRI/WBCSD) partnered in creating standards for reporting the greenhouse gas emissions both of companies (the Corporate Standard, not reviewed here) and of products. This standard provides guidance on requirements for analyzing and reporting the carbon footprint of specific products. Additionally, the WRI/WBCSD provides guidance documents to help interpret and implement the standard.

Analysis

The WRI/WBCSD Corporate Standard is widely used and thus the development of a product standard that is compatible with corporate reporting is a positive step. The product standard is complementary to general ISO LCA standards providing additional information and reporting requirements. The research team has not yet compared the details of this product standard to ISO 14067; however, publications on the GHG Protocol website indicate that WRI/WBCSD participated in the development of ISO 14067 in an attempt to harmonize with the WRI/WBCSD and other ISO standards.

X5 Models: Life Cycle Assessment Methods, Data, and Impacts

X5.1 Introduction

METHODS

LCA analysis is typically conducted using one of the following methodologies: process based LCA, Economic Input Output LCA (EIO-LCA) or Hybrid LCA. Each of these methods is different in how they characterize the system and allocate emissions and environmental impacts to the different materials used and processes performed. Therefore, while all of these models are respected methods of conducting LCA, the results of analysis completed based on different modeling assumptions will have different results. Review of LCA results must thus carefully consider the models and assumptions used in creating the LCA. Analysis and impact models must be identical if results of LCAs are to be compared. Good texts, which provide more detailed information on LCA methodology, include (detailed references at end of document):

1. *The ILCD Handbook: A General guide for Life Cycle Assessment-Detailed Guidance.* European Commission Institute for Environment and Sustainability (2010)
2. *A life cycle approach to buildings: principles, calculations, design tools.* Konig, H. Kholer, N. Kreissig, J. Lutzkendorf, T. (2010)
3. *The Computational Structure of Life Cycle Assessment.* Heijungs & Suh (2002)
4. *Environmental Life Cycle Assessment of Goods and Services: An Input-Output Approach.* Hendrickson, Lave & Matthews (2006)

DATA

The underlying LCI data used in an LCA can either be specific (data collected at the manufacturing site) or generic (based on data from another study). The Swiss government has supported the development of the most comprehensive LCI database currently in use, eco-invent. Data thus represents Swiss manufacturing processes and Swiss electrical energy consumption. The US LCI database needs to be expanded. However, within it are the unit process LCI data for US-specific manufacturing.

Most of these databases model energy generation and use, and the tools provide methods to change the energy source of a manufacturing process to model different production methods. Tools to model the operational energy use in buildings have not been reviewed as part of this study. For more information on this topic see the US Department of Energy's Building Energy Software Tools

Directory at: http://apps1.eere.energy.gov/buildings/tools_directory/software.cfm/ID=347/pagename=alpha_list (accessed July, 2012).

Life cycle inventory and assessment (LCIA) tools are in a state of continuous improvement. Figure X5.1 is provided to show how the tools use databases that provide materials, water and energy use, and waste data to create a product (or process or material)-specific life cycle inventory (LCI). The life cycle inventory is a detailed accounting of all of the 'flows' (quantities of materials, chemicals, etc. that are both taken from and released to nature. For example, an LCI would typically quantify items such as combustion of a quantity of coal and emissions of items such as $C0_2$, methane and mercury as well as resource use (e.g. water). LCI databases exist that quantify the input and emissions for different 'unit processes'. In this section we will review the extent and scope of the primary existing LCI databases.

A comprehensive LCA analysis must carefully account for all of the materials and processes (e.g. iron ore and coal combustion) that are required to manufacture a specific product (e.g. steel). Thus multiple LCIs (unit process data such as coal combustion, iron ore mining and transportation by truck) are combined to get an aggregated LCI for a specific product (e.g. steel wide flange beam). The list of emissions in an LCI from manufacturing a product can include more than 100 different chemical and physical releases. In order to simplify the interpretation of these emissions, LCI results are typically aggregated into an environmental impact category such as climate change or acidification.

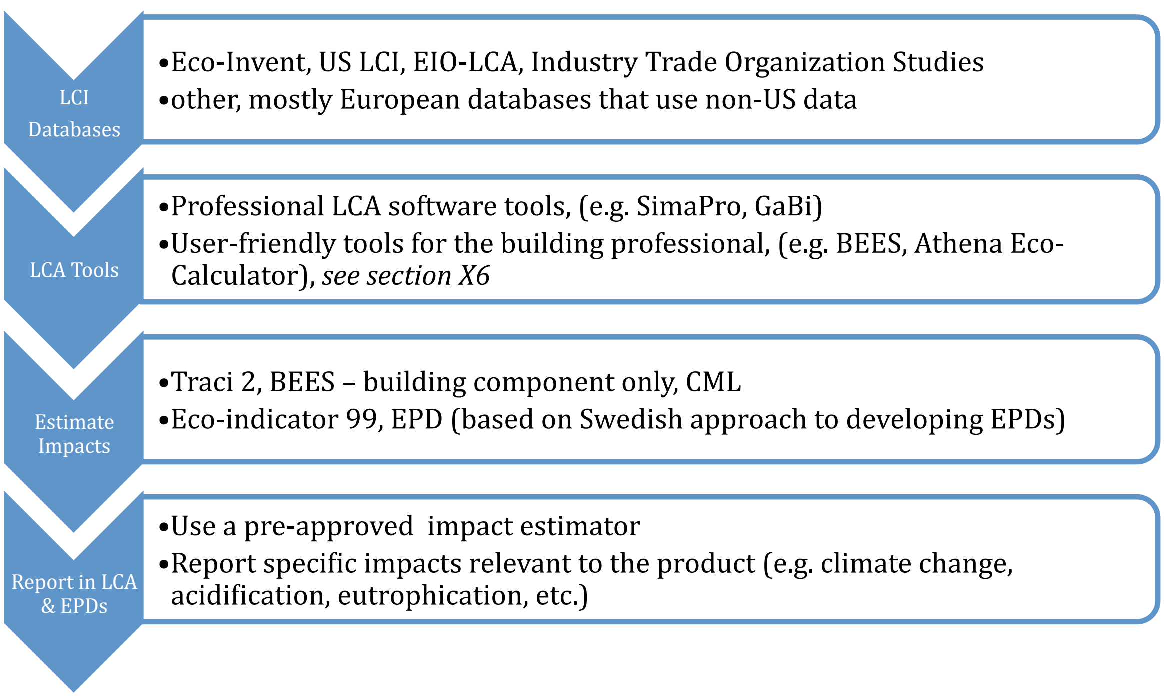


Figure X5.1: Links between LCA databases, tools, impact estimators, and their uses.

IMPACTS

Scientific studies have evaluated the impact of different emissions on specific environmental impacts, such as climate change. These studies enable the creation of characterization factors to model the relative influence of different emissions on the noted environmental impact. For example, as multiple greenhouse gasses (GHG) have been determined to impact climate change, the combined impact of all of these GHGs is reported by multiplying each of the GHGs by a characterization factor (the Global Warming Potential/GWP). The characterization factors can be used to translate multiple emissions into a single environmental impact category (such as equivalent Carbon Dioxide (CO_2e) to represent the climate change impact category). Some of the environmental or resource impacts are well understood by the scientific community and accepted by the public. Other impacts are not as well understood, and impact estimators for them are in their infancy. See discussion in the Introduction to this project for additional information about different environmental impacts and characterization models.

There are additional impacts directly related to resource use (water, non-renewable resources). Often the total LCI for these resources are published as a resulting LCA impact. Of note, methods, databases and tools for estimating the following impacts are still developing and are less uniformly reported: the contribution of direct and indirect land use to climate change or other environmental impacts, impacts on human health, bio-diversity, social impacts, and water use.

The reported results from standard impact categories are the foundation of interpreting results of an LCA and form an integral component of environmental product declarations (EPDs) designed to showcase the environmental and resource footprint of a given product in an understandable format using metrics that are consistent across product categories.

DATABASE TOOLS

Given the complexity of tracking LCI data and combining the unit processes to develop LCA impacts for specific products, LCA tools have been developed to manage (and expand) LCI databases and facilitate the creation of LCAs. These comprehensive LCA tools designed for LCA practitioners are reviewed in this section. Simpler, building industry specific LCA ‘calculators’ are reviewed in the next section of this document.

X5.2 Summary of Studied Items

Pg.	Name	Description	Location	Consensus Based Process?	Implement to bldg std or code?*	LCA Scope Addressed, A-D**
LCI Databases (Unit Process Data)						
7	Bath ICE	Carbon Inventory	UK	N	1B	A,B
8	BEES	Online tool	North America	N	2	A,B,C,D
10	Ecoinvent	LCI database	Europe	Y	1B	Varies
na^	INIES	EPD Database	France	N	1B	Varies
na	LCA Digital Commons	US LCI Data	US	N	1B	Varies
14	US LCI	LCI database	USA	Y	1B	Varies
LCI Databases (EIO Data)						
na	CEDA	Private EIO Database	US, UK, China	N	2	
na	EIO-LCA	Carnegie Mellon EIO Database	US	N	2	
na	OPEN-IO	Developing EIO database	US	N	2	
Environmental Impact Characterization Models						
na	CML	Impact estimator	Global/NL		2	
9	Eco-Indicator99	Impact estimator	European	N	2	Varies
13	TRACI	Impact estimator	US - EPA	N	1B	Varies
LCA Database Tools						
11	GaBi	LCA software	Int.	N	1B	Varies

12	SimaPro	LCA software	Int.	N/A	1B	Varies

* 1 being highest importance, 3 being lowest
** A: Production/Manufacturing and Construction stages (cradle to gate)
B: Use stage
C: End of Life stage
D: Reuse, Recovery, and Recycling stage
^ "na" refers to those databases, tools and models not evaluated in this report due to lesser relevance to the task at hand

X5.3 Recommendations

There are a number of tools that are actively used in the market place. The choice of software is mostly driven by costs and the available datasets within each tool. The use and interpretation of the tool outputs should be conditioned by a data quality analysis as described by the ISO standards as well as consideration of variables such as:

- Do the input data accurately reflect the product of interest?
- Is regional variation accounted for with respect to production processes and emissions?
- Have all upstream factors been accounted for?
- Are the comparisons being made using the same impact estimators?
- Are the impact estimators transparent?
- Do they adequately capture emissions to the environment that are likely to be detrimental?

All the tools and datasets will require on-going investment to ensure updates and improvements to reflect changes in production processes, improved technology, and the addition of regional variation are incorporated for existing products. In addition, some products are simply not yet in the databases. If materials are sourced from countries where LCA data are scarce (or non-existent) and where environmental regulations are less stringent than they are in those countries where data are collected, the risk of underestimating impacts grows. For example, almost 37% of the world's steel production occurs in China and a little over 7% is made in the US (2007 data). An unknown percentage of Chinese steel makes its way into US buildings. Collectively, these elements suggest that improvements are needed in both data quality and quantity for the dominant building products that are used in the US. Requiring LCA as part of a code or standard would lead to substantially better datasets, particularly where current datasets are based on outdated production modes or national or international averages that do not reflect the advanced environmental performance of dominant players in the market place.

Note also that the various items in the list of environmental and resource impacts all have different units. They are not like monetary LCCAs, which have one final unit: US dollars. Therefore, the various impacts in an LCA cannot be readily combined into a single factor for comparison amongst multiple options. One option may have a lower carbon footprint, but contribute more to ozone depletion than an alternative. There are also many tools that weight the various impact factors so that they can be combined into a single environmental impact indicator. However, these methodologies are subjective, and the weights used are variable based on the analysis being performed, as well as other decisions, goals and objectives. This report is not charged with evaluating the various methodologies for deciding between alternatives evaluated by LCA. The authors would also like to caution the State against the use of these weighted single indicators given their subjectivity and possible misinterpretation.

X5.4 Evaluation

The following pages include further review and evaluation of the items listed in X5.2 and deemed omost relevant to this report.

Bath Inventory of Carbon and Energy (ICE)

Organization: University of Bath (U.K.) – Department of Mechanical Engineering
Date: Version 1.6a released 2008
Contact: sert@lists.bath.ac.uk

Consensus: No
Implementation: Possibly (if methodology is applied to U.S.)
LCA Scope: A and B

Description

Within the Mechanical Engineering department at the University of Bath, a research group called the Sustainable Energy Research Team (SERT) has created a database listing the embodied energy (EE) and carbon (EC) in over 200 items. These listed items are typical construction materials such as aluminum, concrete and aggregates. All of the information collected to create the database is of secondary source; that is, they are from sources such as academic papers, articles, product (material) LCAs, etc. Materials are categorized in sub-categories to help the user easily sort through the data. Sub-categories are group headings such as Plastics, Concrete, Windows, etc.

The numbers presented by each material are the coefficients of EE and EC that can be multiplied by the quantity of material under study. This number will represent a fair assessment of the EE or EC contained in that amount of material. The authors of this database go to great lengths to explain that this "fair" assessment is not an actual amount. Because of the uncertainty in the data sourcing, collection methods, and many other variants, no single number can be perfectly accurate. The authors maintain that "results from ICE have proved to be robust when compared to those of other databases."

Analysis

Like other databases, a key factor in evaluating the accuracy of the Bath ICE is in the representation of the energy mixes associated with the data. In this case, it is prominently mentioned by the authors that actual results could vary widely depending on the local energy mix. Other factors to consider are the transportation and density of materials. If the coefficient represents a Cradle to Gate scenario, actual impact data could be quite different than if one needs Cradle to Site data for a material with large mass. The added transportation impact could be of great significance.

That said, this database goes to great lengths to be transparent about all parts of its scope. It indicates where the data is from, what the data entails and the quality of the data. It is a robust database, and a potential user should take time to fully understand the data before using it for their own research.

This database could serve as a good model for the U.S. More specifically, if there were to be a regional breakdown of local and imported materials, a database containing this type of information would be of great use for both practitioners and officials.

BEES - Building for Environmental and Economic Sustainability

Organization: National Institute of Standards and Technology
Initiation Date: June 2000
Contact: http://www.nist.gov/el/economics/BEESSoftware.cfm

Consensus: Yes – Based on consensus standards
Implementation: Yes
LCA Scope: All stages, depending on product

Description

BEES is an online impact assessment tool that looks at the range of building products and generates both life cycle and cost analysis data weighted to whatever ratio is desired by the user. It is based on the ISO 14040 series of standards. BEES includes many more impact categories than most tools, including: global warming potential, acidification, eutrophication potential, fossil fuel depletion, solid waste, indoor air quality, habitat alteration, water intake, criteria air pollutants, smog, eco-toxicity, ozone depletion, and human health.

The impact categories can be weighted four different ways: by applying equal weights, using EPA science advisory board criteria, using BEES stakeholder criteria, or by user-defined criteria. Likewise, the economic and life cycle impacts can be weighted from 0-100%. Outputs include tabular and graphical summaries. The system covers a range of products in selected product groups (e.g. structural/framing/wood). BEES analyses all life stages including raw material acquisition, manufacture, transportation, installation, use, recycling and waste management. BEES uses the ASTM standard life cycle cost method that includes the costs of initial investment, replacement, operation, maintenance and repair, and disposal.

Analysis

The online tool provides a simple framework for analyzing multiple building envelope and non-structural elements, but does not provide an easy comparison between alternatives without a lot of runs. The number of structural and non-structural components in the model is limited, but the framework for including more is solid. The integration of life cycle costs is a particularly attractive attribute of this tool. Its database input first comes from the US LCI database. If the data points are not there, it goes to EcoInvent within SimaPro. The data is referenced at the end in product documentation (personal communication with Barbara Lippiatt). BEES has summarized its limitations, so that one will be aware of how to use the product. It is limited to products and components built in the US.

The database is fairly limited in the types of building materials included in it. As of June 2012, the database is not being funded for future development but additional materials and products will be added as information by industry is submitted. In addition, impact assessment methods are not being updated.

Eco-Indicator 99

Organization: Pré Consultants
Date: June 2001
Contact: http://www.pre-sustainability.com/content/reports

Consensus: No – but collaborative
Implementation: No
LCA Scope: Varies by product

Description

Eco-Indicator 99 is an impact estimator developed by Pré Consultants based on the extensive review of a prior product. The impact estimator was developed to be consistent with ISO 14040 and 14042. The impact estimator has been developed as an 'end-point' estimator in an effort to circumvent the need for users to weight traditional impacts (smog, GWP, acidification, etc.) in a way that reflects their eventual impact on human health, resource depletion, and ecosystem health.

Analysis

The model used by Eco-Indicator 99 employs a weighting filter between the LCI outputs and the final indicator value in an effort to address and incorporate values assessment. For this reason, the relative weights and rankings from Eco-Indicator 99 are quite different from a mid-point impact estimator such as TRACI. If we implicitly trust the model inputs and structure, this method may yield additional value beyond a simple reporting of global warming potential such as would be reported in TRACI and other mid-point impact assessment tools. However, the black box nature of the tool makes it difficult to discern if the impacts in question are the ones that are most critical in the processes under consideration.

EcoInvent

Organization:	Competence Centre of the Swiss Federal Institute of Technology Zürich
Date:	Began in 1997; EcoInvent v1.0 launched in 2003; EcoInvent v2 to launch in 2012 with a new data format
Contact:	http://www.ecoinvent.org/
Consensus:	Yes - Stakeholder driven process for developing the process and protocols that are to be followed for inclusion of information into the database.
Implementation:	Yes
LCA Scope:	Varies by product

Description

The EcoInvent database was initiated in Switzerland using mostly European data. The intent behind its production was to aggregate European LCA data into a common framework for consistency and quality improvement. The EcoInvent database includes upwards of 4,000 processes that can be linked and evaluated using a whole host of impact assessment methodologies including: CML 2001, Cumulative energy demand, Eco-indicator 99, Ecological footprint, Ecological scarcity 1997 and 2006, Ecosystem damage potential – EDP, EDIP'97 and 2003 - Environmental Design of Industrial Products, EPS 2000 - environmental priority strategies in product development, IMPACT 2002+, IPCC 2001 (climate change) and IPCC 2007 (climate change), ReCiPe (Midpoint and Endpoint approach), TRACI, USEtox, and other selected Life Cycle Inventory indicators. The database can be queried as a stand-alone product or incorporated into other software platforms such as SimaPro and GaBi.

Analysis

The database contains processes and materials that are not present in the US LCI database, so in that way they can be used as proxy inputs to augment US data and arrive at a better estimate of the full life cycle impact of a particular product or building component. The inherent limitation is that the manufacturing, transportation, and acquisition of materials used in the US building trade may have a substantially different footprint than is found in Europe or other regions where the data is gathered.

GaBi

Organization: PE International
Date: active
Contact: http://www.gabi-software.com/america/index/

Consensus: No
Implementation: Yes
LCA Scope: Varies by product

Description

GaBi is a sophisticated software package that is used by LCA professionals to develop life cycle inventories. The software provides a range of databases and impact estimators from which to choose in order to build processes (i.e. manageable sub-units that have defined input and outputs that go into your product development) that are connected together to develop a full LCA on the product of interest. The software is a direct competitor with SimaPro software (see next section for more detail) and has many of the same functional attributes and supports the same databases. There are add-on tools that allow users to import bill-of-materials for analysis of a range of design alternatives (GaBi-DfX), to present outputs to non-users (GaBi-Publisher), and to generate LCA for a given design (GaBi-Reader). There is a building industry specific tool (GaBi-Buildit) that is in German and uses only German data.

Analysis

As with SimaPro, the software is not for the casual user as it takes some time to develop proficiency at its use and to understand how the data is structured and aggregated to generate LCA outputs. GaBi provides options for users to purchase multiple databases formatted for use in their tool including EcoInvent, the US LCI database, industry specific datasets and proprietary data collected by PE International. The use of non-US data has its limitations (see overview) and ideally should be modified to reflect regional power sources and transportation impacts. Any use should be noted for transparency in evaluating outputs.

SimaPro

Organization: Pré Consultants
Initiation Date: May 2001
Contact: http://www.pre-sustainability.com/content/simapro-lca-software

Consensus: N/A - it is software.
Implementation: Yes
LCA Scope: Varies by product and can be incorporated into the processes developed.

Description

SimaPro is a sophisticated software package that is used by LCA professionals to develop life cycle inventories. The software provides a range of databases and impact estimators from which to choose in order to build processes (i.e. manageable sub-units that have defined input and outputs that go into your product development) that are connected together to develop a full LCI on the product of interest.

Of interest to the US user community are the US LCI database, the US Input Output database and, for those processes that are missing in these two, the Eco-Invent v.2 database. The Eco-Invent v.2 database has data on raw materials where no US database exists, but the inputs and outputs are not necessarily reflective of US processing and manufacturing conditions. There are a number of other European databases included with the software with the same limitation as the Eco-Invent database.

Once LCI data has been assembled and all processes have been considered for a product, the LCA assessment component of SimaPro can be used to determine overall environmental impacts. These impacts are generated using a number of impact estimators including ReCiPe (which replaces Eco-indicator 99), USEtox (which is focused on a single variable of human toxicity related to cancer), IPCC 2007 (generates only global warming data), EDP, Impact 2002+, CML-IA, TRACI 2, EDIP 2003, Ecological scarcity 2006, EPS 2000, Greenhouse Gas Protocol and others. These provide the characterization factors that are used to indicate the relative impact of individual impact estimators. Of these impact estimators, TRACI 2.0 the most appropriate for incorporation of LCA into the public building code.

Analysis

The software is not for the casual user as it takes some time to develop proficiency at its use and to understand how the data is structured and aggregated to generate LCA outputs. The databases that are included in the software are regularly updated and the best available. The inclusion of multiple data sets allows the development of full process models with proxy data where specific US values are lacking. The use of non-US data has its limitations (see overview), and any use should be noted for transparency in evaluating outputs.

TRACI 2.0 (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts)

Organization: US Environmental Protection Agency (EPA)
Date: 2003
Contact: http://www.epa.gov/nrmrl/std/traci/traci.html

Consensus: No – based on best available science and integration across systems
Implementation: Yes
LCA Scope: Varies by product

Description

TRACI is an impact assessment method that aggregates impacts for a wide range of categories including: ozone depletion, global warming, acidification, eutrophication, photochemical oxidation (smog), eco-toxicity, human health: criteria air pollutants, human health: carcinogenics, human health: non-carcinogenics, and fossil fuel depletion. Additionally, research is being conducted to account for impacts related to land and water use. It incorporates US data, some of it regionally specific, for a wide range of processes, and uses that data to arrive at estimates of environmental impact across a range of categories. TRACI was developed and designed using information in extant LCA literature and relying on coordination with LCA users. The impact factors that are included in the method include factors that EPA was already regulating plus those that were deemed to be of high societal interest. The TRACI method provides a 'mid-point' impact estimation as compared to Eco-Indicator 99 (see p. X5-9) which provides an 'end-point' impact estimation.

Analysis

TRACI is a 'made in the US' impact estimator that is consistent with the environmental regulatory framework in this country. For that reason alone, its use is probably desirable over other impact estimators because it reflects the collective knowledge of US LCA practitioners and regulatory agencies. As a mid-point estimator, TRACI provides quantifiable data on emissions or outputs without applying normative assessments as to the impact of the emissions on the impacts we are most concerned with: end-points such as human health, environmental degradation, or resource depletion.

US LCI database

Organization: National Renewable Energy Laboratory
Initiation Date: May 2001
Contact: http://www.nrel.gov/lci/database/ - (Database is temporarily hosted at https://www.lcacommons.gov/nrel/search)

Consensus: Yes - Stakeholder driven process for developing the process and protocols that are to be followed for inclusion of information into the database.
Implementation: Yes
LCA Scope: Varies by product

Description

The United States Life Cycle Inventory (USLCI) database is a national repository of life cycle inventory data held and maintained by the National Renewable Energy Laboratory in Boulder, Colorado, and currently hosted by the US Department of Agriculture at their LCA digital commons. This database is publicly available and subject to data standards that were developed by stakeholders to be consistent with evolving ISO standards.

The data are archived by process, with upstream processes included in the downstream product. Recent upgrades include the development of 25 different electrical grids across the USA to reflect differences in production processes associated with energy generation in different regions of the country (i.e. relative percentages of hydro, coal, wind, solar, natural gas, and nuclear).

Analysis

The database is only as good as the input data provided by practitioners, industry, and collaborators, but data quality is (usually) notated clearly so that the user can tell the degree of aggregation and/or specificity that applies.

The data are publicly available but not for 'use by the general public' - a notation included specifically in the USLCI data guidelines as a warning that the data are not akin to a full LCA report in that they must be aggregated so that all processes that are significant to a product life cycle are included in the appropriate proportion to their impact. This means that the US LCI database requires some sophistication and expertise on the part of the user to ensure that the LCA that emerges from the analysis actually includes all relevant elements.

Not all building products are covered by the database, and some products have incomplete upstream processes because those processes have not yet been quantified from US sources. In cases where no US data is available for a particular process, 'dummy variables' are substituted and noted in the database to indicate the missing data. Failure to accurately account for the dummy variables in a comparative analysis can lead to erroneous results.

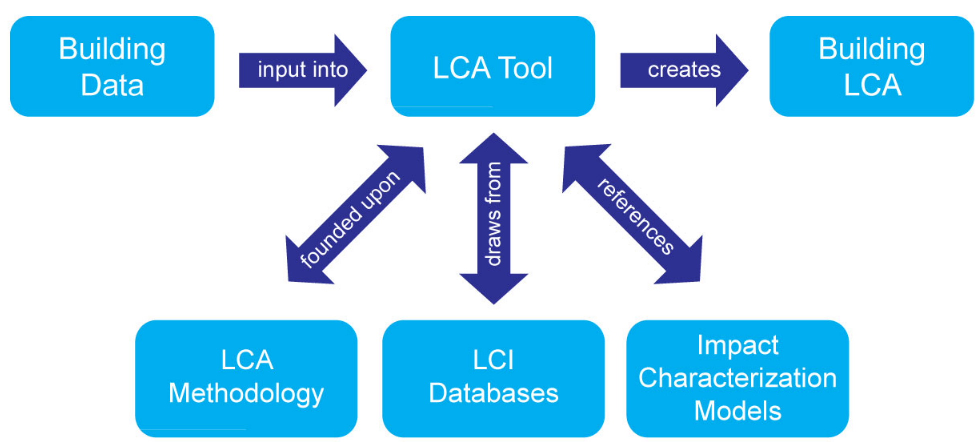
X6 Building Industry Specific LCA Tools

X6.1 Introduction

As LCA continues to gain momentum as a method to improve our ability to quantify and reduce the environmental impact of buildings, numerous organizations around the world are investing in tools to simplify the LCA calculations of buildings and building products. These organizations are both academic and professional, often jointly developing software for the design community to implement LCA into practice for decision-making. In this section, we have identified national and international tools using LCA as guidance that could be used to develop common, agreed-upon levels of compliance.

General LCA tools typically provide more detail and flexibility for a comprehensive analysis but are more complex than is appropriate for use by general practitioners. These general tools were reviewed in the previous section. In order to implement LCA in building practice, users typically use an LCA tool to provide a user-friendly interface to integrate LCA data according to a specific model (or methodology), see figure X6.1. The tool (software) provides the user interface to enable the link between construction materials and systems and LCI data. Models/methods of LCA provide the structure to integrate the LCI data consistently. Tools that use the same model and data should be able to get comparable results.

These tools tend to be regionally specific and are often designed to support specific laws, mandates, and other directives implemented by nations around the world. There are varying levels of complexity to each tool, ranging from those requiring a high-level of user sophistication to simple online calculators. The robustness of the results often parallel the sophistication of input required.



Additionally, some of the software and online tools are more applicable to this research project than others. Section X6.2 lists the items that were reviewed with a summary of their status and their relative importance to this effort. The table indicates which tools are more viable models for implementation and the LCA scope that they cover. Items currently under development need to be further updated as information becomes available. Some of the tools do not appear to have any system in place for improvement or future development.

In this section, we summarize a few of the many tools in use within the US as well as internationally, with an emphasis on those tools that use US data and US impact assessment methods. We discuss the integration of these tools into a system that can be used to incorporate LCA into building codes.

X6.2 Summary of Studied Items

Pg.	Name	Description	Location	Consensus Based Process?	Relevance*	Implement to bldg std or code?	LCA Scope Addressed, A-D**
North America							
7	Athena EcoCalculator	LCA spreadsheet tool	CA	N	1B	2	A,B,C
8	Athena Impact Estimator	LCA software tool	CA	N	1B	2	A,B,C
9	BEES	Online Calculator	US	N	1B	2	A,B,C,D
NR	BIRDS	In Development whole building LCA tool/data by NIST	US	N	1B	?	A,B,C
10	Build Carbon Neutral	Online Calculator	US	N	1B	2	A
11	CostLab	Web-Based Costing Tool	US	N	3	3	B
12	Green Footstep	Online Calculator	US	N	1B	2	A,B
13	Sustainable Minds	Web-Based LCA tool	US	N	3	2	A,B,C,D
Europe							
14	BEAT	LCA software tool	NL	N	2	?	n/a
15	BeCost	Web-Based LCA tool	FI	?	2	2	A
16	Boustead	LCA software tool	UK	N	1C	B	n/a
NR	Eco-bat	LCA software tool	CH				
17	Eco-Quantum	LCA software tool	NL	N	3	3	A,B,C
18	EcoSoft	LCA spreadsheet tool	FI	N	2	2	A,B,C,D
NR	e-licco	Whole building LCA	FR	N	1C+	1	A,B,C,D
NR	Elodie	Whole Building LCA tool	FR	N	1C	1	A,B,C,D
19	Envest 2	Web-Based LCA tool	UK	N	1	2	A,B,C

20	Environment Agency Carbon Calculator	Online Calculator	UK	N	2	2	A
21	Equer	LCA software tool	FR	N	1C+	P	A,B,C
NR	Gabi Build It		DE	N	1C		
22	GreenCalc+	LCA software tool	NL	N	1C+	2	A,B
23	GPR	LCA software tool	NL	N	1C	2	A,B,C
24	IMPACT	LCA software tool	UK	N	2C	n/a	n/a
25	LEGEP	LCA software tool	DE	N	1C+	P	A,B,C
26	Low Carbon Building (LCB) Method	LCA spreadsheet tool	UK	N	1C	P	A,B,C,D
27	TEAM	LCA software tool	UK	N	2	P	A,B,C
28	Umberto	Process software tool	DE	N	3	N	A,B,C
Australia							
29	LCADesign	LCA modeling software tool	AU	?		P	?
30	LCAid	LCA software tool	AU	?		?	?
31	LISA	LCA software tool	AU	Y		P	A,B,C,D

* 1 being highest importance, 3 being lowest

** A: Production/Manufacturing and Construction stages (cradle to gate)
B: Use stage
C: End of Life stage
D: Reuse, Recovery, and Recycling stage

NR: Not reviewed in detail. See below for evaluation.

X6.3 Evaluation

Based on our team's review of the tools listed above, there are some important aspects that these tools should provide the user:

01: Usability – In order for architects and engineers to implement an additional tool, it cannot come with a difficult learning curve. A tool must be easy and intuitive to use. This requires a clear user interface and methods to efficiently collect information about the building project.

02: Regional character – A tool that does not take into account data specific to its region can result in misrepresentative data, leading to inaccurate decisions. Tools should reference regional LCI data and, in the US, should be able to account for the regional differences in electricity generation and building methods.

03: Expansion and Integration – LCA done in isolation cannot change cultural directions in the construction industry. A tool must have the ability to grow with changing data, expand its capabilities as needed in local or statewide settings, and be inexpensive and easy to implement.

Building industry LCA tools can vary in detail and complexity from quite simple and intuitive (e.g. Build Carbon Neutral or the Green Footstep) to more complex and detailed (e.g. Gabi Build it or Athena Impact Estimator). In France, where LCA mandates have been in development at both the federal and regional level for some time, there are multiple nationally-specific LCA tools developed to respond to slightly different regulatory requirements and objectives. These LCA tool developers have organized to develop a consistent LCA database for use in France and are working to harmonize analysis models/methodology so that the underlying assumptions of the tools are consistent and what differs is the user interface for collecting and reporting data.

Currently, the Athena Institute produces the only US-specific building industry LCA tools (Eco Calculator and Impact Estimator). NIST is sponsoring the development of a whole building LCA tool, BIRDS, that uses a Hybrid LCA approach; however, the details of this tool are not yet known. When looking to assess the potential of integrating LCA into codes or rating systems, one should be careful to limit possibilities based on the tools currently available and rather should also evaluate the characteristics of an LCA tool that might be needed to achieve a certain objective. As demonstrated throughout Europe, multiple LCA tools are being developed in multiple regions. While the tools are based upon EU data, their methodology and interfaces can be evaluated to demonstrate the range of potential LCA tools and could be used as guides for future US-specific LCA tool development.

Towards the end of the research project, the research team became aware of multiple LCA tools that are in development in Europe. In some cases, these tools are built upon harmonized LCI data and methodology that would enable comparisons between results. The details of all tools have not been reviewed in this report but should be considered for future study. A summary of the most relevant EU LCA tools is outlined below:

Name	***Region***	***Description***
E-Licco	France	Developed to support requirements for whole building LCA established by the Bourgogne region. Used modified eco-invent data (not the EPD data). http://e-licco.cycleco.eu
Elodie	France	Developed by CSTB (French Center for Building Science and Technology) to support full building LCA. Uses Both EPD specific and generic data. Targeted to require buildings to perform under a baseline by 2013. http://www.elodie-cstb.fr/
EQUERE	France	Tool developed for comprehensive building analysis (including energy/lighting) that integrates whole building (and community) LCA data and methods. www.izub.fr *Reviewed in more detail below*.
LEGEP	Germany	LCA tool that integrates with the German building specification method utilizing common building component descriptions and interfacing to Building Information Modeling (BIM). Enables integration of LCA and LCC and health risk assessment, termed Integrated LCA or iLCA. www.legep.de *Reviewed in more detail below*.
GaBi Build-it	Germany	Interface for the GaBi LCA tool specifically for developing LCAs of German buildings. In conformance with ISO 14040/14044 and the DGNB (German Green Building Council).
Greencalc	Netherlands	Of note, both Greencalc and GPR are reportedly developed based upon harmonized methodology and databases, so that the unique features of the tools are related to user interface. Results from the tools should be comparable (statements on harmonization need to be verified). www.greencalc.com *Reviewed in more detail below*.
GPR	Netherlands	http://www.gprgebouw.nl *Reviewed in more detail below*.
Eco-Bat	Switzerland	LCA modeling tool with plug-ins to enable comprehensive LCA including both operational energy and material impacts. www.eco-bat.ch
Envest2	UK	Software tool combining LCA and LCCA. www.envest2.bre.co.uk *Reviewed in more detail below*.
LCB Method	UK	The Low-Carbon Buildings Method. Provides a template and building industry specific carbon footprint database for use in compiling carbon assessments of buildings. www.lcbmethod.com *Reviewed in more detail below*.

Athena EcoCalculator

Organization: Athena Sustainable Materials Institute
Date: 11.16.2011
Reference: http://www.athenasmi.org

Consensus: No
Implementation: Possibly
Tested by team: Yes
LCA Scope: A3, A3, B1, B5-7, C1 (are expressly mentioned, others possible)

Description

The EcoCalculator is a basic tool meant to be available to any design professional as an introduction to working with LCA in practice. It is a high-level overview of the building design and is designed to be a material decision-making aid in early design stages when rough comparisons will be most beneficial. The tool is in the form of a spreadsheet. A designer can create multiple option scenarios quickly because it is easy to change the variables and see results. The tool is freely available to download.

Analysis

This tool is useful for a quick analysis to compare the life cycle impacts of primary elements of building construction. The limited options of materials make it only appropriate for major, conventional material systems. One feature that shows promise is that a user can choose either a residential or commercial spreadsheet. Each contains a material inventory that is more in line with assembly types associated with one of those two building types.

The EcoCalculator is simpler to use and more intuitive than its parent counterpart, Athena's Impact Estimator, which is the source of all the calculation's data. It operates as an Excel spreadsheet where almost everything is visible and the calculation methodology is transparent. Its simplicity is its greatest strength, but also can be seen as its greatest weakness. Preliminary use has found users frustrated with their inability to customize materials within the program to reflect actual conditions of a specific design option. The tool does not permit optimization of materials and systems (e.g. optimizing cement content in concrete or developing material efficient structural systems). Many of the things that EcoCalculator cannot do, such as assessing and comparing options at a deeper assembly level, are found in the Impact Estimator (see next page).

Athena Impact Estimator

Organization: Athena Sustainable Materials Institute
Date: 11.16.2011
Reference: http://www.athenasmi.org

Consensus: No
Implementation: Possibly
Tested by team: Yes
LCA Scope: A3, A3, B1, B5-7, C1 (are expressly mentioned, others possible)

Description

The Impact Estimator is a detailed tool for evaluating multiple or individual material assemblies. It is designed to allow architects, engineers and researchers to understand the impact of material choice on the environment when designing buildings. The tool uses data that is compliant with ISO 14040 standards covering several building types: residential, commercial, institutional, industrial, etc. The user can distinguish whether the building is a rental or owner occupied facility. The building's operating energy impacts are NOT a part of the spreadsheet, but that data can be entered from another source. The spreadsheet is then capable of including that data into the overall bottom line impact.

Athena accounts for regional variation in its programs. The program's integrated emissions factors are automatically updated to use a region's energy mix and average transportation emissions when the user specifies the project's location. The generated data is meant to be a "conceptual building design" and therefore does not have an extensive amount of design criteria available. The database that Athena uses is comprised of information collected by the Athena Institute and data taken from the US LCI database at NREL, along with other sources. A great amount of this data is listed on the Athena Institute site as companion database reports. The current limitation is that there are only about 150 materials listed, though additional options are available within the expandable menus.

Analysis

This tool is fairly intuitive. It does not take long for a user to understand and begin inputting data. Users must develop material quantity take offs and know the building dimensions. The program's limitations are in the variety of input options. For example, newer materials like photovoltaic panels are not yet accounted for and are not possible inputs. One can add material surrogates for such items but the accuracy will suffer. It does not allow for manipulation of the material such as user variation within the sets of concrete mixes or steel production type. The Impact Estimator produces useful graphs and charts of multiple environmental impact categories. The Impact Estimator can compare up to five design scenarios at once. This feature is key to quick material comparisons. The regional applicability carries great weight in that differences in energy mixes, seismic zones and transport distances in North America can result in variations in impact results.

Building for Environmental and Economic Sustainability (BEES)

Organization: National Institute for Standards and Technology (NIST)
Date: 11.28.2011
Reference: http://ws680.nist.gov/Bees/Default.aspx

Consensus: No
Implementation: Possibly used in addition to another tool or program
Tested by team: Yes
LCA Scope: A1-5, B1-7, C1-4, D

Description

From the NIST website:

> *The BEES software brings to your fingertips a powerful technique for selecting cost-effective, environmentally-preferable building products. Developed by the NIST (National Institute of Standards and Technology) Engineering Laboratory, the tool is based on consensus standards and designed to be practical, flexible, and transparent. BEES Online, aimed at designers, builders, and product manufacturers, includes actual environmental and economic performance data for 230 building products.*
>
> *BEES measures the environmental performance of building products by using the life-cycle assessment approach specified in the ISO 14040 series of standards. All stages in the life of a product are analyzed… Economic performance is measured using the ASTM standard life-cycle cost method…. Environmental and economic performance are combined … using the ASTM standard for Multi-Attribute Decision Analysis.*
>
> *Building elements are organized by functional use using the hierarchical structure of the ASTM standard UNIFORMAT II classification system: by Major Group Element, Group Element, and Individual Element.*

Analysis

BEES is a customizable tool. The user has the option to decide how important each impact category is, and the built-in calculator will weigh the results to reflect it. This weighted system melds all impact category numbers into a single impact indicator. The user also has the option to NOT weight the data, in which case the data is not aggregated. BEES combines environmental impact and cost analysis in an interesting way. The developers acknowledge that economic inflation occurs and allow the user to determine what percentage change there could be in the future costs of maintenance or replacement. They also allow the user to determine how important the economic aspect is compared to the environmental by altering the weighted percentages.

Because the material selection is so limited, BEES could be described best as a building product comparison tool. There are not enough available options for a whole building LCA report to emerge. NIST is no longer funding the development/refinement of this tool; however, they will continue to accept additions to the database. Note: BIRDS, a hybrid model of whole building LCA, is currently under development and scheduled for release in 2013.

Build Carbon Neutral

Organization: Mithun Architects, The Wildflower Center at UT Austin and UW
Date: 11.26.2011
Reference: http://buildcarbonneutral.org

Consensus: No
Implementation: Possibly
Tested by team: Yes
LCA Scope: A4-5

Description

The Build Carbon Neutral Calculator is a simple to use, online calculator that requires the user to input data into only nine fields. Any building could use it for a quick estimate of its net carbon footprint. The description as excerpted from the website states:

> *The Construction Carbon Calculator estimates embodied carbon. This calculator looks at an entire project, and takes into account the site disturbance, landscape and ecosystem installation or restoration, building size and base materials of construction. It does this simply, requiring only basic information that is available to a project team very early in the design process. The calculator provides an estimate that establishes a base number to clarify the carbon implications of the construction process - to be used as tool to address the reduction of that footprint. The value of the building carbon model will increase through user input and more data sets. The base model takes the overall building square footage and divides it evenly between floors.*

Of note, this calculator provides methods to account for the impact of landscape disruption and planting as well as operational impacts in a relatively straightforward manner.

Analysis

Of the nine input fields, five are user-supplied square footages, three are drop down menus and one is a multiple choice. There is a plethora of information about the data on the site, tool development references, and the reasons assumptions were made. The primary benefits of this calculator are the relative ease of use and simplified methodology. It is not being developed or maintained. This calculator is not a whole building LCA tool.

As assessed on the project website:

> *The Calculator's estimation demonstrates the role of the immediate landscape in the site carbon footprint and how it should be considered in the whole site design. The results you obtain will be estimates and approximate - accurate within 25%, plus or minus.*

CostLab

Organization: Whitestone Research
Date: 11.26.2011
Reference: https://secure.whitestoneresearch.com/products/view/CostLab-Level-1

Consensus: No
Implementation: No
Tested by team: No
LCA Scope: B1-7

Description

CostLab is an online facilities cost tool targeted for real estate property holders to estimate the life cycle costing of operations, repair and maintenance decisions. Whitestone Research supplies all of the data for cost analysis and benchmarking. This model takes into account operation costs ranging from custodial supply and labor to energy use to security to water/sewer and so on. It does not analyze environmental impacts associated with these operations.

Analysis

This tool provides only operation cost analysis, not environmental data.

Green Footstep

Organization: Rocky Mountain Institute
Date: 11.16.2011
Reference: http://greenfootstep.org/

Consensus: No
Implementation: Possibly
Tested by team: Yes
LCA Scope: A5, B1-6

Description

Green Footstep has been developed by RMI to evaluate the built environment with regard to "carrying capacity." It can be used as a "common language" between architecture, urban and transport design, and ecology. It is a very simple online tool to assess a design's total carbon footprint due to site development, construction, and operations. It can also help stakeholders to set emissions targets, especially if the building is designed for certifications or other goals. This tool does not weigh a building's design against a baseline building.

Green Footstep accounts for carbon emissions three ways: Site Development, Construction, and Building Operations. Users will find it a simple calculator to navigate. It does not require a lot of technical input. The metric typically most familiar to users will be the project cost. Green Footstep will use LCA EIO (Economic Input/Output) to convert project cost to emissions produced.

The results aim to show the user a path to a carbon neutral building. It will calculate the amount of carbon offsets needing to be purchased to achieve this goal through on-site or off-site renewable energy sources.

Analysis

Green Footstep guides users through steps asking for a minimal amount of technical information. With most steps, pull-down menus accompany the entry field. There are also easy to access information tabs that provide explanations. Even though the calculator's interface has a simplistic nature, all of the calculation data is available through the website.

Because Green Footstep takes into account site development, construction and operations, it is a unique tool to help understand a building's carbon footprint. The resulting delivered analysis is very thorough and accurate in these areas. However, it does not yet take into account individual building materials, environmental impacts or transportation. The user can input this data, but it must come from another source, i.e. Athena Impact Estimator.

Sustainable Minds

Organization: Sustainable Minds, LLC
Date: 11.15.2011
Reference: http://www.sustainableminds.com/

Consensus: No
Implementation: Possibly
Tested by team: No
LCA Scope: A1-3, B1-2, B5-6, C1-4, D

Description

The following information was attained via *Comparative Case Study in Life Cycle Assessment Modeling Software for Buildings,* Erin Moore and Eva Peterson, University of Oregon, pgs 6&7 (2012).

Sustainable Minds is designed as a product and process LCA tool. It has a limited amount of data that can be used for buildings; mostly this would be on a materials level. The company is currently partnered with Autodesk, presumably to augment its visibility and development. Sustainable Minds is designed as a comparison tool, so copying and creating alternative scenarios is easy. It asks the user to set up a baseline scenario, which acts as a reference throughout a new project design or redesign. This tool is meant for internal comparisons only; a full LCA, such as those needed for some types of marketing, would likely be done after final design is complete. Sustainable Minds is a web-based program; therefore, the user can access his/her models from any computer. There are very comprehensive web-based teaching and support services included. The program is designed for use only in North and South America, Asia, and Australia, not in Europe. This tool includes data aggregated from a variety of sources—NIST, US EPA, Franklin US LCI, Ideamat, US Ecoinvent 2.0.

Analysis

Data must input as weights of each material, so completing a material takeoff before using Sustainable Minds is necessary. It uses its own list of ten impact indicators that they say is based on TRACI: acidification, ecotoxicity, global warming, ozone depletion, water eutrophication, fossil fuels, human respiratory, human carcinogens, human toxicity, and smog. Sustainable Minds seems to emphasize the single number impact factor more than the midpoints listed above. (Moore & Peterson, 2012)

Building Environmental Assessment Tool (BEAT)

Organization: Danish Building Research Institute (SBi) - Aalborg University, the Netherlands
Date: 11.11.2011
Reference: http://www.en.sbi.dk/publications/programs_models/beat-2002

Consensus: No
Implementation: Possibly
Tested by team: No
LCA Scope: N/A

Description

BEAT 2002 (Building Environmental Assessment Tool) is software tool developed by the Danish Building Research Institute at Aalborg University. Born from energy modeling applications, it has grown to be fully capable of whole building life cycle assessment. It contains three elements: an integrated LCI database, an interface tool to manipulate that database and an inventory tool allowing the user to run calculations to various outputs. The user can adjust the database interface to his or her common units, allowing for a more customized experience. The programs can calculate up to six scenarios at once, giving the user an understanding of material choice.

Analysis

The database is built from information attained from Danish companies including product and transport data. The outputs are similar to other LCA tools. Based on the amount and specificity of the input data, BEAT 2002 can be very detailed. The status of the program's availability is unknown at this time. It is also unknown if it has been or will be developed any further beyond this 2002 version.

BeCost

Organization: VTT Technical Research Centre of Finland
Date: 11.27.2011
Reference: http://virtual.vtt.fi/virtual/proj6/environ/ohjelmat_e.html

Consensus: No
Implementation: No
Tested by team: No
LCA Scope: A2-5

Description

From the VTT website:

> *BeCost is a web-based tool for life cycle assessment of building structures and for the whole building. It includes environmental profiles, costs and maintenance costs of building materials produced in Finland, structures for designing exterior and interior walls, roofs, floors, etc., material quantity calculations, environmental profile calculations for the designed structure, and results that are plotted environmental profiles (emissions), energy- and raw-material use, and cost impact for the structure and whole building.*
>
> *BeCost is easy to use. The user first defines the building by making relevant material and structure choices, giving quantities in square meters and by choosing the service life of the building. This is done to examine the ecological effect of building choices related to materials used and service life of the whole building (designer and constructors use). It is also done to verify environmental characteristics' fulfillment, if such has been demanded (designer use) and for owners to examine their building's environmental profiles (owner use). Also for checking the affect of care, maintenance and repairing actions on the environment, comparing environmental profiles of structures having the same functional units, and comparing environmental impacts of produced- and competing materials in certain structure or building (use of building material producer).*

Analysis

BeCost is no longer being granted licenses, nor is it being updated. It was developed prior to BIM becoming the technology of choice for the industry, and the interfaces were not compatible. They chose to not re-engineer the software and instead have taken the base knowledge to two other LCA tool developments. Neither of these has yet to be released (per email correspondence with developers).

Boustead Model

Organization: Boustead Consultancy Ltd.
Date: 11.16.2011
Reference: http://lca.jrc.ec.europa.eu/lcainfohub/tool2.vm?tid=186

Consensus: No
Implementation: Possibly
Tested by team: No
LCA Scope: Info not available at this time

Description

From the European Commission, Joint Research Centre website:

> *The Boustead Model is a self-contained database and software application, which enables the user to construct full life-cycle inventories for virtually any process situated anywhere in the world. The database that accompanies the application is a large, open and fully-editable inventory database. Like all previous versions of the Boustead Model released over the last ten years, version 5.0 includes new features requested by Boustead Model users. This fact, coupled with our considerable LCA experience gained over the last 34 years, makes the Boustead Model one of the most detailed, yet relevant and easy-to-use LCA tools currently available.*
>
> *Besides determining inventory datasets, the Boustead Model also offers automatic global warming (GWP) calculation. The global/regional environmental effects module features a tool with the ability to aggregate air emissions, water emissions and solid waste emissions on a national, regional or a global basis and the airborne acidification analysis now has historical precipitation data for 2300+ locations worldwide.*
>
> *The Boustead Model database and software are aimed primarily at educational users (both in teaching and research), large companies or companies who manufacture a large number of different products, technical trade associations, government agencies and consultancy firms requiring an LCA capability.*

Analysis

According to the European Commission's Joint Research Center's website for LCA tools, Services and Data, the Boustead Model can be used as a tool for calculating lifecycle assessment using its proprietary database. The research team was not able to gain access to either for evaluation. Reviews indicate that the data modules for energy carriers, fuels production, transportation and others are extensive. Individual process, segment, and complete product data are included for common process operation segments and commodity materials manufacturing subsystems. There are approximately 13,000 individual unit operations in the database, making it one of the most extensive in the world. The model has recently been updated to its fifth version.

Eco-Quantum

Organization: IVAM Research and Consultancy on Sustainability
Date: 11.09.2011
Reference: http://www.ivam.uva.nl/index.php?id=373&L=1

Consensus: No
Implementation: Possibly
Tested by team: No
LCA Scope: A2-3, A5, B2, B4, C1

Description

Eco-Quantum was developed by the Dutch research and consultancy agency, IVAM. Part of their ongoing work is in "chain management," meaning managing the supply chain of materials for building construction and operation. The Eco-Quantum tool was designed for use by designers, architects and engineers, and commissioners, owners and operators who want to set criteria for operational use. Included in Eco-Quantum is the VO tool, which is to be used in early design phases to guide selections, while Eco-Quantum is meant to assess the whole design once finished. IVAM is looking for this tool to be used to help comply with the new Energy Performance Certificate (EPC) scheme, which is due to replace the EU Directive on the Energy Performance of Buildings (DEPB). The input device is an Excel-based form of data entry with embedded calculations. The impact categories addressed can be extensive. The user can choose to reduce that number to show the impact of a few specific criteria such as Human Health criteria or Acidification potential. The LCA data output is compliant with ISO 14040.

Analysis

As of December 2011, Eco-Quantum will no longer be offered. It is being replaced (mainframe, interface, databases, calculation processes) by two other tools that are being used in conjunction with Dutch national, green building state directives (Dutch Building Decree 2012). Those tools, GreenCalc and GPR, come out of the Dutch extension of BREEAM-NL and IVAM.

EcoSoft

Organization: IBO (Austrian Institute for Healthy and Ecological Building)
Date: 11.22.2011
Reference: http://www.ibo.at/en/ecosoft.htm

Consensus: No
Implementation: Possibly
Tested by team: No
LCA Scope: A1-5, B1-5, C1-2, C4, D

Description

ECOSOFT is a software tool for the ecological assessment of structures and whole buildings. Per the IBO website, the basis of the tool is the IBO building materials database that is "constantly updated and extended." It is already used for the green building elements catalog, which they provide.

The ECOSOFT building materials database is based on the IBO building materials database and currently comprises more than 500 building materials (guide values in Eco Soft terminology). At present, ECOSOFT is delivered with the IBO building materials database 2008. There is no information available as to when that may be updated. All processes leading to the ready-for-delivery product (single materials or a whole building) are taken into consideration. For every process step, material, transport and energy inputs as well as emissions into air, soil, water and waste are determined. The calculations for the building material assessment are carried out with the program SimaPro based on CML2 Baseline 2001.

Analysis

Based on the final report, *Inter-comparison and Benchmarking of LCA- Based Environmental Assessment and Design Tools* (Peuportier & Putzeys, 2005), ECOSOFT is a program for the ecological assessment of built structures and buildings on the basis of the eco-indicator, OI3. OI3 is a measurement indicator corresponding to one square meter (a functional unit for calculation) in terms of "points." These OI3 points make the addition and subtraction of materials easier for users to understand. ECOSOFT is based on the MS Office application EXCEL and was developed by the IBO, the Austrian Institute for Healthy and Ecological Building.

Envest 2

Organization: BRe Global
Date: 11.07.2011
Reference: http://envest2.bre.co.uk/

Consensus: No
Implementation: Possibly
Tested by team: No
LCA Scope: A2, A3-4, B1-4, B6, C1-2, C4 (are expressly mentioned, others possible)

Description

Envest 2 is owned, distributed and developed by BRe Global. Envest 2 is an online tool that allows the user to model the environmental and whole life costing impacts through the construction and operation of a whole building over a specified time period. It has the ability to show environmental and financial tradeoffs to further optimize the conditions per the user. The user creates a building within the tool by first designating the shape, dimensions and general details about the building and then adds detail by assigning materials to each building element. The results are displayed as totals for the whole building and are broken down in several ways by showing which elements of the construction contribute the highest impacts as "Ecopoint" scores and by the reference units for each environmental impact category.

The Estimator and the Calculator versions of the tool work in similar ways. The building model is built up in exactly the same way for both. The Calculator version allows you to enter your own values for the whole life costing scenarios, whereas the Estimator uses generic compiled data. All environmental and financial data can be supplied by the user to customize the data output while being more specific their location and materials. It is also web-based to allow users the ability to store data externally and to have remote access.

Analysis

There are a number of ways in which designers can use the tool, which performs a variety of functions. The designer can use Envest 2 to make comparisons between different buildings and specifications and to graphically illustrate the different environmental impacts of various design options to clients. All environmental impacts are measured using a single point scale called Ecopoints, allowing designers to make direct comparisons between different designs and specifications (*Building Energy Software Tool Directory*, accessed October 28, 2011, http://apps1.eere.energy.gov/buildings/tools_directory/software.cfm/ID=267/pagename=alpha_list_sub).

According to the developers, Envest2 is not moving forward at the moment due to the development of another LCA tool based on some of the same platform.

Environmental Agency Carbon Calculator for Construction Activities

Organization: Environment Agency, UK
Date: 11.27.2011
Reference: http://www.environment-agency.gov.uk/business/sectors/37543.aspx

Consensus: No
Implementation: Possibly
Tested by team: Yes
LCA Scope: A4-5

Description

From the Environmental Agency website:

> *The carbon calculator is an Excel spreadsheet that calculates the embodied carbon dioxide of materials plus the carbon dioxide associated with their transportation. It also considers personal travel, site energy use and waste management. It is built to help users make decisions on the sustainability of construction activities. This tool helps assess and compare the sustainability of different designs, in terms of carbon dioxide and influences option choice at early design stages. It helps to highlight where significant carbon savings can occur. It can also be used to calculate the total carbon footprint from construction. The tool was developed with river flow and coastal construction projects in mind; however, other designers, contractors and consultants may find it useful when assessing their own activities.*

Analysis

The Carbon Calculator has a fair amount of flexibility and provides good information to the users. The amount of data input options gives the user ample opportunity to vary their design to gage relative impacts associated with a particular material. The programmers acknowledge the inherent uncertainty in the data and give users the warning of an accuracy of +/- 25%. These uncertainties are not factored in with any weighting scheme. The programmers instruct users to use this tool as an internal comparison tool to understand a relative magnitude of impact from one material choice to another. The means of extrapolating a total carbon footprint is simply a tally of the carbon embodied in the choices the user selects. This also means that the data will not be substantiated enough to stand in as a declaration of the carbon footprint.

From a user's perspective, the spreadsheet is easy to navigate and input options are well explained and straightforward. The user is expected to do all of the quantitative work up front by doing takeoffs for all materials to be entered and gather transport data. In the case that data is not known, the user can opt to allow the spreadsheet to enter default data that is based on the region and other construction duration factors.

Equer

Organization: Ecole des Mines de Paris/ Izuba Energies
Date: 11.07.2011
Reference: http://www.cenerg.ensmp.fr/english/logiciel/indexequer.html

Consensus: ??
Implementation: Possibly
Tested by team: No
LCA Scope: A3, B1, B5-7, C1

Description

Equer is developed by the Center for Energy and Processes in Paris. Izuba Energy, an engineering company, built the user interface, which is currently only available in French. As a LCA tool, it considers all phases of a building's lifecycle, cradle to grave, plus it can include the building's operational energy use. Operational energy use is calculated from data and duration input by the user.

The manner of user input is in the form of a building model. A building project is first modeled using Alcyone, a 3D graphical tool. The composition of walls, floors, ceilings, etc. is provided by the user's input. The graphical tool exports data to the thermal simulation tool and to the LCA tool, so that material quantities are calculated in the LCA tool. The user gives a surplus percentage corresponding to material losses on the building site (e.g. concrete surplus, broken tiles, etc.) (personal communications with Bruno Peuportier, November 8, 2011). The impact categories that are defined by Equer are: exhaustion of abiotic resources, primary energy consumption, water consumption, acidification, eutrophication, global warming potential, non-radioactive waste, radioactive waste, odors, aquatic ecotoxicity, human toxicity, and photochemical ozone.

Analysis

Equer is currently used by approximately 200 architects, contractors and consultants, with another 2,000 using the accompanying thermal comfort software, COMFIE (personal communication with Bruno Peuportier, November 8, 2011). It is a simplified LCA program, so high levels of knowledge of LCA are not required for use. A Swiss database, Ecoinvent, and a French database, Inies (collected in the European REGENER project) are used for material fabrication and other processes (energy, water, waste, transport) for program input. The REGENER project was also developed through the Ecole des Mines de Paris, where Equer was developed. The developer acknowledges that there is uncertainty in this field, and therefore recommends this tool not as a method of material selection, but rather as a tool to improve technical solutions.

GreenCalc+

Organization: Sureac Foundation and BREEAM
Date: 12.15.2011
Reference: http://www.greencalc.com/

Consensus: No
Implementation: Possibly
Tested by team: No
LCA Scope: A1, A3, A5, B1, B6-7

Description

GreenCalc+, as it is known, is a tool to show the “hidden costs” of building. This is their term for the negative environmental impact associated with construction and its building materials. It measures how much money it would take to remediate and prevent the adverse effects of pollutants due to construction activity. In their view, “preventing damage is the best way to sustainable development.” It takes into account not only environmental costs but also social costs. These factors are “add ons,” like extra percentages for costs above and beyond. It address up to 17 environmental indicator categories, four categories of human health factors and five land use categories.

The latest news (May 2011) on GreenCalc+ is that, in the future, it will be developed by and for BREEAM as a new tool called BREEAM Light.

Analysis

GreenCalc+ is intended to combine materials, energy and water into a single numerical index called the MIG or the Environmental Building Index. Buildings computed through this program will come out with a single numeric score ranging from 0 to 750+, with 0 being a badly performing building. MIG compares buildings against a 1990 baseline at 100 points. Buildings above that are better performing and below are not as well performing. GreenCalc+ displays the buildings’ score in terms of three “modules:” materials, energy and water. (per email with research lead)

GPR

Organization: City of Tilburg and W/E Consultants
Date: 12.15.2011
Reference: http://www.gprgebouw.nl/english/index.asp?id=2&sid=0

Consensus: No
Implementation: Possibly
Tested by team: No
LCA Scope: A2-3, A5, B2, B4, C1

Description

Per GPR's website:

> *GPR is a software tool which quantifies the environmental impact and the design quality for new buildings as well as for the refurbishment of existing buildings. It is suitable as a decision making tool as it helps to find an optimum between the reduction of environmental load along with improvement of the quality of the building. Thus, a building is rated for several themes on a scale of 1 to 10.*

GPR is similar in composition and functionality to Greencalc+. Like Greencalc+, it has "modules" that provide the ranking scores. Those modules are energy, materials, water, waste, health and living quality. The version for existing buildings also has a module for "Future Value." The information entered into this module requires current values (before renovation) and future values to represent an increase in performance.

Analysis

GPR uses the modules to define a single environmental building score. Each module has a range from 1 to 10. At the project's beginning, the designers set a desired "ambition" or level of achievement. As design progresses, the team can enter updates to material or system information, and the program will ascertain if the target ambitions are on track, satisfied or have more to go.

GPR is developed to assist architects and owners in compliance with the Dutch building directive EPBD. The engineers that update internal protocol can modify the programing to meet specifications for other countries' legislation upon request.

Two versions are currently available. Version 3.2 is for new construction and 1.0 is for existing buildings. It is currently in beta phase.

Organization: BRe Global and Integrated Environmental Solutions (IES)
Date: 08.08.2012
Reference: http://www.impactwba.com

Consensus: No
Implementation: Possibly
Tested by team: No
LCA Scope: A,B,C,D

Description

IMPACT (Integrated Material Profile And Costing Tool), "allows construction professionals to measure the embodied environmental impact and life cycle cost performance of buildings. IMPACT is integrated into 3D CAD/BIM (Building Information Modeling) software tools." It was released as Phase I in March of 2012. It is being developed by a consortium led by BRe Global and IES. IES, the software developer, has created IMPACT plug-ins to be integrated with Revit, Sketchup and Trelligence Affinity. These plug-ins are modules that can be installed individually (i.e., Carbon/Energy, Solar, Lighting,etc.) or as a suite. Phase II (available beginning October of 2013) will open up development of plug-ins to other software developers worldwide.

Built upon the BIM platform of design, the basic functionality is to assign material components (possibly Families in Revit) values that can be extrapolated and compiled in real-time as the model is built virtually. These assigned values is NOT user derived but directly linked to an "integrated" database. Per IMPACT's website, the software and database cannot be separated as their functionality depends on their being linked. This is to say that it appears that the user cannot add additional databases, such as EcoInvent, to the software, nor use the IMPACT database for another program. It is unclear what the 'database' is or where it comes from. There is no indication at this time that they are using any other database than their own. IMPACT is being based on the 2008 version of BRE Environmental Profiles Methodology. This is an update over the 1999 version, which Envest 2 is built upon. The 2008 Methodology is designed to be ISO 14040 and 14044 compliant.

Analysis

Based on the information provided on their website, IMPACT promises to be a potential break-through tool in the arena of LCA. Depending on the data related to the forms created in the building's design, the design team could in real-time be able to evaluate the building's environmental profile including carbon footprint, waste stream and other relevant associations. Per their website, this tool will use ISO compliant data thereby creating a data stream that is compliant to international standards. In addition to LCA, it also offers life cycle costing data (LCC), which could be appealing to many users. The tying together of LCA and LCC could be a boost for environmental profiling on a much larger scale. Other environmental issues will be available for reporting in IMPACT including waste, resource use and toxicity.

All information sourced from IMPACT's website and personal communications with BRe personnel.

LEGEP

Organization: Ascona Koenig, Germany
Date: 11.21.2011
Reference: http://www.legep.de

Consensus: No
Implementation: Possibly
Tested by team: No
LCA Scope: A3, A5, B1 -7, C1

Description

LEGEP is a tool for integrated life cycle analysis. It supports the planning teams in the design and construction of new and existing buildings or building products. It is used as a tool to provide information to designers regarding several DIN (German Standards and Regulations). Information is structured along lifecycle phases, construction through demolition. LEGEP is used to establish energy needs for the building design and their costs.

A building can be described using either pre-assembled elements or by defining elements from scratch. The user can also define a specific composition by exchanging layers or descriptions of the element. The advantage of the top-down approach is its completeness: if an element is not explicitly changed or eliminated it will remain in the calculation. This corresponds to an increase in applicable knowledge during the design and planning process. It allows the building to be described in more detail without losing the overall framework. At each level (lifecycle), a complete evaluation can be made and documented automatically.

Analysis

LEGEP is organized along four software tools, each with an individual database. The method is based on cost planning by "elements". Elements at each level contain all necessary data for cost, energy, and mass-flow and impact evaluation. The costs of the elements are established by the SIRADOS database, which is published each year. There are about 6,000 elements "ready for use" for the building fabric, technical equipment and landscape work.

At present, LEGEP is used mainly for the design of newly built buildings, taking into account the future life cycle. The information is "highly appreciated" by clients and facility managers in that it presents to them a future value for their investment. For existing buildings, LEGEP assists in the decisions on refurbishment operations and the long term, sustainable management of buildings and building stocks. The information in this section was gathered from the LEGEP website listed above.

Researchers using this tool are currently collecting data for diverse examples in attempts to establish baseline ranges (Lutzkendorf et al., 2012).

Low Carbon Building Method (LCB Method)

Organization: Guillaume Fabre at LCB Method
Date: 11.15.2011
Reference: http://www.lcbmethod.com/

Consensus: No
Implementation: Possibly
Tested by team: Yes
LCA Scope: A1-5, B2-3, B5, C1-4, D

Description

LCBM is a "simplified" methodology for estimating GHG emissions resulting from a building's construction. It is a calculating spreadsheet that builds emission data for the construction phase, reuse/deconstruction phase and renovation. The free online spreadsheet is accompanied by a $24 downloadable e-book (also available in hardcopy) that has expanded definitions for the emissions equations, a glossary of terms, and the database of emissions factors related to the material chosen.

This tool is built and promoted for architects, engineers, construction managers, owners, or "anyone interested in low carbon buildings" across the design and construction industry. It is built to handle all building types, as well as residential, commercial, industrial, interior design and infrastructure project types. It has factors for durability of materials, though it only accounts for cradle to gate conditions, not the operational life.

The process of evaluating a building is threefold. First, the user inputs the data for the building as designed. The tool then shows the quantity of emissions. Second, a baseline or target building is built, to which to compare your building's data. Third, the program identifies the areas where savings are most needed, accessible and affordable.

This tool is built on compounding data through material weight. The use of weight in this case equalizes all materials, where normally quantities would be presented in a variety of different units. LCBM is built on PAS 2050, a Publicly Available Specification (PAS), not on ISO 14040.

Analysis

LCBM's emissions database has over 500 factors for different building materials. The database is "open" so that any producer can pass along their data to make the database more robust. The spreadsheet has a default limit of 45 materials per building. It allows the user to input a dollar amount for purchase of a unit of carbon offset and will show a total cost to purchase offset for the whole building to become 'carbon neutral'. This package also contains a "Material Comparator" to help the user choose between two materials.

TEAM

Organization: EcoBilan (EcoBalance in US)
Date: 11.12.2011
Reference: https://www.ecobilan.com/uk_team.php

Consensus: No
Implementation: Possibly
Tested by team: No
LCA Scope: A1, A2-5, B1-7, C1-4 (are expressly mentioned, others possible)

Description

TEAM is developed by Ecobilan (known as Ecobalance in US) of France, a technical advisory group to industry and the government on the environmental performance of products and services. They have specifically used their expertise to assist in making, distributing and disposing of products in a more environmentally friendly manner across the EU. Ecobilan has created software that is able to catalog the bill of substances within a product. This bill passes first through their inventory check and then through their impact assessment to give the client an understanding of that product's impact. Their inventory is an in-house collection of data called Data for Environmental Analysis and Management (DEAM). A starter module of DEAM is integrated with TEAM, their major tool for the life cycle assessment of products and processes. Though it is not targeted directly at building assessments, it has the ability, possibly better than other programs, to fully understand the impacts associated with the individual building materials. In this aspect, this tool can be very powerful.

Analysis

> *Selecting and defining inputs and outputs within the lowest process/unit level is quite simple using the tool bar; flows may be defined by values or variables and equations. TEAM allows the user to build and use a large database and model any system representing the operations associated with products, processes, and activities.*

Excerpt from *AIA Guide to Building Life Cycle Assessment in Practice*, Dr. Charlene Bayer, Michael Gamble, Dr. Russell Gentry, & Surabhi Joshi (2010), pg. 88.

Umberto

Organization: IFU Hamburg
Date: 11.15.2011
Reference: http://www.umberto.de/en/

Consensus: No
Implementation: Possibly
Tested by team: No
LCA Scope: A3, A3, B1, B5-7, C1

Description

Umberto is developed by the research consortium, Institute for Environmental Informatics (IFU) in Hamburg, along with the Institute for Energy and Environmental Research (IFEU). Based on the concept of material flow networks, the calculation algorithm of Umberto allows the user to determine all material and energy flows in the system under study. The user can define the system boundaries and can analyze the flows by "zooming" into the hierarchical model and the desired level of detail. Material and process costs can be entered to calculate cost balances, adding financial perspective to the inventory, and thus supporting the decision making process. Umberto is currently developed to be PAS 2050-compliant and is targeted to be ISO 14067-compliant when it is released.

Analysis

Both site/process-oriented as well as product-related analyses are possible. Different technology alternatives can be compared by scenario comparison. Results can be displayed as tables or diagrams. The user can assess the results with individually defined key indicators or apply environmental impact assessment methods (such as the Eco Indicators) to study the environmental performance of a process system. Umberto is a planning and control refinement program.

Analysis information gathered from *Building Energy Software Tool Directory*, accessed October 28, 2011, http://apps1.eere.energy.gov/buildings/tools_directory/software.cfm/ID=267/pagename=alpha_list_sub

LCADesign

Organization: Ecquate Pty Ltd and The Cooperative Research Centre for Construction Innovation, Australia
Date: 11.29.2011
Reference: http://www.ecquate.com/index.html

Consensus: ??
Implementation: Possibly
Tested by team: No
LCA Scope: N/A

Description

LCADesign is a whole building LCA software project developed by the Cooperative Research Centre for Construction Innovation (CRCCI) in Brisbane, Australia. It is a BIM-style user interface where a building model is imported from another program. It accepts models from any program using an IFC 2.3 standard. It calculates the volume and surface area of every structural element in the building by "tagging" them within the model. This software provides a quick environmental assessment of a building by automating the arithmetic of LCA. The operational estimates are also entered by the user. This way, the environmental impact of every element is assessed and made available for analysis in any number of combinations.

Per the Ecquate website:

> *LCADesign offers objective results for clients to assess and compare their building, fitout and product design, procurement, supply, tenders and bids. It provides dimensionally relevant measures for new and existing commercial, residential, industrial and infrastructure development. Users can select one eco-indicator point-score or up to seventy other impact measures including details of climate change, human and ecosystem health, and resource depletion. LCADesign also assesses energy and water use impacts of building operations.*

Analysis

LCADesign is currently not available, as it has been pulled from the market to resolve some performance issues. However, based upon information on their website including demonstration videos, LCADesign has a great potential for use throughout the architectural and engineering design industry because of its integrative qualities into BIM.

LCAid

Organization: NSW Dept. of Public Works & Services/ University of Western Australia
Date: 11.07.2011
Reference: http://buildlca.rmit.edu.au/CaseStud/Buxton/BuxtonPS_LCAid_use.html

Consensus: ??
Implementation: Possibly
Tested by team: No
LCA Scope: N/A

Description

LCAid is developed by DPWS through the University of Western Australia's Department of Architectural Sciences. LCAid gives a whole building life cycle assessment including the operational phase. LCAid assists environmental decision making in the initial phase of building design and provides a benchmark of building performance. With LCAid, users can quickly provide input to the design process during a design charette. The program allows for a fast assessment of the design solutions that the charette generates. LCAid can be linked to CAD files, can read model files from the extensive Boustead life-cycle inventories database, and has a template for data to be entered from other LCA packages. The program reports results in two ways: it compares the proposed design to a benchmark building, and it presents the environmental impacts of the design, thus identifying the life-cycle stages that make the greatest contribution to a building's overall environmental impacts (*Sustainable Building*, Apr 2001, p 38, by Zig Peshos and Murray Hall, accessed through www.greenclips.com/01issues/180.htm, on October 27, 2011).

Analysis

The team could not locate this tool or anyone associated with it. From the limited results data available, LCAid reports the environmental impacts of a building in two different ways. First, the environmental performance is determined by comparing a design to a benchmarked building. Second, it identifies the environmental impacts for a design at each stage of the building's life cycle, producing bar graphs of information. It is able to compare up to five building options at once.

We are not sure if this tool is still available as attempts to contact the researcher were not responded to.

LCA in Sustainable Architecture (LISA)

Organization: BlueScope Steel & University of Newcastle
Date: 11.14.2011
Reference: http://www.lisa.au.com

Consensus: Yes
Implementation: Possibly
Tested by team: No
LCA Scope: A1-5, B1-7, C1-4, D

Description

LISA is an Australian tool that was developed "in response to requests by architects and industry professionals for a simplified LCA tool to assist in green design." The outputs are meant so that the user can focus on the key environmental issues as opposed to an exhaustive LCA report. It was commissioned by the BlueScope Steel Corporation, a division of BHP Billiton, a large steel producer in the Oceania region. The data used in its inventories comes from the UK, Sweden, Australia and global steel averages.

Analysis

LISA is considered a decision support tool demonstrating the emissions outputs at any stage. Data is represented in graphical and tabular forms. LISA is a free download via their website.

Given that the website has not been modified since 2003, it appears that this research project is no longer being supported.

X7 Research

X7.1 Introduction

Research related to LCA and building materials and construction can be categorized into two primary categories: (1) Research into the methods and standardization of LCA, and (2) research that uses LCA to evaluate building materials, products and/or complete buildings. We have organized our review of LCA research accordingly and have focused our assessment on research related to methodologies to implement LCA into regulatory frameworks, and that related to design and construction practice based LCAs.

Additionally, an overview of select building industry specific LCAs is provided with both an overview of their content (materials, region, ISO compliance and LCA scope) and a brief synopsis of the report conclusions.

This is not an exhaustive review of all published LCAs but rather a selection of LCAs, many of which were submitted to us for review by stakeholders.

X7.2 Research: Implementing LCA

Typically, designers and regulators looking to reduce the environmental impacts of buildings have focused on reducing the operating energy use of buildings. Many LCA studies that include all life cycle phases of buildings show that over a typical life span, the operational impacts represent 70-90% of the total impacts, which supports this focus. However, with increasing energy efficiency and on-site generation, net-zero operational energy buildings are becoming more common. Thus, the impacts of materials, construction and demolition become relatively more significant. Policy makers and industry non-profits (Architecture 2030, USGBC, Governments of France, Germany, Switzerland, Netherlands & Washington State) are beginning to look to LCA as a method to track and reduce the environmental impacts of materials and products used in the built environment.

Relevant US codes and ratings systems are either still developing (USGBC) or were published in 2011 & 2012 (ASHRAE 189.1, IgCC). We have identified little significant research that studies or tests these methods. Joshi (2009) provides an overview of LCA tools at the time and outlines seven different scenarios to help identify the different potential users of LCA tools. Additionally, this report provides case studies of LCA used in design and construction practice. Studies that reference the recent standards have been limited to reports on the state of code development and encouragements towards integrating LCA to improve the 'Rational Framework' for evaluating green building construction (Contreras, Roth, Lewis, 2011 & Simonen, 2011).

Research is being undertaken to test simplified methods of integrating LCA into construction practice (Malmqvist et al, 2010, Lasvaux et al, 2012a&b, Ventura, 2012, Kohler, 2012). Additional research is needed to test the validity of simplified methods when used to implement LCA standards in practice. Case studies of practice based LCA analysis have been reported (Annemans, Verhaegen & Debacker, 2012).

In order to implement LCA in practice, a harmonized and more complete US LCI database would be of great value.

More established regulations in both France and Germany have prompted the development of research projects that attempt to develop whole building LCA benchmarks (Lutzkendorf, Kohler and Konig, 2012, Lebert, et al, 2012). Of particular note is the French HQE study in which 74 buildings (20 single family residences, 19 multi-family residences, 21 office buildings and 14 academic or research buildings) were assessed during the design process using the building LCA software Elodie developed by the French research organization CSTB. In this study, the LCA efforts were simultaneously checked by LCA experts and the time and difficulty of implementation were recorded. A summary of this research was published in English (HQE, 2012). This study would be an appropriate model to use in formulating a study to assess the implementation impacts and benefits of integrating LCA into the Washington State building code.

X7.3 Research: Building Industry Specific LCAs Overview

The following section provides a sampling of building industry specific LCAs as identified by the research team and stakeholders as of early 2012. This is not comprehensive of all building industry specific LCAs and some of the work listed here is not yet finalized. Given the variability in LCA methods and building construction, great care should be taken when attempting to use the results of a specific LCA to make generalized conclusions for the building industry as a whole.

X7.4 Research: Summary of Select Building Industry LCAs

Name	Description	Research Sponsor	Primary Materials	Location	Peer Reviewed	ISO Format	LCA Scope Addressed
AISC 2010	LCA steel and concrete office building comparison	AISC	S, C	U.S.	N	Y	A & C
AISI 2000	Galvanized Steel Production for Residential Construction - Life Cycle Stressor-Effects Assessment	Steel Recycling Inst., AISI & US Steel	S	U.S.	Y*	Y	A & C
Akbarian et al. 2011	LCA for concrete pavement	PCA	C	U.S.	Y	Y	A,B,C,D
Alvarez 2007	The of state America's forests - overview of efforts and achievements	Society of American Foresters	W	U.S.	N	N	n/a
Athena 2002	LCI update of US and Canadian Steel Production (updated)	Athena Institute	S	CAN /U.S.	N	N	A & B
Bayer et al. 2010	AIA Guide to Building LCA in Practice	AIA	n/a	U.S.	N	N	n/a
Bergman et al. 2010	Environmental impact of manufacturing softwood lumber in northeastern and north central United States	CORRIM	W	U.S.	?	Y	A,B
Bowyer 2011	Paper delivered to SEAOC Conference identifying flaws in the good intentions of creating more sustainable products	n/a	W, C, S	U.S.	N	N	A,B,C,D
Bowyer et al. 2008	Carbon storage during grow and within product storage should be considered	n/a	W	U.S.	N	N	A & B
Brown et al. 2011	LCA for concrete structures (multiple building types represented)	PCA	C, S, W	U.S.	Y	Y	A,B,C,D
Buchanan et al. 2008	LCA comparison of multi-story buildings built from	NZ Agriculture & Forestry	W	N.Z.	?	Y	A,B,C,D

	different materials						
Carbon Working Group 2012	Carbon and the Structural Engineer: What Structural Engineers Can Do About Climate Change	Structural Engineering Institute					
Cole 1999	Energy and Greenhouse Gas Emissions Associated with the Construction of Alternative Structural Systems	n/a	W, C, S	U.S.	Y	N	n/a
Guggemos and Horvath 2005	Comparison of Environmental Effects of Steel and Concrete Framed Buildings	n/a	S, C	U.S.	Y	N	n/a
Hein 2007	A Life Cycle Perspective on Concrete and Asphalt Roadways: Embodied Primary Energy and Global Warming Potential	Cement Assoc. of Canada	A, C	CAN	N	Y	A & B
HQE 2011	HQE Performance: First trends for new buildings	HQE Association	n/a	FRA	Y	N	A,B,C,D
Hubbard & Bowe 2010	A gate-to-gate life-cycle inventory of solid hardwood flooring in the eastern US	CORRIM	W	U.S.	?	Y	A,B
Johnson et al. 2005	Life-Cycle Impacts of Forest Resource Activities in the Pacific Northwest and the Southeast United States	CORRIM	W	U.S.	?	Y	A,B
Karsell 2011	Taking A Stand for Credible Environmental Standards; presented paper calling for rigor in standards	n/a	n/a	U.K.	Y	N	n/a
Kestner 2010	Sustainability Guidelines for the Structural Engineers	?	?	U.S.	?	?	n/a
Kline 2005	Gate-to-gate Life-Cycle Inventory of Oriented Strand Board Production	CORRIM	W	U.S.	?	Y	A,B
Konig et al. 2010	A life cycle approach to buildings: principles, calculations, design tools	n/a	n/a	DE	N	N	A,B,C,D
Lane 2010	British article highlighting developing tools and	n/a	n/a	U.K.	N	N	A

	standards aimed at embodied energy research						
Lippke et al. 2010	Characterizing the importance of carbon stored in wood products	CORRIM	W	U.S.	?	Y	A,B
Lippke et al. 2005	Environmental Performance Index for the Forest						
Lippke & Edmonds 2006	Environmental Performance Improvement in Residential Construction						
Marceau, Nisbet & VanGeem 2007	Life Cycle Inventory of Portland Cement Concrete	PCA	C	U.S.	Y*	Y	A,B
Marceau & VanGeem 2008	LCA comparison of a concrete masonry house and a wood frame house	PCA	M,W	U.S.	N	Y	A,B,C
Marceau & VanGeem 2007	LCI report containing information on three concrete products: ready mix concrete, concrete masonry and precast concrete	PCA	C	U.S.	N	N	n/a
Martin et al. 2000	Emerging Energy-Efficient Industrial Technologies	US EPA, DOE & Pacific Gas & Electric	n/a	U.S.	N	N	n/a
Milota et al. 2005	Gate-to-gate Life-Cycle Inventory of Softwood Lumber Production	CORRIM	W	U.S.	?	Y	A,B
Murray et al. 2006	Biomass Energy Consumption in the Forest Products Industry	US EIA, DOE & Office of Coal, Nuclear, Electric and Alternate Fuels	n/a	U.S.	N	N	n/a
Natural Resources Defense Council 1998	Efficient Wood Use in Residential Construction: A Practical Guide to Saving Wood, Money, and Forests	n/a	C, S, W	U.S.	N	N	D
Ochsendorf et al. 2011	Methods, Impacts, and Opportunities in the Concrete Building Life Cycle	PCA and RMC Research and Education Foundation		U.S.			
O'Connor 2004	Survey on Actual Service Lives for North American Buildings	Athena Institute	C, S, W	U.S.	N	N	D

Oneil et al. 2010	Life-cycle impacts of Inland Northwest and Northeast/North Central forest resources	CORRIM	W	U.S.	?	Y	A,B
Oneil & Lippke 2010	Integrating products, emission offsets, and wildfire into carbon assessments of Inland Northwest forests	CORRIM	W	U.S.	?	Y	A,B
Perez-Garcia et al. 2005	An Assessment of Carbon Pools, Storage, and Wood Products Market Substitution Using LCA Results						
Perez-Garcia et al. 2005	The Environmental Performance of Renewable Building Materials in the Context of Residential Construction	CORRIM	W	U.S.	?	Y	A,B
Pinto 2011	LCA of steel and concrete construction. Also includes summary of LCA tools for construction industry	Can. Steel Inst, Steel Structures Educ & MITACS Accelerate	S, C	U.S.	N	Y	A,B,C
Preservation Green Lab 2012	The Greenest Building: Quantifying the Environmental Value of Building Reuse	Nat'l Trust for Historic Preservation	n/a	U.S.	Y	N	A,B,C,D
Puettmann et al. 2010	Cradle-to-gate life-cycle inventory of US wood products production: CORRIM Phase I and Phase II products	CORRIM	W	U.S.	?	Y	A,B
Puettmann et al. 2010	Life-cycle inventory of softwood lumber from the Inland Northwest US	CORRIM	W	U.S.	?	Y	A,B
Puettmann & Wilson 2005	Gate-to-gate Life-Cycle Inventory of Glued Laminated Timber Production	CORRIM	W	U.S.	?	Y	A,B
Puettmann & Wilson 2005	Life-Cycle Analysis of Wood Products: Cradle-to-gate LCI of Residential Building Materials	CORRIM	W	U.S.	?	Y	A,B

Scientific Certification Systems 2000	Analysis of Galvanized Steel Production Suitable for Residential Construction Based on Life Cycle Stressor Effects Assessment	n/a		US	Y		
Seo 2002	International review of environmental assessment tools, databases and rating systems	n/a	n/a	AU	Y	N	n/a
Sovinski 2009	Life Cycle Cost Analysis: Fort Lewis Barracks Project	International Masonry Institute		US			
Stadel et al. 2012	Life-Cycle Evaluation of Concrete Building Construction as a Strategy for Sustainable Cities	PCA	C	U.S.	N	N	A & C
Steel Recycling Institute 2009	Recycled content of EAF and BOF steel production methods	Steel Recycling Institute	S	U.S.	N	N	n/a
Stubbles 2007	Both processes of steel making are nearing energy efficiency peak	Steel Manufacturer's Assoc.	S	U.S.	N	N	n/a
Target Zero 2011	A supplemental report identifying paths to zero carbon buildings by 2019	BCSA & Tata Steel	S	U.K.	N	N	A & C
TRADA 2009	Timber Carbon Footprint: Calculated Values	TRADA	W	U.K.	N	N	A & C
Venta 1998	Life Cycle Analysis of Brick and Mortar Products	Athena Institute	M	CAN	Y*	N	A,B
Volz and Stovner 2010	Reducing Embodied Energy in Masonry Construction: Part 2	n/a	M	U.S.	N	N	A,B
Webster 2004	Relevance of Structural Engineers to Sustainable Design of Buildings	?	?	U.S.	?	?	n/a
Weisenberger 2010	The fabricator's role in the overall environmental impact picture of structural steel is shown to be significant in this article	AISC	S	U.S.	N	N	n/a

Wilson 2010	Life-cycle inventory of formaldehyde-based resins used in wood composites in terms of resources, emissions, energy and carbon	CORRIM	W	U.S.	?	Y	A,B
Wilson 2010	Life-cycle inventory of medium density fiberboard in terms of resources, emissions, energy and carbon	CORRIM	W	U.S.	?	Y	A,B
Wilson 2010	Life-cycle inventory of particleboard in terms of resources, emissions, energy and carbon	CORRIM	W	U.S.	?	Y	A,B
Wilson & Dancer 2005	Gate-to-gate Life-Cycle Inventory of I-joist Production	CORRIM	W	U.S.	?	Y	A,B
Wilson & Dancer 2005	Gate-to-gate Life-Cycle Inventory of Laminated Veneer Lumber Production	CORRIM	W	U.S.	?	Y	A,B
Wilson & Sakimoto 2005	Gate-to-gate Life-Cycle Inventory of Softwood Plywood Production	CORRIM	W	U.S.	?	Y	A,B
Winistorfer et al. 2005	Energy Consumption and Greenhouse Gas Emissions Related to the Use, Maintenance and Disposal of a Residential Structure	CORRIM	W	U.S.	?	Y	A,B
*	First trends for new buildings						

Akbarian, M., Loijos, A., Ochsendorf, J. & Santero, N. (2011). *Methods, Impacts, and Opportunities in the Concrete Pavement Life Cycle*. http://web.mit.edu/cshub/news/pdf/MIT%20Pavement%20LCA%20Report.pdf Accessed 08/28/12.

Report from the Concrete Sustainability Hub at the Massachusetts Institute of Technology; sponsored by the Portland Cement Association (PCA) and the Ready Mixed Concrete (RMC) Research and Education Foundation. *The researchers at MIT CSH have, with this paper, created a support device for the evaluation and improvement of concrete pavement through development of a LCA model. To get there, they lay out a LCA methodology describing the concepts necessary to develop and conduct a LCA. They then apply this methodology to gather quantities for study. The paper goes on to give some "best practices" guidelines and estimate potential carbon dioxide reductions, fuel saving and overall cost savings.*

Alvarez, M. (2007). The State of America's Forests. Bethesda, MD: Society of American Foresters.

The forestry industry has shaped the way our national forests have gone for many decades now. This paper summarizes and highlights the ups and down of that management. Specifically it focuses on domestic efforts but also compares the US and North America to the rest of the world.

Athena Institute (2002). "Cradle-to-Gate Life Cycle Inventory: Canadian and US Steel Production by Mill Type", March 2002.

This 2002 ongoing inventory research updates a similar early 90's report. They give overviews of both the US and Canadian steel industries as well as product and process descriptions. The main results of the project are an updated set of inventory inputs and outputs.

Bayer, C., Gamble, M., Gentry, R., Joshi, S., (2010) *AIA Guide to Building Life Cycle Assessment in Practice.* Retrieved at http://www.aia.org/aiaucmp/groups/aia/documents/pdf/aiab082942.pdf

Targeted toward architects, this report is meant as a guide to the use of LCA as an assessment tool in the design process through the identification of scenarios where LCA could be best used. It reviews other literature on the subject, extrapolates on surveys among architects and presents case study documentation. In addition, limitations to the use and integration of LCA as a design evaluation tool are listed and discussed with recommendations provided for overcoming these barriers.

Bergman, Richard D. and Scott A. Bowe (2010). "Environmental impact of manufacturing softwood lumber in northeastern and north central United States." p67-78.

LCI of the gate-to-gate processes of softwood lumber manufacturing in the Northeastern and North Central of the US. This primary data was collected from lumber mills representing a substantial amount of the total production of the region.

Bowyer, J. (2011, Sept). "Green Building Programs – Influencing Positive Change, But Fundamental Flaws Inhibit Effectiveness."

Paper presented at the Structural Engineers Association of California (SEAOC) Convention 2011, Las Vegas, Nevada. *While green building programs have grown in stature and demand in North Americ,a they are perhaps missing some important points of evaluation. They are arguably driving down energy and water consumption in buildings but miss deeper environmental impacts by not evaluating the energy embodied in materials, transportation or construction activity. Moreover, these programs must maintain an objective perspective (not to value one method of material over another) and scientific rigor to ensure their continued importance in the sustainable building movement.*

Bowyer J., Bratkovich S., Lindburg A. and Fernholz K. (2008). *Wood Products and Carbon Protocols – carbon storage and low energy intensity should be considered*. Dovetail Partners, Inc.

The authors argue that policy analysts, when talking about environmental impacts and materials profiles, should consider the carbon sequestration during tree growth and its subsequent storage as a timber product. Multiple scenarios and metrics are considered.

Buchanan, A., John S., Nebel, B. & Perez N. (2008, update 2009). *Environmental Impacts of Multi-Storey Buildings Using Different Construction Materials.*

Unpublished report commissioned by the Ministry of Agriculture and Forestry under proposal POR/7811. *In April of 2007, the Ministry of Agriculture commissioned the University of Canterbury in New Zealand to investigate how much wood could be utilized in building construction. This optimal amount of wood for a given situation was investigated by an LCA performed to determine the sustainable benefits (if any) that would occur resulting in that choice of wood utilization. The investigation used a single building as a case study and tested alternate schemes of wood, steel, concrete and "timber plus" for a 60 year service life* *duration. Both initial and recurring (with maintenance and repair) embodied energies were to be accounted for.*

Carbon Working Group of the Structural Engineering Institute's Sustainability Committee, (Unpublished, in draft form), *Carbon and the Structural Engineer: What Structural Engineers Can do About Climate Change.*

Anticipated publication in 2012 on website http://www.seisustainability.org/

Cole, Raymond J. (1999). "Energy and Greenhouse Gas Emissions Associated with the Construction of Alternative Structural Systems," *Building and Environment*, v. 34, pp. 335-348.

This paper provides an overview of an examination of the energy and greenhouse emissions associated with the construction of a selection of different wood, steel and concrete structural assemblies. The report's objective is to "ascertain the relative proportion that the construction process represents of the total initial embodied energy and greenhouse gas emissions and whether there are significant differences between the structural material alternatives."

Guggemos, A. A. and Horvath, A., *Comparison of Environmental Effects of Steel and Concrete Framed Buildings,* ASCE Journal of Infrastructure Systems, June 2005, American Society of Civil Engineers, Reston, VA, 2005.

As the title suggests, this paper compares a cast-in-place concrete frame building to one of similar size and stature of structural steel. The paper focuses primarily on the construction phase to distinguish a difference in the energy needed to erect each material and to quantify the emissions associated with each. The authors go on to extrapolate what those points of energy and emissions would be if each material were to be measured throughout its lifecycle.

Hein, D (2007). *A Life Cycle Perspective on Concrete and Asphalt Roadways: Embodied Primary Energy and Global Warming Potential*.

Unpublished report commissioned by the Cement Association of Canada. *To compare the potential embodied primary energy usage and global warming potential over a 50-year lifecycle of "comparable" flexible asphalt and rigid Portland cement concrete pavings, four road sections types in different regions were used. With a functional unit of a two kilometer section (shoulder to shoulder), the sub-base was considered along with the actual material of study. The resulting pattern showed the PCC roadways were much less impactful than the asphalt counterpart.*

HQE Association (2011). "HQE Performance: First trends for new buildings."

As a non-profit entity, HQE has been working to foster education and communication among the decision-makers in France since 2004. With the realization that energy efficiency in buildings is growing and becoming more common, they have begun to address whole building lifecycle thinking as part of their new platform. "This reference framework, called 'HQE Performance,' takes into account: Energy and Environment, Health and Comfort (IAQ) and Economy."

Hubbard, Steven S. and Scott A. Bowe (2010). "A gate-to-gate life-cycle inventory of solid hardwood flooring in the eastern US." P79-89.

LCI of the gate-to-gate processes of solid hardwood flooring in the eastern US. This primary data was collected from lumber mills representing a substantial amount of the total production of the region.

Johnson, L., B. Lippke, J. Marshall, and J. Comnick (2005). "Life-Cycle Impacts of Forest Resource Activities in the Pacific Northwest and the Southeast United States." Wood Fiber Sci. 37 Dec. 2005: p30-46.

This article provides data for the comparison of Pacific Northwest and Southeast "resource activity," which includes seeding, fertilizing, harvesting the raw materials (logs) and others to produce wood products. The researchers provide three scenarios of intensity to cover a wide range of practices in these different regions as well as the resulting average intensity level. They also estimate the impacts of a proposed higher intensity management with specific corrections to the practices as found earlier in the study. This could lead to higher yields while minimizing impacts to the environment.

Karsell, B. (2011). "Taking A Stand for Credible Environmental Standards: A Call to Action." Loughborough University.

Review not completed

Kestner (2010). Kestner, D. M., Goupil, J., and Lorenz, E. (eds), *Sustainability Guidelines for the Structural Engineer*, sponsored by the Sustainability Committee of the Structural Engineering Institute (SEI) of the American Society of Civil Engineers.

Review not completed

Kline, D. (2005). "Gate-to-gate Life-Cycle Inventory of Oriented Strand Board Production." Wood Fiber Sci. Vol 37 Dec. 2005: p74-84.

In keeping with CORRIM's gathering of data related to various wood products, this gate-to-gate LCI gathers primary data from a representative amount of OSB producers in the Southeast.

Konig, H. Kholer, N. Kreissig, J. Lutzkendorf, T. (2010). *A life cycle approach to buildings: principles, calculations, design tools.* Radaktion DETAIL, Munich.

This book is a broad and extensive look at what LCA is and how the entire lifecycle of buildings can affect the built environment. It places emphasis on the need for decision makers to utilize LCA early in the design process when many more scenarios are available. The book recognizes that the facts needed by these planners are often missing. The book is designed to offer those facts and arguments for the evaluation of the design and the materials. It covers not only the environmental impacts but also social and economic consequences.

Lane, T (2010). Embodied energy: The next big carbon challenge. *Building.co.uk*. Retrieved October 10, 2011, from http://www.building.co.uk/technical/embodied-energy-the-next-big-carbon-challenge/5000487.article

Lane lays out a guide to understanding what embodied carbon is and how it is relative to the building industry (specifically the UK) in light of recent legislative decisions and reports on green building.

Lippke, B., Comnick, J. and Johnson, L. (2005). "Environmental Performance Index for the Forest." Wood Fiber Sci. 37 Dec. 2005: p149-155.

Comparatively speaking, the difference between raw material extractions for wood materials versus other materials is vast and "problematic," as the author says. Forests are dynamic and respond differently for different management strategies in different regions. This article investigates management alternatives that could contribute to differing effects, such as pre-settlement restoration, habitat restoration, benchmarking for different purposes and much more. The findings support the need for management despite some economic pushback.

Lippke, B. and Edmonds, L. (2006). "Environmental Performance Improvement in Residential Construction: the impact of products, biofuels and processes (a Phase 2 research module)." *Forest Products Journal.*

Review not completed

Lippke, B., Wilson, J., Meil, J. and Taylor, A. (2010). "Characterizing the importance of carbon stored in wood products." P5-14.

Researchers at multiple universities collaborate to investigate the carbon emissions and storage within the lifecycle of wood products in comparison to other alternative materials. The context used for investigation is a single family residential home, and the alternative materials investigated were steel and concrete.

Marceau, M. L., Nisbet, M. A., and VanGeem, M. G. (2007). *Life Cycle Inventory of Portland Cement Concrete, SN3011,* Portland Cement Association, Skokie, Illinois, PCA.

This report is the second update on the environmental LCI of PCC originally published in 2000. It covers the same seven impact categories as before, using similar methods of concrete plant surveys for three products: ready-mix concrete, masonry concrete and pre-cast concrete. They postulate in the findings as to why both emissions and embodied energies of the products has been reduced since the first update in 2002. The report reports data from cradle to gate.

Marceau, M., & VanGeem, M. (2008). *Comparison of the Life Cycle Assessments of a Concrete Masonry House and a Wood Frame House. SN3042,* Portland Cement Association, Skokie, Illinois, PCA.

Marceau and VanGeem's report is a comparison LCA of two common building materials in a single family dwelling. Their LCA quantifies the environmental attributes of each material in five different climates. Metrics are used to determine both embodied energies and operational energies. The results show that the occupant behavior has a far greater impact on the environmental performance as the difference in materials is negligible.

Marceau, M.L, and VanGeem, M.G. (2007). *Modeling Energy Performance of Concrete Buildings for LEED-NC Version 2.2: Energy and Atmosphere Credit 1*, SN2880a, Portland Cement Association, Skokie, IL, 2007a, 55 pp.

This paper presents a path to achieving LEED credit points under the EA section. That path is a detailed one involving consistent energy modeling. The authors present case studies of the same building utilizing different structural materials to show that with the use of pre-cast concrete and proper modeling, energy savings can be substantial.

Martin, N.; Worrell, E.; Ruth, M.; Price, L.; Elliott, R.N.; Shipley, A.M.; and Thorne, J. *Emerging Energy-Efficient Industrial Technologies*, Ernest Orlando Lawrence Berkeley National Laboratory, Environmental Energy, Technologies Division, October 2000.

Targeting the industrial sector, this paper outlines 50 potentially key, emerging energy efficient technologies that will aide this sector in environmental sustainability and overall economic competitiveness. It emphasizes that technology growth is essential for continued growth and to retain a leadership role in a national and global marketplace. The authors use their platform to create a decision-making model for identifying and choosing the best technologies per the application.

Milota, M., C. West, and I. Hartley (2005). "Gate-to-gate Life-Cycle Inventory of Softwood Lumber Production." Wood Fiber Sci. Vol. 37 Dec. 2005: p47-57.

LCI of the gate-to-gate processes of softwood lumber manufacturing in the Pacific Northwest. This primary data was collected from lumber mills representing a substantial amount of the region's total production.

Murray, B., Nicholson, R., Ross, M., Holloway, T. and Patil, S. (2006). *Biomass energy consumption in the forest products industry*. Washington, DC: U.S. Department of Energy; Research Triangle Park, NC: RTI International.

Beginning with the fact that 60% of all biomass fuel is consumed by the wood products industry, this report investigates how this trend is changing and why. The costs of fossil fuel derived heat and electrical sources are driving the industry to be more efficient and innovative with biomass fuel sources.

Natural Resources Defense Council (1998). *Efficient Wood Use in Residential Construction - A Practical Guide to Saving Wood, Money, and Forests*, NRDC New York, NY. Access at: http://www.nrdc.org/cities/building/rwoodus.asp

A best practices guide to being resource efficient, the authors provide a strategy with effective ranges for consideration. Because it is a handbook, the pacing takes a step-by-step stance. This guide looks to be straight-forward, easy to read and compartmentalized for efficient access for the user.

Ochsendorf, J., Brown, D., Durschlag, H., Hsu, S., Love, A., Norford, L., Santero, N., Swei, O. Webb, A. & Wildnauer, M. (2011). *Methods, Impacts, and Opportunities in the Concrete Building Life Cycle*.

Unpublished report from the Concrete Sustainability Hub at the Massachusetts Institute of Technology; sponsored by the Portland Cement Association (PCA) and the Ready Mixed Concrete (RMC) Research and Education Foundation. *Similarly to the MIT concrete pavement LCA, this paper sets forth a methodology and commences to gather data to evaluate. Data is gathered on a range of buildings with the goal of benchmarking the emissions associated with one built of concrete versus one built of other materials. They identify opportunities to reduce emissions with a mix of case studies in multiple climate situations. Within this mix are different building types and ranges of size.*

O'Connor, Jennifer. "Survey on Actual Service Lives for North American Buildings," *Woodframe Housing Durability and Disaster Issues Conference*, 2004.

Presented in 2004 to a durability and disaster issues conference, this paper looks at a survey of buildings demolished in a major US city. It found that the vast majority of buildings are not demolished because of structural failure making them unsuitable for use. Instead, the majority of reasons were economic, such as the building being too expensive to upgrade due to non-structural material failure per lack of maintenance, or unsuitability for current functionality or land use. The author purports that a shift in our thinking is in order along the lines of adaptability in design, deconstructability and changing impact expectation with regard to assessment of building's lifespan, e.g. life cycles.

Oneil, E. E. and Lippke, B. (2010). "Integrating products, emission offsets, and wildfire into carbon assessments of Inland Northwest forests." P144-164.

Using data gathered as part of the ongoing data collection of timber products and forest management practices, this report estimates the impacts of "management actions" on carbon accounts that can build up over time. The data comparison is split over three ownership groups in the US: privately held and managed forests, State-owned forests and National Forests. They break down the percentages to indicate the impacts and improvement opportunities surrounding each.

Oneil, E. E., Johnson, L., Lippke, B., McCarter, J., McDill, M., Roth, P., and Finley, J. (2010). "Life-cycle impacts of Inland Northwest and Northeast/North Central forest resources." P29-51.

At the front end of any LCA is the extraction of the raw material. In the case of wood products, that raw material is in the growth and management of the forest stock. This paper focuses on the measurement and creation of an LCI of different forest management strategies in different regions around the US. Moreover, the authors create various scenarios per region to show both variation and potential best practices.

Perez-Garcia, J., B. Lippke, J. Comnick, and C. Manriquez. (2005). "An Assessment of Carbon Pools, Storage, and Wood Products Market Substitution Using Life-Cycle Analysis Results." Wood Fiber Sci. 37 Dec. 2005: p140-148.

Using an LCA of housing construction, this article analyzes a wood product's role in energy displacement and carbon cycling. With the LCA data, they are able to track and evaluate carbon in the products from sequestration to substitutions in end-use markets. The article evaluates three carbon pools in timber products and gives estimates based on different scenarios looking for ways to optimize the material's use.

Perez-Garcia, J., B. Lippke, D. Briggs, J. Wilson, J. Bowyer, and J. Meil (2005). "The Environmental Performance of Renewable Building Materials in the Context of Residential Construction." Wood Fiber Sci. Vol 37 Dec. 2005: p3-17.

In the cradle-to-gate LCA of a residential home, the authors evaluate the various environmental impacts of alternate building materials. There is particular attention paid to wood products including a "temporal distribution of events," meaning that they look at the initial embodied carbon and the recurring carbon associated with events such as repair, maintenance and replacement of the materials. The process followed collects the input/output data and then identifies opportunities for improvements.

Pinto, I. (2011). *LCA comparison of structural frame alternatives for office buildings.*

Unpublished report commissioned by the Canadian Institute of Steel Construction with funding from the Steel Structures Education Foundation and MITACS Accelerate. *The author uses a simplified commercial building to perform an LCA comparison between a designed steel structural frame and a comparable concrete alternative. He uses three LCA software tools in different combinations to create four scenarios in which to compare the systems. Interestingly enough, though the study is meant to compare two structural materials (and it does so), it becomes an exploration of how LCA tools function and the ranges they can produce.*

Preservation Green Lab Report. (2012). "The Greenest Building: Quantifying the Environmental Value of Building Reuse." Accessible at http://www.preservationnation.org/information-center/sustainable-communities/sustainability/green-lab/lca/The_Greenest_Building_lowres.pdf

The comprehensive report looks at seven building typologies in four US climate regions to determine the "value" of reusing an existing structure by renovating to a certain energy criteria versus new construction of similar type and similar energy use. What has been intuitively assumed by many preservationists has, with this report, been quantified. The two major findings are the percentage reduction in embodied energy with reuse and the duration of time needed for a new building with similar energy use to over take the reused building in energy savings.

Puettmann, Maureen E., Richard Bergman, Steve Hubbard, Leonard Johnson, Bruce Lippke, Elaine Oneil, and Francis G. Wagner (2010). "Cradle-to-gate life-cycle inventory of US wood products production: CORRIM Phase I and Phase II products." P15-28.

The timber products examined for this article come from softwood and hardwood lumber and hardwood strip flooring manufacturing. It is a lifecycle inventory focusing on all inputs and outputs to air and water, resource use and primary energy consumed. In the results, they determine that the greatest impacts occur during manufacturing and that forest management practices in the Northeast and North Central regions are more insensitive than in the Northwest.

Puettmann, Maureen E., Francis G. Wagner, and Leonard Johnson (2010). "Life-cycle inventory of softwood lumber from the Inland Northwest US." P52-66.

LCI of the gate-to-gate processes of softwood lumber manufacturing in the Inland Northwest of the US. This primary data was collected from lumber mills representing a substantial amount of the total production of *the region.*

Puettmann, M. and J. Wilson (2005). "Gate-to-gate Life-Cycle Inventory of Glued Laminated Timber Production." Wood Fiber Sci. Vol 37 Dec. 2005: p99-113.

LCI of the gate-to-gate processes of glue-laminated lumber manufacturing in the Pacific Northwest and the Southeastern parts of the US. This primary data was collected from lumber mills representing a substantial amount of the total production of the region.

Puettmann, M. and J. Wilson (2005). "Life-Cycle Analysis of Wood Products: Cradle-to-gate LCI of Residential Building Materials." Wood Fiber Sci. Vol 37 Dec. 2005: p18-29.

This article compiles LCI data from other CORRIM LCI reports to give an overview of wood product impacts, including soft and hardwood products as well as engineered products. A particular finding within the context of comparing several products is fuel usage, its sourcing and associated environmental burdens. When the lifecycle system boundaries are taken to be cradle-to-gate, 1/3 of the energy used is derived from biomass. When the boundaries are shrunk to gate-to-gate only nearly 50% is from biomass.

Scientific Certification Systems, Inc. (2000). "Analysis of Galvanized Steel Production Suitable for Residential Construction Based on Life Cycle Stressor-Effects Assessment: A U.S. Case Study."

Prepared for the Steel Recycling Institute, American Iron and Steel Institute, and U.S. Steel Corporation. Industry peer reviewed. *In the year 2000, the North American steel industry was trying to go beyond the collection of data in LCIs. They were trying to better their products and understand their real impact on the environment. This paper is about the methodology and results of a model they developed called Life-Cycle Stressor-Effects Assessment (LCSEA). Based on their cradle to gate LCI of a single steel production system, they created a corresponding Impact Profile.*

Seo, S. (2002). "International review of environmental assessment tools and databases." Cooperative Research Centre for Construction Innovation.

In 2001, the CRC for CI was founded. This paper is an effort to review the burgeoning building rating systems movement and LCA tools developed at the time. The major rating systems reviewed are BREEAM, LEED, Green Globes and NABERS (Australian National System). The major tools reviewed are Athena, BEES, GreenCalc, Envest, LCAid, BEAT and Eco-Quantum.

Sovinski, D. (2009). Life Cycle Cost Analysis: Fort Lewis Barracks Project. International Masonry Institute.

Review not completed

Stadel, A., Gursel, P. and Masanet, E. (2012). "Life-Cycle Evaluation of Concrete Building Construction as a Strategy for Sustainable Cities." Lawrence Berkeley National Lab.

Unpublished report. *This report provides an overview of the development and use of a new LCA model for structural materials. The Berkeley Lab Building Materials Pathways (B-PATH) model aims to be a better decision-making tool when selecting structural materials in a commercial building design.*

Steel Recycling Institute (2009). "2008 The Inherent Recycled Content of Today's Steel," updated December 2009.

Quick overview of the recycled content going into both BOF and EAF steel production methods.

Stubbles, J (2007). "Carbon 'Footprints' in U.S. Steelmaking." Steel Manufacturers Association.

This short article about the energy efficiency trend of the steel industry centers on its dependency on fossil fuels for both EAF and blast furnace production. Though efficiency has grown tremendously, they are nearing the peak of potential efficiency.

Target Zero. (2011) *Cost Effective Routes to Carbon Reduction* (Supplement, 16 March). Retrieved from http://www.targetzero.info/news/release/the_target_zero_supplement/

This supplement is a downloadable form of the website's articles. Each article is on a different building type but all focus on how to move that building typology closer to net zero carbon. Target Zero is a research project funded across industries to aid in the development of strategies for design professionals to get their buildings in line with government (UK) directives. The articles reflect a concern of the costs, both monetary and cultural, involved in moving the industry in that direction.

TRADA Technology Ltd. (2009). *Timber Carbon Footprints: Calculated Values* (version 1, Dec 2009). Buckinghamshire, U.K. Retrieved from www.trada.co.uk/downloads/.../CO2%20Calculated %20Values.pdf

TRADA, a research center and collective advocacy group in the UK, published this construction brief as a newsletter-type distribution in 2009. It explains what LCA is and how the timber industry is affected by it. As an advocacy unit of the wood industry, they lay out how timber is well positioned to benefit from LCA and carbon footprinting as a holistic practice. Regarding the technical side of the brief, it goes through a few species as carbon balance examples and offers a couple of scenarios to demonstrate variation.

Venta, G. (1998). *Life Cycle Analysis of Brick and Mortar Products,* Venta, Glaser and Associates, Athena Sustainable Materials Institute.

This report was commissioned by the Athena Sustainable Materials Institute for their ongoing database project. It is a straightforward collection of the inventory inputs needed to produce three types of brick and one type of mortar. It also includes emissions associated with these materials and their potential recyclability.

Volz, V., and Stovner, E. (2010) *Reducing Embodied Energy in Masonry Construction. Part 2: Evaluating New Masonry Materials.* Structure Magazine, September 2010.

Material substitutes that claim to be a "greener" version of their counterpart must be vetted by multiple criteria before they can be used. This is the position of the authors demonstrating that it is the place of the structural engineer to evaluate the product for aesthetic differences, environmental impacts and interface with other materials before acceptance. The article looks into one such product, a fly-ash brick, to compare it to a regular clay-fired brick.

Webster, Mark D. "Relevance of Structural Engineers to Sustainable Design of Buildings," *Structural Engineering International*, 2004.

Review not completed

Weisenberger (2010). "The Fabrication Factor," *Modern Steel Construction*, July 2010.

The author argues that, based on a recent survey of US Steel fabricators, the efficiency at which they perform could be the difference in whether a design utilizes structural steel or concrete to lower the building's carbon footprint. This data has not been known until now, and it shows that though performance efficiency is not the majority of energy use or emissions, it is significant to the whole.

Wilson, James B. (2010). "Life-cycle inventory of formaldehyde-based resins used in wood composites in terms of resources, emissions, energy and carbon." p.125-143.

This study was conducted to provide environmental impact data on resin, which is heavily used in *engineered wood products. It could be used separately to identify opportunities for material improvement or, as it is now, in LCAs of composite wood production.*

Wilson, James B. (2010). "Life-cycle inventory of medium density fiberboard in terms of resources, emissions, energy and carbon." p.107-124.

Data is compiled of the gate-to-gate environmental impacts of medium-density fiberboard (MDF) in this LCI. Also provided is additional cradle-to-gate information including transport and other pre-manufacturing data.

Wilson, James B. (2010). "Life-cycle inventory of particleboard in terms of resources, emissions, energy and carbon." p.90-106.

The author gathers data to compile a gate-to-gate LCI of particleboard to serve as data points for green certification programs and a general, deeper understanding of the environmental impacts of the material. He also provides additional cradle-to-gate information including transport and other pre-manufacturing data.

Wilson, J. and E. Dancer (2005). "Gate-to-gate Life-Cycle Inventory of I-joist Production." Wood Fiber Sci. Vol 37 Dec. 2005: p85-98.

LCI of the gate-to-gate processes of I-Joist manufacturing in the Pacific Northwest and the Southeast US. Included are LCIs of the two components of I-Joists: the LVL for the top and bottom chord members and the OSB web between. It excludes the production of the logs. This primary data was collected from lumber mills representing a substantial amount of the total production of the region.

Wilson, J. and E. Dancer (2005). "Gate-to-gate Life-Cycle Inventory of Laminated Veneer Lumber Production." Wood Fiber Sci. Vol 37. Dec. 2005: p114-127.

LCI of the gate-to-gate processes of Laminated Veneer Lumber manufacturing in the Pacific Northwest and the Southeast US. It includes the production of the logs. This primary data was collected from lumber mills representing a substantial amount of the total production of the region.

Wilson, J. and E. Sakimoto. (2005). "Gate-to-gate Life-Cycle Inventory of Softwood Plywood Production." Wood Fiber Sci. Vol. 37 Dec. 2005: p58-73.

LCI of the gate-to-gate processes of softwood lumber plywood manufacturing in the Pacific Northwest and the Southeast US. This primary data was collected from lumber mills representing a substantial amount of the total production of the region. Covered in this report is fuel and electricity use, co-product creation and other inputs/outputs related to the manufacturing process.

Winistorfer, P., Z. Chen, B. Lippke, and N. Stevens. (2005). "Energy Consumption and Greenhouse Gas Emissions Related to the Use, Maintenance and Disposal of a Residential Structure." Wood Fiber Sci. 37 Dec. 2005: p128-139.

Many lifecycle assessment studies negate or leave out the use phase of a building's life altogether. This study includes it as a study of the gate-to-grave stages of a single-family residence's life. With an assumed life of 75 years, the researchers perform calculations of a virtual house with three different structural types in two different US climates to determine the energy use and emissions associated with each. This energy use and emission accounting includes operations, regular, scheduled maintenance, and options for deconstruction and disposal.

Additional references provided by stakeholders not received in time for review:

Marceau, M. L., and M. G. VanGeem. (2006). "Comparison of the Life Cycle Assessments of an Insulating Concrete Form House and a Wood Frame House." Paper ID JAI13637. *Journal of ASTM International* Vol. 3, No. 9, American Society for Testing and Materials, West Conshohocken, Pennsylvania, October.

Marceau, M. L., and M. G. VanGeem. (2002). *Life Cycle Assessment of an Insulating Concrete Form House Compared to a Wood Frame House*. PCA R&D Serial No. 2571, Portland Cement Association.

State of Oregon's Department of Environmental Quality (DEQ), (2010). *A Life Cycle Approach to Prioritizing Methods of Preventing Waste from the Residential Construction Sector in the State of Oregon.* Phase 2 Report Version 1.4 September 29, 2010. Accessed Aug 28, 2012 from http://www.deq.state.or.us/lq/sw/wasteprevention/greenbuilding.htm.