Athena Sustainable Materials Institute

www.athenasmi.org

Athena Guide to Whole-Building LCA in Green Building Programs

1st Edition

March 2014

This Guide references:

- Athena Impact Estimator for Buildings v4.5
- Green Globes® (June 2013 release) and the Guiding Principles Compliance for New Construction
- LEED® v4 and LEED® pilot credit 63
- International Green Construction Code (IgCC) 2012
- California Green Building Standards Code (CALGreen) 2010 (and 2012 supplement)

- ASTM E2921-13
- EN 15978:2011

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This document can be found on the Athena software web site calculatelca.com. It will be periodically updated as required.

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Disclaimer

This document addresses a topic that frequently changes. The Athena Institute makes no warranty as to the accuracy of the information in this document other than that addressing our own software.

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List of Abbreviations

EPD	Environmental Product Declaration
IE4B	Impact Estimator for Buildings
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LCI	Life Cycle Inventory

1 INTRODUCTION

The Athena Sustainable Materials Institute is the pioneer of whole-building life cycle assessment (LCA) in North America. We have been a key force behind a steady uptake of LCA by the manufacturers of construction materials and, more recently, by an increasing number of building designers. Since our launch in 1997 (to advance research work that began in 1991), we have been pursuing a common-good mandate to bring rigorous quantification to sustainability in the built environment. We work with product manufacturers, trade associations, green building associations, and architectural and engineering firms to help quantify environmental impacts and to demystify and assist teams with LCA.

LCA is an analytical method for quantifying and interpreting flows between a product and the environment. It is used in the industrial sector to understand environmental “hot spots” in products so that improvements can most effectively be made. Similarly, LCA can help building designers focus their efforts when a reduced footprint is desired. This application is called “whole-building LCA” when the entire building project is considered holistically in an LCA exercise – as opposed to LCA applied to parts of a building (for example, LCA for only the floor assembly, or LCA used when selecting individual products). Whole-building LCA allows maximum flexibility in trade-offs. For example, the addition of more insulation will result in increased material impacts of a building, but will often result in a net life cycle benefit due to reduced operating energy consumption.

LCA is a complex science typically practiced by experts. In order to make LCA accessible for building designers, the Athena Institute developed a simplified LCA tool specifically for that audience. We first released the Athena *Impact Estimator for Buildings* in 2002 and have been continuously improving it ever since.[1]

Green building codes, standards and rating systems (referred to in this document as "programs") in North America have recently adopted LCA provisions as an important step towards bringing a performance basis to sustainable design. The Impact Estimator for Buildings is the most likely route to achieving compliance, and this guide provides help for doing that. More specifically, this guide summarizes and interprets the various program provisions, provides tips on how to incorporate LCA during the building design process, and presents our supplementary best-practice recommendations for performing whole-building LCA in general.

This guide draws on our experience performing whole-building LCA as well as two whole-building LCA standards. The American standard ASTM E2921[2] provides minimum requirements when conducting whole-building LCA for the purpose of attaining building rating system and code compliance. The European EN 15978[3] is an LCA standard that is increasingly becoming the common method for describing the system boundary of whole-building LCA.

Your feedback on this guide and on the Impact Estimator for Buildings is always welcome. Contact us through our web site: **www.athenasmi.org**

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[1] The Impact Estimator for Buildings was developed in partnership with Morrison Hershfield and is supported by the Athena Institute’s network of members and other funders. We regularly update this software package with new data, improved functionality and the latest LCA methodology. It is available for free download at calculatelca.com.

[2] ASTM E2921-13 - Standard Practice for Minimum Criteria for Comparing Whole Building Life Cycle Assessments for Use with Building Codes and Rating Systems.

[3] EN 15978:2011 - Assessment of environmental performance of buildings - Calculation method

2 THE IMPACT ESTIMATOR FOR BUILDINGS

The Athena *Impact Estimator for Building* (IE4B) makes LCA accessible for architects, engineers, and other non-LCA experts in design and construction professions. It can model constructed works at any scale (whole-building, building element, construction assembly, building product) and can be used for various types of buildings (residential, commercial, industrial) and construction projects (new construction, renovation, refurbishment). The geographic coverage of the tool is the United States and Canada. Environmental profiles of the building products and operating energy fuels typically reflect industry-average practice (i.e. not specific to any particular manufacturing plant or energy producer). All data is specific to the region where the building is located; this is an important aspect to the LCA calculations and is a distinguishing quality feature of the Athena databases.

IE4B modeling capacity currently encompasses a building's structure, enclosure, and interior partitions and doors. Building products can be combined in various ways to model the vast majority of construction assemblies commonly in use in North America (an estimated 1,200+ combinations using the IE4B built-in elements). The LCA modeling can also optionally include the operating energy use of the building, if that data is available – energy use is calculated using other means, and fuel consumption results are entered in the IE4B for the associated LCA impacts of fuel use.

The IE4B reports results for the following environmental impact measures consistent with the US EPA TRACI methodology[4]: global warming potential, acidification potential, human health respiratory effects potential, ozone depletion potential, smog potential, and eutrophication potential. The IE4B additionally reports various resource uses (e.g. primary energy), and emissions to air, water, and land. Users can view data in a number of different ways. The reporting functions make it easy to find environmental hot spots and to compare design options.

2.1 How it Works

See Figure 1 below for a schematic diagram of how the IE4B works. LCA modeling with the program involves the following steps:

1. The user provides project data:
    a. General information about the project, and annual operating use (optional) in the "Add/Modify Project" input dialog[5].
    b. Assembly geometry and loading in the "Assembly" input dialogs and/or material takeoffs in the "Extra Basic Materials" input dialog to define the building's material usage.

[4] *Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts* (TRACI) is a life cycle impact assessment methodology developed by the US EPA and the most commonly used method in North America.

[5] In general, the detail of the required inputs is at the level of an architect or other designer who is generally familiar with different types of building materials and assemblies, but is not necessarily a specialist in a specific field. For example, a structural engineer is not required to compare various structural assemblies.

2. The user selects the report format and results type(s) to be produced via the "Reports" dialog and executes the calculations.
3. The IE4B draws on its internal databases to perform the necessary calculations:
    a. Scenario databases to quantify all life cycle material and energy use.
    b. The Athena LCI Database to calculate a life cycle inventory.
    c. The TRACI methodology to perform life cycle impact assessment.
4. Results reports are generated.

Please refer to our User Manual for a more in-depth information on the inner workings of the IE4B.

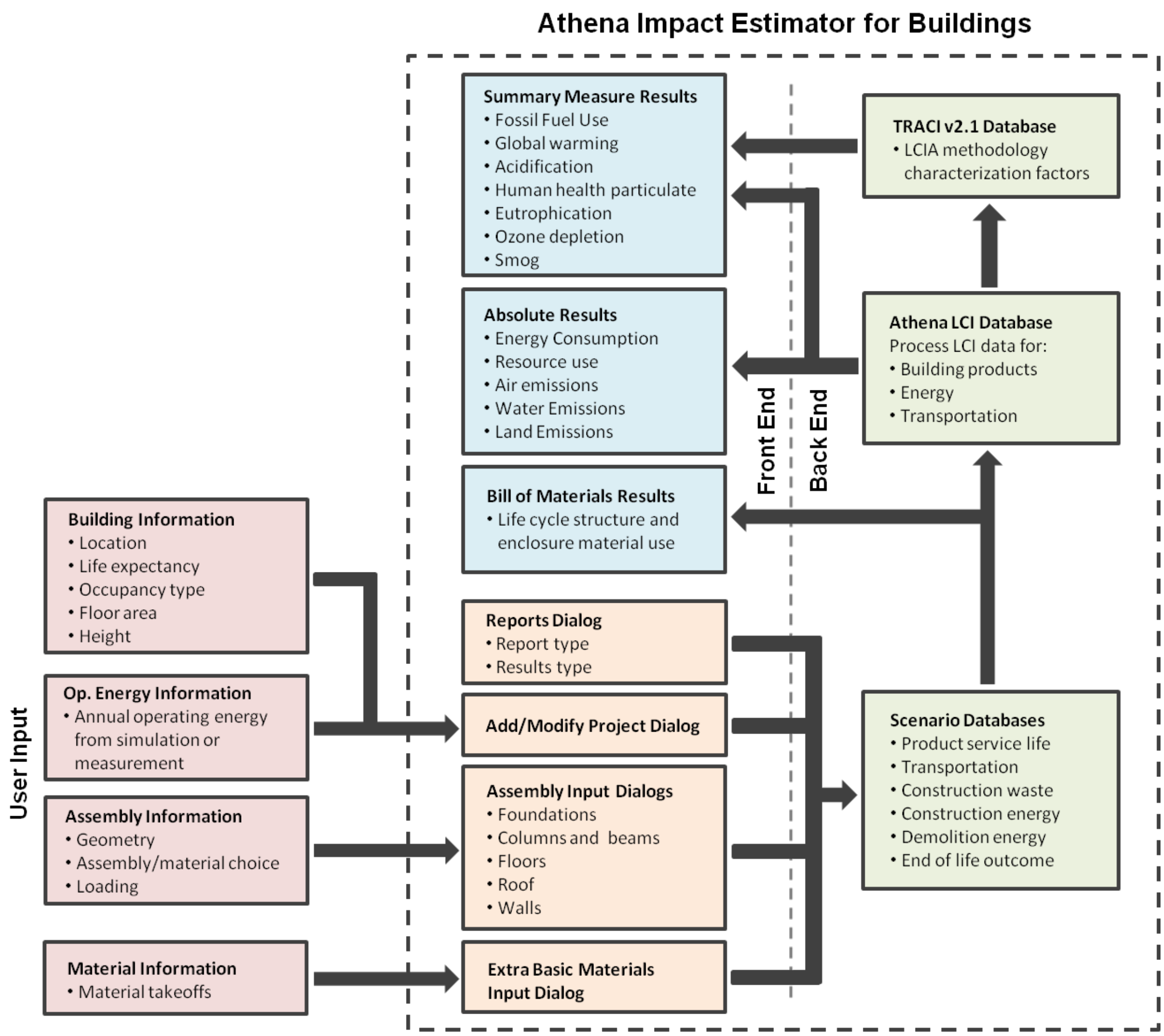

Figure 1: How the Impact Estimator for Buildings Works

2.2 Finding the Software and Resources

Free download of the Impact Estimator for Buildings software
http://calculatelca.com

User manual, video tutorials and FAQs
http://calculatelca.com/resources/

More description about the Impact Estimator for Buildings
http://www.athenasmi.org/our-software-data/impact-estimator/

LCI/LCA product reports and other LCA information
http://www.athenasmi.org/resources

3 INTERPRETATION OF LCA PROVISIONS IN GREEN BUILDING PROGRAMS

Whole-building LCA appears in several North American codes, standards and rating programs. These LCA provisions typically provide a compliance path or an opportunity to earn points when designers use LCA to measure environmental performance during design, leading to design refinements that reflect best LCA performance of the whole building. The Athena free software tool, the IE4B, is the most likely way for design teams to participate in these LCA opportunities within green building programs.

In this section, we provide our interpretation of LCA provisions in the following programs[6]:

1. **LEED® v4 MR Credit Building Life-Cycle Impact Reduction (option 4) and LEED® Pilot Credit 63**
   These Materials and Resources credits provide a whole-building (core and shell) comparative LCA opportunity to earn points. Version 4 of the *Leadership in Energy and Environmental Design* (LEED) green building rating program, Material and Resources *Building Life-Cycle Impact Reduction,* option 4 is worth three points and is included in the following systems:
   - New Construction
   - Core and Shell
   - Schools - New Construction
   - Retail - New Construction

[6] A note on *ASHRAE 189.1 (2011) - Standard for the Design of High-performance Green Buildings*: while this standard also contains a whole-building comparative LCA option, we do not address it in this document. In our opinion, the complexity of this standard requires the assistance of an LCA expert for compliance.

- Healthcare
- Hospitality - New Construction
- Data centers - New Construction
- Warehouse and distribution centers - New Construction

2. **Green Globes® for New Construction (June 2013 release) – Section 3.5.1.1 Path A**
   In the Materials and Resources section, this is a whole-building comparative LCA performance path option for building core and shell worth 33 points (versus 20 points for the prescriptive path).

3. **Guiding Principles Compliance for New Construction**
   A whole-building comparative LCA performance path option for building core and shell is provided as an option for meeting federal compliance with materials.

4. **The 2012 *International Green Construction Code* (IgCC) building code - Section 303**
   Whole-building comparative LCA (core and shell) is available as a performance path alternative to prescriptive material requirements.

5. **The 2010 *California Green Building Standard Code* (CALGreen) building code - Section A5.409.2**
   In this version (including the 2012 supplement), whole-building comparative LCA (core and shell) is available as a performance path alternative to prescriptive material requirements.

3.1 Compliance Requirements

All of the programs addressed here require an LCA comparison of two building designs. The first building design is a base case – we call this the **Reference Building** throughout this document. The second building is the design seeking green building program compliance – we call this the **Proposed Building** in this document.

LCA results are to be provided for both buildings, and each program sets performance targets for the **Proposed Building versus the Reference Building** in order to achieve compliance. Practitioners familiar with energy performance requirements such as those based on ASHRAE 90.1 will see that the approach is similar.

All of the programs require results for both buildings in six LCA metrics. Compliance is achieved if the Proposed Building achieves a specified minimum improvement in impact over the Reference Building, for at least some of the metrics, over a given study period[7]. In addition, two of the programs put a limit on the Proposed Building exceeding the Reference Building in any of the impact metrics.

See Figure 2 for an illustration of how this works. In the graph, results for the Reference Building are set as the 100% baseline, and results for the Proposed Building are shown as percent of the Reference Building results (in other words, this is a benchmark graph with the Reference Building as the baseline). The green and red arrows indicate where the Proposed Building shows improvement and exceedance relative to the Reference Building, respectively.

[7] Please note that the study period may be different than the estimated service life of a building.

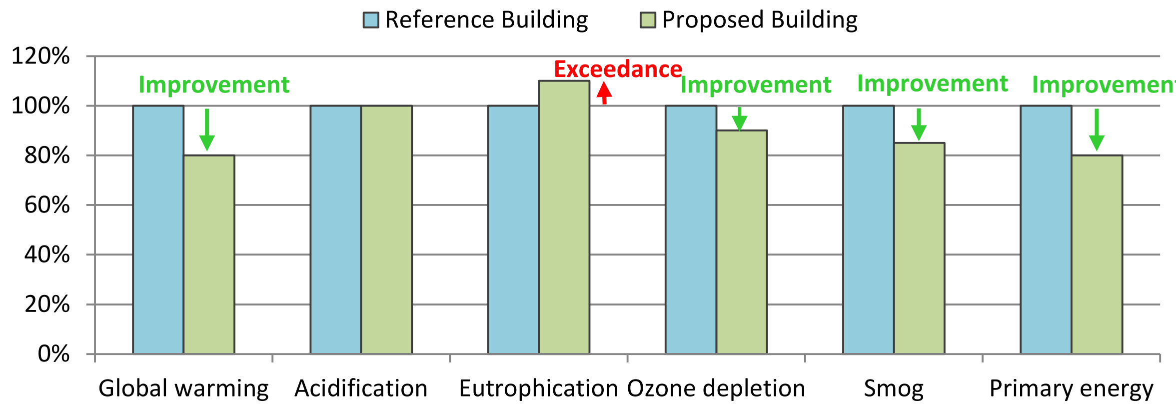

Figure 2: The Comparative Concept in the Green Building Programs

Table 1 shows an example of how comparative results might be presented for program compliance.

Table 1: Example of a Comparative LCA Results Table

Impacts	Units	Reference Building	Proposed Building	% Change
Global Warming	kg CO_2 eq.	384,786	338,612	-12%
Acidification	kg SO_2 eq.	3,231	3,199	-1%
Eutrophication	kg N eq.	44.1	45.9	4%
Ozone depletion	kg CFC-11 eq.	0.00034	0.00034	0%
Smog	kg O_3 eq.	10,820	9,738	-10%
Primary Energy	MJ	6,560,563	5,576,479	-15%

Table 1 Notes:

The percent reduction/increase is calculated using the following equation (a negative result is a reduction):

$$P_n = 100 * (PB_n - RB_n) / RB_n$$

where,

P_n is the percent reduction/increase of the Proposed Building with respect to the Reference Building, for impact indicator n

RB_n is the life cycle result of the Reference Building case, for impact indicator n

PB_n is the life cycle result of the Proposed Building case, for impact indicator n

See Table 2 for a list of requirements for each program: study period, improvement target, exceedance limit and LCA metrics to include.

The first five indicators shown in Table 2 (i.e. global warming potential through smog potential) are common to all programs. What differentiates the programs is the sixth indicator to be quantified related to energy resource use – these indicators are summations of different types of primary energy use. Please see the IE4B User Manual for further information on the impact indicators and how they are calculated.

We provide extended interpretation of the compliance requirements in Appendix A.

Table 2: Compliance Requirements in the Programs

	LEED v4	**Green Globes 2013**[8]	**IgCC 2012**	**CALGreen 2010/2012**
Impact Indicators to be Quantified	Global warming potential Acidification potential Eutrophication potential Ozone depletion potential Smog potential			
	Non-renewable primary energy	Fossil fuel primary energy	Total primary energy	Fossil fuel primary energy
Improvement Target (Proposed Building relative to Reference Building)	Minimum 10% reduction for at least three of the impact indicators, one of which must be global warming potential.[9]	Minimum 10% reduction for at least three impact indicators, one of which must be global warming potential; or, minimum 15% reduction for at two indicators, one of which must be GWP; or, minimum 20% reduction in GWP.	Minimum 20% reduction for at least three impact indicators, one of which must be global warming potential.	Minimum 10% reduction for at least three impact indicators, one of which must be global warming potential.
Exceedance Limit (Proposed Building relative to Reference Building)	Maximum 5% increase for any impact indicator	No more than one impact indicator can increase.	None stated	None stated
Study Period	Minimum 60 years	Minimum of 60 years and maximum of 120 years, unless otherwise approved by a Green Globes assessor	None stated	Minimum 60 years unless approved by the enforcing agency

[8] Use this column as well for the Guiding Principles Compliance for New Construction.

[9] Exemplary performance for achieving "any improvement over the required credit thresholds in all six impact measures." See LEED reference manual for detail.

3.2 What to Include

Buildings are complicated subjects for LCA. They include multiple assemblies of many products, some of which are periodically maintained or replaced, and they include dynamic systems like plumbing and HVAC which involve the on-going consumption of resources and creation of wastes. It's important to define what precisely is included in the LCA, in other words, the scope.

LCA currently excels at estimating the environmental effects associated with building materials, operating energy, and operating water use[10]. However, data limitations – and modeling difficulties for non-experts in LCA – restrict what is included in the LCA provisions of each program.

There are two important scoping considerations when establishing what is to be included in the assessments:

1. The **object of assessment**, i.e. which materials, and operating energy and water end-uses are to be included; and
2. The assessment **system boundary**, i.e. which life cycle activities the object of assessment undergoes are to be included.

"Object of assessment" and "system boundary" are LCA terms we use throughout this document for precision and accuracy in nomenclature. The object is what we're looking at: which parts of the building and which of its operations we are including in the calculation. For example, the green building programs address core and shell components and generally leave out finishes and furnishings. The boundary describes how far we cast our net in the calculation. For example, the programs include material manufacturing, but optionally include material off-gassing that occurs during building occupancy.

To help define the object of assessment, see Table 3 for building components and operations that are required, excluded or optional for each program. Material components have been presented according to the UNIFORMAT II elemental format; typically, the major components of structure, envelope, and interior partitions will be included, and finishes optionally included. All other building elements are to be excluded, for example HVAC, electrical and plumbing equipment. All programs currently exclude operating water use. When operating energy is to be analyzed, the LCA should include the same energy end-uses covered by the operating energy performance provisions of the respective green building program. In other words, when a performance-based operating energy performance pathway has been used to demonstrate compliance (e.g. via simulation), the LCA should include all required end-uses, whereas when a prescriptive-based operating energy performance pathway has been used, the LCA should include all end-uses covered (directly or by proxy) by the provisions.

[10] Please note that LCA is not a methodology to calculate a building's annual operating energy or water demand. It calculates the environmental impacts of the consumption of those resources.

Table 3: Building Aspects Included and Excluded

		LEED v4	Green Globes 2013[11]	IgCC 2012[1]	CALGreen 2010
Materials (UNIFORMAT II elemental format)	A1010 Standard Foundations	✓	✓	✓	✓
	A1020 Special Foundations	✓	✓	✓	✓
	A1030 Slab on Grade	✓	✓	✓	✓
	A2010 Basement Excavation	×	×	×	×
	A2020 Basement Walls	✓	✓	✓	✓
	B1010 Floor Construction	✓	✓	✓	✓
	B1020 Roof Construction	✓	✓	✓	✓
	B2010 Exterior Walls	✓	✓	✓	✓
	B2020 Exterior Windows	✓	✓	✓	✓
	B2030 Exterior Doors	✓	✓	✓	✓
	B3010 Roof Coverings	✓	✓	✓	✓
	B3020 Roof Openings	✓	✓	✓	✓
	C1010 Partitions	?	?	✓	✓
	C1020 Interior Doors	?	?	✓	✓
	C1030 Fittings	×	×	×	×
	C2010 Stair Construction	✓	✓	✓	✓
	C2020 Stair Finishes	?	?	✓	?
	C3010 Wall Finishes	?	?	✓	?
	C3020 Floor Finishes	?	?	✓	?
	C3030 Ceiling Finishes	?	?	✓	?
	Groups D-G	×	×	×	×
Operating Energy		×	?	✓[2]	✓
Operating Water		×	×	×	×

Table 3 Notes

[1] The required elements are to be assessed to the extent that data are available in the selected LCA tool

[2] Process loads may be optionally included

✓ Include

? Optional

× Exclude

Table 4 is presented to assist in defining the system boundary of the assessments. In the table, we present our interpretation of the program requirements according to the format of the European standard EN 15978. EN 15978 characterizes the life cycle of buildings according to alpha-numeric "information modules", which are groups of processes (i.e. activities) that are similar in nature. Note that the only difference between programs is whether the information module *Operational Energy Use* (B6) is to be included. Modules to be included are those generally specified by the green building programs, are representative of contemporary North American LCA practice, and are calculated by the IE4B. In our opinion, other modules not directly specified by the green building programs which relate to material use (modules B1, B3, B5, C3) should be optionally available to be included. Please note that these modules are currently not well supported by North American LCA databases and tools.

See Appendix A for our further recommendations regarding what to include.

[11] Use this column as well for the Guiding Principles Compliance for New Construction.

Table 4: Information Modules Included and Excluded (EN 15978 format)

Life Cycle Stage	Information Module	LEED v4	Green Globes 2013[12]	IgCC 2012	CALGreen 2010/2012
Product	A1 Raw Material Supply	✓	✓	✓	✓
	A2 Transport	✓	✓	✓	✓
	A3 Manufacturing	✓	✓	✓	✓
Construction Installation	A4 Transport	✓	✓	✓	✓
	A5 Construction-installation Process	✓	✓	✓	✓
Use	B1 Use	?	?	?	?
	B2 Maintenance	✓	✓	✓	✓
	B3 Repair	?	?	?	?
	B4 Replacement	✓	✓	✓	✓
	B5 Refurbishment	?	?	?	?
	B6 Operational Energy Use	×	?	✓	✓
	B7 Operational Water Use	×	×	×	×
End of Life	C1 De-construction Demolition	✓	✓	✓	✓
	C2 Transport	✓	✓	✓	✓
	C3 Waste Processing	?	?	?	?
	C4 Disposal	✓	✓	✓	✓

Table 4 Notes
✓ Include
? Optional
× Exclude

3.3 Data Sources, Methodology and Tools

LCA requires life cycle inventory (LCI) data for all materials and processes, a life cycle impact assessment (LCIA) method, and a software tool to do the work. LCI data is the inventory of all flows to and from nature due to a product or process – it's a long list of substances and quantities which involves complex considerations in boundary, allocation methods and so forth. The LCIA method translates those flows into environmental impact potentials – it's the "what does it mean" step. The LCA software tool brings the LCI data and the LCIA method together and additionally helps the practitioner address assumptions, known as "scenarios" in LCA lingo[13].

It's important that the underlying LCI data, LCIA method, and scenarios of the LCA tool be regionally appropriate for the building being studied. In particular, be wary of off-shore data or software which is likely to be inappropriate for North American applications. Without regionally appropriate data, the results may be

[12] Use this column as well for the Guiding Principles Compliance for New Construction.

[13] Due to the fact that not all information is practically available to the assessor and buildings have long and uncertain lives, *Scenarios* (i.e. assumptions) are required to provide a complete description of a building over its life cycle. Examples include the replacement rates of materials, and the disposition of materials at the end of life of the building.

significantly inaccurate and could lead to design decisions that actually increase the environmental impact of a building.

All LCI data used must be compliant with the international LCA standards ISO 14040 and 14044. For North American construction projects, the LCI data should be North American in origin, and the LCIA method should be TRACI[14]. See Table 5 for LCIA requirements of each program. Where no methodology is stipulated, we recommend the latest version of TRACI be applied.

Table 5: LCIA Methodology Requirements

LEED v4	Green Globes 2013[15]	IgCC 2012	Calgreen 2010/2012
•TRACI, v2.1 or newer; or •CML, v2001 or newer; or • ReCiPe, v1.07 or newer.	TRACI, v2.1 or newer	none stated	none stated

The IE4B is in alignment with these North American data and method requirements, and additionally meets all of the other requirements of each program. In other words, practitioners using the IE4B for program compliance do not need to concern themselves with the underlying data and method. Note as well that the IE4B has been specifically designed for non-LCA practitioners working in construction-sector applications.

Whole-building LCA can alternatively be approached from first principles, using LCA practitioner software tools such as SimaPro and GaBi. This is a complex process undertaken by LCA professionals and will require careful adherence to the data, method and boundary provisions of the programs.

For those wishing to dive deeper, we provide supplementary best-practice recommendations related to data sources, methodology, and tools in Appendix A.

[14] *Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts* (TRACI) is an LCIA methodology developed by the US EPA. See: *http://www.epa.gov/nrmrl/std/traci/traci.html* for further information.

[15] Use this column as well for the Guiding Principles Compliance for New Construction.

3.4 Achieving a Fair Comparison

When using LCA to compare one object to another, it's critical that the two objects of study be functionally equivalent – their designs must deliver the same function(s). For example, a small school and a large hospital are both buildings, but they are not functionally equivalent.

The two buildings being compared must have the same:

- Use (type of occupancy);
- Gross floor area[16];
- Location.

In addition, the Reference Building should be a legitimate alternative to the Proposed Building. None of the programs provide detailed guidance in crafting a Reference Building that is a legitimate alternative. In our opinion, both buildings should meet minimum relevant building code and other regulatory requirements, and the Reference Building should be a reasonable solution to the design problem at hand; in other words, it meets client expectations and is appropriate within its context. There is considerable room for individual interpretation of what defines a legitimate Reference Building. See our recommendations in Appendix B for our opinion on this matter.

Regarding operating energy, although only some programs include this in the LCA results, all programs have requirements to assist with functional equivalency. See Table 6.

Table 6: Operating Energy Performance Functional Equivalency Requirements

LEED v4	Green Globes 2013[17]	IgCC 2012	CALGreen 2010/2012
The same operating energy performance and at least meets the requirements of the EA prerequisite *Minimum energy performance*	If the assessments exclude operating energy, the operating energy performance of the building enclosure elements must be equivalent. If the assessments include operating energy, the buildings must comply with Green Globes minimum energy performance requirements.	Meets the minimum energy requirements of the IgCC	Meets the minimum requirements of the 2010 California Energy Code

[16] It is widely recognized that in many cases "number of occupants" is conceptually a better metric than "gross floor area" to evaluate whether two or more buildings are functionally equivalent, since it incentivizes efficient use of floor area (i.e. using less materials to serve the same need). Similar to energy performance evaluation, the whole-building LCA provisions in green building programs do not yet incorporate a credible basis (e.g. statistics) for project teams to demonstrate increased occupant density.

[17] Use this column as well for the Guiding Principles Compliance for New Construction.

The exclusion or inclusion of operating energy from LCA scope influences how to approach the Reference Building design:

1. **When operating energy is excluded from LCA scope, the Reference Building must have an energy performance equivalent to the Proposed Building**.
   This provision helps keep the comparison fair because buildings with different energy performance characteristics (e.g. thermal properties of the envelope) likely have different types and volumes of materials in the envelope. For example, a "passive house" has much more material mass (and therefore higher embodied LCA impact) than a traditional light-frame house. We can only compare these two in LCA if we also include the energy performance, so that the "passive house" will get credit over the life cycle for its reduced operating impact. When operating energy is excluded from the LCA, the focus is strictly on materials and therefore we need to ensure that the materials are functionally equivalent – the thermal envelope of both buildings must deliver the same thermal performance. Otherwise, a proposed building with very little insulation will beat a highly-insulated reference building.

2. **When operating energy is included in the LCA, the Reference Building must have at least the minimum energy performance noted in Table 6.**
   In this case, the tradeoffs or benefits of operating energy design are included in the LCA scope and should therefore be used to advantage. If the operating energy design of the Proposed Building exceeds the minimum requirements of Table 6, it will generally use more materials (and have higher embodied effects), but use less operating energy (which means lower operating energy use effects), relative to a functionally equivalent Reference Building that meets the minimum requirements. While not always the case, reducing operating energy at the expense of increased material usage generally has a positive net effect on the environmental performance of a building. Therefore, the most common strategy will be for the Reference Building to have the minimum operating energy performance stipulated in Table 6, such that the Proposed Building (with assumed better energy performance) shows reduced impacts relative to it.

The way in which the two assessments are conducted must also be the same to ensure the results are comparable. This requires that the following are the same:

- Object of assessment;
- System boundary;
- Study period;
- Scope and precision of material and operating energy use estimates;
- LCA tool used and underlying data sources.

See Appendix A for further suggestions and opinions on achieving a fair comparison.

4 THE ASSESSMENT PROCESS

The programs considered in this document require that the project team perform whole-building LCA for two building designs: the **Proposed Building** seeking compliance, and a **Reference Building** that serves as a performance benchmark. The general process by which compliance is met using the IE4B is shown schematically in Figure 3.

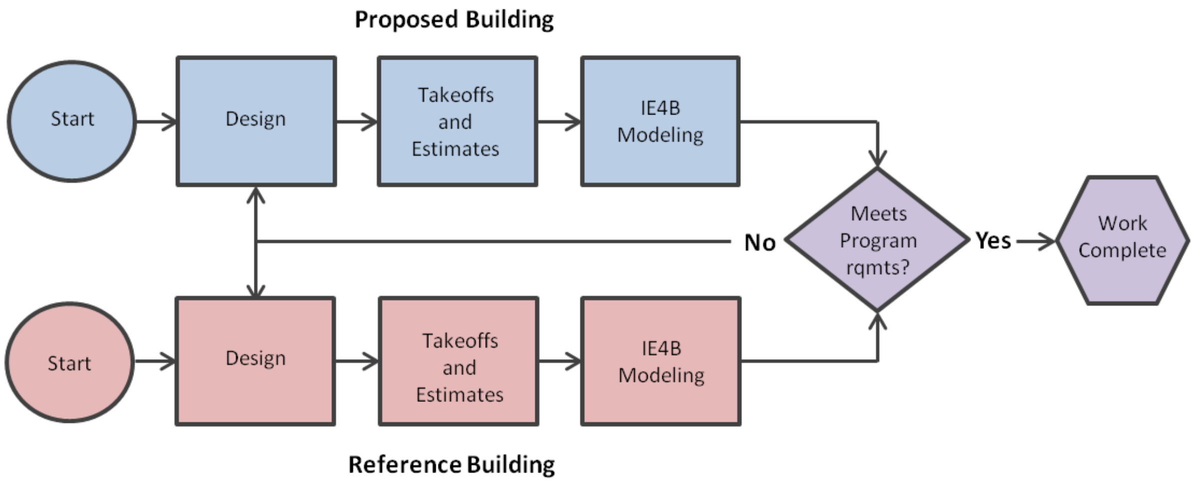

Figure 3: Comparative Whole-building LCA Process

The points at which the various tasks occur during the design phase of a project will vary, but this will generally be an iterative process because:

- The Proposed Building design will become more detailed and likely will be modified over the course of the design phases. The Reference Building may have to be correspondingly modified to maintain functional equivalency (e.g. a situation where the Proposed Building's gross floor area is reduced).
- The Proposed Building will not always meet the improvement target – either the Proposed Building, the Reference Building, or both may be modified in that case.

The LCA work is complete when the Proposed Building design iteration that is to be submitted to officials to demonstrate compliance (i.e. not an early iteration) meets the program requirements.

The process of conducting a single assessment iteration requires the following four tasks be performed:

1. Building design: determine building geometry, and select and size construction assemblies. The IE4B performs some structural sizing – see Section 4.3.1 for further information.
2. Takeoffs and estimates: If not using the IE4B built-in bill of material estimates, perform manual takeoffs or prepare a bill of materials output file from a CAD program. If operating energy is included in assessment scope, collect fuel use information from energy simulation software or another source.

3. Perform LCA modeling with the IE4B.
4. Check for compliance with program targets and confirm that LCA study requirements are met. If not, repeat the steps.

To put this process in a familiar context, consider that LCA's role and task requirements during building design are similar to traditional cost estimating practice – both aim to inform the project team whether the design meets particular criteria (i.e. a cost or environmental impact target) based a building's use of resources (e.g. materials, energy). Cost estimating practice provides a good template for operationalizing the use of LCA during building design. For example, we recommend the following:

- The scope and accuracy of the assessments should generally mirror that of the Proposed Building as it progresses through the design phases. The primary goal of whole-building LCA work should be to confirm with sufficient confidence that the Proposed Building is generally on track to meet compliance requirements or find ways to keep it on track – not produce overly detailed results before the design is finalized.
- If a cost estimator is involved in the project, the timing of LCA work should be aligned with the costing process to provide integrated economic-environmental decision-making to the extent possible.

4.1 Developing the Reference Building Design

The requirement that the Proposed and Reference Buildings be functionally equivalent provides a starting point to interpret the design requirements of the Reference Building. Yet, none of the green building programs is clear on the definition of a Reference Building. The functional equivalency of two or more buildings ensures a degree of comparability between them – but comparability alone does not address what a proper performance benchmark ought to be. In our opinion, this is the major challenge facing anyone who is trying to comply with these programs. Our suggested Reference Building best-practice recommendations found in Appendix B aim to fill some of the gaps on this issue.

When designing the Reference Building, first consider the following two tips for reducing the amount of Reference Building design work:

- At least some of the design may be identical to the Proposed Building. For example, if the Reference Building structure provides sufficient impact reductions to demonstrate program compliance, it is unnecessary that it additionally have a unique partition layout, choice of finishes, etc.
- Table 3 identifies mandatory and optional building elements to include. Don't include the optional elements unless you are sure they will help you.

Then, consider the operating energy performance requirements presented in Table 6. To recap:

- For programs that <u>exclude</u> operating energy in assessment scope, the intent is that the Reference Building have the same operating energy performance as the Proposed Building. In this case, some project teams may choose to retain the Proposed Building enclosure design in order to more easily demonstrate operating energy performance equivalency.

- For programs that include operating energy in assessment scope, the most common approach will be for the Reference Building to have the minimum stipulated operating energy performance. In most cases, the Reference building will therefore have an enclosure design that is different than that of the Proposed Building;

Finally, given the lack of direction provided by the programs, we anticipate that design aspects (e.g. structure, partitions) unique to the Reference Building will generally come from any combination of the following:

1. **An early iteration of the Proposed Building.**
   The intention behind the LCA provisions seems to be the following: to motivate the use of LCA in design development. In other words, the Reference Building is the Proposed Building design at the conceptual stage – LCA results for this early design are used to make design refinements for reduced environmental impact, leading to a Proposed Building with better LCA results. This is an application for LCA that we strongly support. Please note that the Reference Building design may have to be modified somewhat such that it is functionally equivalent to the final Proposed Building design.

2. **An alternative design.**
   If the project team was considering more than one design option for the building, a rejected option could be used for the Reference Building. LCA investigation of design options could be part of the decision-making process in choosing a final design for the building.

3. **An existing building.**
   The Reference Building could be a constructed building where sufficient documents (e.g. drawings, specifications etc.) are available to the project team such that accurate materials takeoffs and energy simulation (if included) can be performed. The intent of this approach is two-fold: to provide a real-world benchmark for the project team to demonstrate design improvement, and to reduce the amount of Reference Building design work. The complication of this approach is that the existing building must be modified to ensure that it is functionally equivalent to the Proposed Building – this inevitably requires some interpretation. We think this approach is particularly applicable to defining the structural design of the Reference Building. To this end, we have proposed two streamlined methods for using the structure of an existing building – see Appendix C.

4. **A building archetype.**
   The Reference Building could be an already-completed but unconstructed building design. The intent of this approach is to reduce the amount of Reference Building design work. Similar to the use of an existing building, the complication of this approach is that the design must be modified to ensure that it is functionally equivalent to the Proposed Building, which inevitably requires some interpretation.

The IE4B can perform some of the tasks associated with the design of the Reference Building, which we explain below in the section on modeling.

Given that the Reference Building design may be a composite of the various design approaches noted above and change over the course of the design process, care must be taken to ensure that its final design is a seamless, feasible, and constructible building. For example, design aspects that would not be approved by local building officials should not be used.

When the Proposed Building is complicated or material-intensive, care should be taken in designing a well-matched Reference Building; for example, the Reference Building should be equally material-intensive – otherwise, the Proposed Building will be unable to show relative improvement. One tip for achieving a fair playing field is to design the Reference Building with the same building geometry and basic structural layout.

4.2 Take-offs and Estimates

Before starting the IE4B modeling, users need to quantify the building's use of materials (i.e. material takeoffs) and, if operating energy is included, annual use of fuels for operation as estimated via energy simulation or other calculation means. The accuracy of a whole-building LCA can be as dependent on the quality of the material and operating energy use calculations as it is on the LCA data and methods used. Good practice at this stage of work is therefore very important to ensuring reliable LCA results.

Material takeoff quantification and energy simulation are well-established practices and guidance on how to perform these tasks is not in the scope of this document. However, in our opinion the whole-building LCA model inputs should be of similar quality as standard practice in other types of building performance assessment tasks. More specifically:

- The scope and accuracy of material takeoffs should generally be equivalent to those performed for cost estimating, e.g. as advocated by the American Society of Professional Estimators (ASPE), Canadian Institute of Quantity Surveyors (CIQS), etc.;
- Energy simulation should be performed in accordance with the requirements of the green building program.

Material takeoff quantification can be time consuming, particularly for those unfamiliar with the practice. When project teams include an individual that is either already calculating material takeoffs (e.g. a cost estimator) for the Proposed Building, or has the capacity to do so efficiently (e.g. a BIM modeler), we recommend that these sources of takeoffs be used whenever practical so that work is not duplicated.

4.3 IE4B Modeling

The IE4B functionality allows any member of the project team with a basic understanding of the software to perform whole-building LCA modeling. See the IE4B User Manual for detailed guidance and to better understand the inner workings and find best-practice tips. In this section, we provide only an overview with respect to use of the IE4B for green building program compliance.

4.3.1 Building Materials

The IE4B software performs LCA calculations on the materials and construction assemblies contained in the building. User inputs help the software determine the type and quantity of materials. There are two approaches to doing this: the software can automatically determine materials and quantities based on some high-level inputs from the user (area, spans, loads, type of construction system, etc), or the user can directly input material information (for example, by generating a bill of materials output file from a CAD program). In other words, building material modeling with the IE4B can be performed using either of the following two approaches, or a combination:

- Building geometry is input into the program's various "Assembly" input dialogs and the assembly characteristics are prescribed. The IE4B then performs some of the structural design (e.g. beam sizing), calculates the resulting bill of materials, and generates LCA results.
- Material takeoffs are calculated outside the program (for example, by hand or by a CAD program) and input into the "Extra Basic Materials" input dialog. The IE4B then generates LCA results based on the bill of materials (BOM) of quantities input.

Maintaining a fair comparison between the Reference and Proposed Buildings requires some care with regard to how material quantities are created in the IE4B. Letting the software calculate materials via the Assembly dialogs is the quickest and easiest way to use the software, but there are some drawbacks. It is important to understand that the Assembly dialog functionality was developed for use during the early stages of design, in particular for informing conceptual design. More specifically, the dialogs excel at quickly modeling common construction assemblies because the user doesn't need to do structural sizing or material takeoffs. This enables easy and quick high-level comparison of building design options during early design. But the Assembly dialogs can be limiting in later design stages, when more detailed assessments are required. This is because the dialogs have most, but not all common assemblies available, they can't model complicated design details, and they model generic assemblies – not the specific structural design of a building.

A combination approach can overcome the limitations of the Assembly dialogs. After initially creating a project using Assembly dialogs, the user can then tweak the material quantities and types directly, by using the Extra Basic Materials dialog.

The most flexible and precise approach is to use only the Extra Basic Materials dialog for identifying material types and quantities. This is easily done when the building is already created in a CAD program, which can then be used to export a bill of materials file. The IE4B has in import function to read that file and map the CAD materials to the IE4B material files. Alternatively, material quantity take-offs according to the specifications previously described also works well.

It may be tempting to use only the quick Assembly dialogs to create the LCA models for both the Reference and the Proposed buildings. However, in our opinion, the final Proposed Building assessment needs to reflect the actual building design as closely as possible. This means actual material quantities (input through the Extra Basic Materials dialog) should be used, rather than the estimated material quantities internally generated by the IEB when using the Assembly dialogs. In other words, the various elements comprising the final Proposed Building assessment should be modeled via either:

1. The Extra Basic Materials dialog with takeoffs calculated outside the IE4B; or
2. The Assembly dialogs, provided the resulting bill of materials is adjusted using the Extra Basic Materials dialog to reflect the actual material usage of the Proposed Building element(s) modeled.

There is more flexibility in how the final Reference Building can be modeled, since its design is only subject to the green building program requirements. In this case, the various elements comprising the final Reference Building assessment should be modeled via either:

1. The Extra Basic Materials dialog with takeoffs calculated outside the IE4B; or
2. The Assembly dialogs, provided the model is representative of the Reference Building element(s) modeled, or otherwise provided the resulting bill of materials is adjusted using the Extra Basic Materials dialog to reflect the actual material usage of the Reference Building element(s) modeled.

We consider an Assembly dialog model to be "representative" of the Reference Building design if all of the following requirements are met:

1. The Assembly dialog models the same assembly and/or materials as specified by the Reference Building design.
2. Geometric properties of the assembly (e.g. spans, wall thicknesses, etc.) are within the allowable limits of the Assembly dialog and/or among the available prescriptive options in the Assembly dialog.
3. Where relevant, the applied live loading is available in the Assembly dialog.

When assessing which modeling approach to take (i.e. use of the Assembly dialogs vs. the Extra Basic Materials dialog), consider the following:

- The Assembly dialogs are very useful for the conceptual design phase; however, as the design is formalized (i.e. more detailed), the assessor may wish to switch to modeling via the Extra Basic Materials dialogs. In such cases, be aware that results (particularly those related to structure) may noticeably change as the underlying material takeoffs are adjusted.
- Modeling via the Assembly dialogs produces structural designs that are generally low in material use since they [1] reflect minimum requirements, i.e. they don't include a comfort factor, and [2] they don't account for design details that tend to be more material-intensive.
- The Assembly dialogs automatically include some ancillary materials (e.g. roof assemblies incorporate flashing materials). While these materials tend not to account for a significant share of impacts, they may create unwanted differences when the Proposed and Reference Buildings are modeled using different approaches.

4.3.2 Operating Energy

The IE4B is not an energy simulation program but it does include the option of inserting energy modeling results to determine resulting LCA impacts. This is quite straightforward – the user simply inputs annual fuel use estimates for each fuel (as calculated outside the IE4B) into the "Modify/Add project" input dialog.

4.3.3 Combining IE4B and EPD Results

We anticipate that some IE4B users will want to add the results of a product-level EPD to whole-building results produced by the software. While we don't recommend this practice for people new to LCA, IE4B and EPD results may be combined provided the EPD:

1. Has not expired;
2. Is applicable to the project location;
3. Reports all indicators and cradle-to-grave information modules required by the program;
4. Characterizes the impact categories reported according to TRACI v2.1 methodology;
5. Can be applied to the study period of the assessments;
6. Does not reflect industry-wide weighted average results of a material or fuel available in the IE4B.

4.4 Reducing Environmental Impact

LCA provides performance data such that we can take action to reduce the environmental impact of a building design, the same way cost estimates inform the process of reducing construction costs. We recommend the three-step procedure outlined in this section to use LCA to efficiently inform decision-making throughout the building design process leading to minimized environmental impact of the final building.

Step 1: Identify the building's environmental "hot spots"
Hot spots are building aspects that are responsible for large shares of impact, i.e. those we want to direct our attention to when looking to make significant improvements. This can be done by grouping LCA results in various ways, or in LCA lingo, performing "contribution analysis."

Try grouping results by:

- Life cycle stage or information module;
- Embodied versus operating energy effects;
- Building element or trade (embodied effects only);
- Energy end-use or fuel type (operating energy effects only);
- Portions of building with different use of materials and/or construction assemblies and/or operating energy performance;
- Floor level, building wing, project phase, etc.

Contribution analysis requires detailed, granular LCA models that can be time consuming and may be outside the scope of the IE4B. Save time by applying experience and intuition to make some informed assumptions about the hot spots. For example, it is intuitive that a roof assembly will contribute more to the impact of a one-storey industrial building than a high-rise residential building.

Step 2: Evaluate strategies to reduce environmental impact
Having found the hot spots, now propose some approaches for improvement and then evaluate them. Experiment with each proposed change one at a time: incorporate each change in the base model and compare the new IE4B results to the original results. Reject strategies that make no difference. Maybe there’s a clear winner that makes a big difference by itself. Or maybe several strategies make a small difference on their own – combine them. The

analyses should include all six required impact indicators in order to avoid hidden impact tradeoffs that might occur.

An easy way to reduce LCA impacts is to reduce the quantity of materials used and fuels consumed. Strategies for reducing building material and operating energy fuel use might include:

- Minimizing the surface area of the building.
- Establishing the building geometry (e.g. footprint, floor thicknesses) and structural layout/system in tandem in order to produce an efficient structure.
- Reviewing structural member sizing and typical details in order to reduce material use where possible.
- Reducing the use of materials that are not specifically needed to fulfill the performance requirements of an assembly (e.g. leaving structure exposed).
- Selecting materials and/or construction assemblies with longer service lives, such that they are replaced less over the building life cycle.
- Reducing operating energy consumption. This strategy is often the low-hanging fruit in terms of lowering the environmental impact of a building, but often involves increased material usage (e.g. thicker insulation) and/or use of high-impact materials (e.g. photovoltaic systems). When exploring energy reduction strategies, additionally consider implications in terms of embodied effects.

Another tactic is to search for lower-impact building materials and operating energy fuels. Strategies might include:

- Substituting new materials with salvaged materials – see the IE4B User Manual for instructions on how to model this.
- Modifying the composition of the concrete mix – this can be done within the IE4B input dialogs.
- Evaluating material or construction assembly alternatives that perform the same function (e.g. comparing various cladding types on a per-unit-area basis). Be careful to consider unintended design consequences that might occur, e.g. brick cladding requiring a thicker foundation wall.
- Switching service systems to those that use lower impact operating fuels, e.g. a natural gas fuelled chiller may perform better than an electric chiller when the building draws on grid electricity that is generated predominantly by coal-fired plants.

Step 3: Finalize strategies within the project context

Narrow down the options by considering which impact-reducing strategies fit best with other design criteria such as cost, constructability, aesthetics and so forth. Or, take a deeper LCA look – there are advanced LCA strategies such as normalization and weighting that can be applied, or LCA results can be integrated with other performance metrics in multi-attribute decision analysis. These advanced techniques are beyond the scope of this document.

5 A FEW LAST WORDS

LCA is a powerful tool to help sustainable design move towards a performance basis. LCA puts real numbers on some of the environmental impacts caused by construction, and provides a rational basis for sustainability choices in design. If we're going to claim environmental benefit for design strategies, we ought to have a verifiable scientific basis for doing so, and LCA is one of those mechanisms.

But LCA is a complicated science typically left to experts to practice. At the Athena Institute, we've created a tool to make LCA accessible for construction sector practitioners. This requires us to simultaneously assist in the proper application of LCA. We are doing this through webinars, educational resources on our web site, and guides like this document. It's important that anyone new to LCA fully understand its complexities and limitations. LCA is a predictive science with uncertainties and data gaps. It should be used as an estimating tool, not a tool that measures precisely. This means it should inform but not necessarily dictate design decisions. Most importantly, LCA addresses only some of the environmental impacts of interest in a sustainability agenda. The other impacts need to be measured with other tools.

The incorporation of LCA in green building programs is a very ambitious leap forward. We expect to see substantial evolution of the LCA provisions in those programs as design professionals and sustainability consultants increasingly pick up LCA. The science of LCA will evolve as well – the methods and databases are constantly improving.

It's important that LCA be used appropriately; otherwise, it can be the basis for sophisticated greenwash or – worse – lead to the wrong choices. But when used carefully, LCA is a tremendous help for designers leading the way to the next generation of sustainable buildings.

The Athena Institute has a mandate to bring LCA to the entire construction sector for a verifiably lighter footprint of the built environment. Our supporters help us continually refine and extend our LCA databases on construction materials and processes, regularly update the IE4B and keep it free, and provide LCA education and advocacy. Visit us at www.athenasmi.org to learn more.

APPENDIX A: FURTHER RECOMMENDATIONS FOR PROGRAM COMPLIANCE

This appendix provides our opinions and recommendations for program compliance beyond the minimum guidance we address in the main document. These are our advanced best-practice tips based on our take on the green building programs. Please note these recommendations are strictly our own and should not be interpreted as in any way required by the green building programs.

Note: some of the recommendations presented are automatically taken care of when using the IE4B, particularly sections related to "System Boundary" (Recommendation B), and "Scenarios" and "LCI Data" (Recommendation C).

Recommendation A: Compliance Requirements

A.1. Where no exceedance limit is stipulated in Table 2, the Proposed Building impact indictor results may exceed that of the Reference Building by any amount.

A.2. The default study period should be the required service life of the owner or relevant regulation, or determined via service life planning methods. In the case that the default study period is outside the allowable bounds stipulated by the green building program, it should be the appropriate minimum or maximum.

Recommendation B: What to Include

__Object of Assessment__

B.1. The following building products may be excluded from the object of assessment scope, provided they are excluded from both Proposed Building and Reference Building assessments:

a. Non-structural fasteners, clips, etc. connections (e.g. nails, screws, bolts);
b. Surface treatments (e.g. weatherproofing, fire retarding coatings);
c. Adhesives and sealants;
d. Gypsum board ancillary and finish materials (e.g. joint compound, paper tape, paint) provided wall and/or ceiling finish elements are not in assessment scope;
e. Flashing, fascia, soffit, drain covers, vents, roof hatches, etc.;

f. Temporary works used during construction and demolition/de-construction phases (e.g. shoring, formwork);
g. Other building products forming part of the Proposed Building that are unavailable in the LCA tool, provided:
    i. The use of proxy materials is not possible; and
    ii. The product accounts for less than 1% of the building mass and capital cost.

B.2. The object of assessment should include the material effects of the following renewable energy generation system components, including support structure, if they are accounted for in the operating energy performance of a building assessment:
a. Photovoltaic panels;
b. Solar thermal collector panels;
c. Wind turbines.

System Boundary

B.3. Unless otherwise noted, the system boundary of assessments should conform to the requirements of EN 15978, for life cycle activities required by the program.

B.4. When included in the assessments, the system boundary of the following EN 15978 information modules should at minimum include the effects of:
a. *Raw Material Supply* (A1), *Transport* (A2), and *Manufacturing* (A3): all relevant cradle-to-gate activities.
b. *Transport* (A4): transport of materials to site.
c. *Construction-installation Process* (A5): construction equipment energy use, and the production, transport, and disposal of material waste produced during construction.
d. *Use* (B1): emissions to and from materials during building use.
e. *Maintenance* (B2), *Repair* (B3), *Replacement* (B4), *Refurbishment* (B5): the production and transport of replacement materials, and transport and disposal of replaced materials.
f. *Operational Energy Use* (B6): energy extraction, transport/distribution, and combustion/use.
g. *De-construction Demolition* (C1): de-construction/demolition equipment energy use.
h. *Transport* (C2): transport of waste to disposal facility; transport to waste processing/storage facilities when *Waste Processing* (C3) is included.
i. *Waste Processing* (C3): energy use of waste handling and processing activities post de-construction/demolition until an end-of-waste state for relevant materials is reached.
j. *Disposal* (C4): disposal facility waste handling and landfilling/incineration effects.

B.5. The system boundary may be expanded to include EN 15978 information module *Benefits and Loads Beyond the System Boundary* (D) for a particular material, provided:
a. For any given material, the same system expansion occurs in both Reference and Proposed Buildings assessments (e.g. the structural steel of both building cases);
b. If system expansion has been applied, it similarly needs to be applied in both the Reference and Proposed Building cases on an assembly-equivalent basis (e.g. Reference vs. Proposed Building roof structure);
c. The system boundary includes information module *Waste Processing* (C3) for materials

which undergo system expansion.

B.6. The system boundary may be expanded to include EN 15978 information module *D Benefits and Loads Beyond the System Boundary* for energy exported from the building, provided the system is expanded for all types of energy exported, for both Reference and Proposed Buildings assessments.

B.7. Carbon sequestration of wood products and/or carbonation of concrete may be included in the system boundary, provided:

a. They are included in both Reference and Proposed Building assessments;
b. The methodology used has been published in a peer-reviewed journal and is considered contemporary acceptable practice;
c. The underlying data (e.g. methodological parameters, scenarios) used is representative of the project.

B.8. The global warming potential effects of land use change at the project site may be excluded from the system boundary.

Recommendation C: Data, Methodology and Tools

Scenarios

C.1. Scenarios should be representative of contemporary technologies and/or practice, and the project location.

C.2. Scenarios should by default come from the LCA tool (i.e. internal databases) and/or EPDs used, and otherwise may come from (in order of preference):

a. Known project-specific information (e.g. material transportation distances);
b. Product-specific information produced in accordance with a recognized standard (e.g. a service life planning report in accordance with the ISO 15868 standard series);
c. Generic third-party information applicable to the product (e.g. other databases or statistics);
d. Product-specific information not produced in accordance with a recognized standard.

C.3. If the service life of a building product is less than the study period of the assessments, the number of times product replacement occurs over the study period should be calculated according to the following equation:

Number of Replacements = (Study Period - Product Service Life) / Product Service Life

C.4. Operating energy use over the study period may be based on an energy use estimate determined for a single year.

C.5. Proposed Building information module *Refurbishment* (B5) scenarios should come from a documented (including completed design), building owner approved refurbishment plan. When required, the Reference Building assessment should include an assumed refurbishment scenario to maintain functional equivalency with the Proposed Building.

LCI Data

C.6. The LCI datasets used should be representative of contemporary technologies and/or practice, and the project location.
C.7. The grid electricity LCI data used should by default be the dataset available in the LCA tool that is most representative of the project location, and should at minimum reflect a national average.
C.8. The grid electricity LCI data used should not reflect the purchase of Renewable Energy Certificates (RECs) and/or bundled green power products.
C.9. Methodologies used to calculate emissions for information module *Use* (B1) (e.g. VOC off-gassing) should come from a recognized standard.

LCA Results

C.10. Global warming potential results should not be reduced with carbon offsets purchased for the project.
C.11. Results from the LCA tool and an EPD may be combined provided the EPD:
- a. Has not expired;
- b. Is applicable to the project location;
- c. Uses the same LCIA methodology as results generated by the LCA tool;
- d. Reports all indicators and information modules required by the program;
- e. Can be applied to the study period of the assessments.

Recommendation D: Ensuring a Fair Comparison

D.1. The Proposed Building and Reference Building should have the same:
- a. Pattern of use;
- b. Usable floor area for each type of occupancy;
- c. Required or estimated service life.

D.2. Gross floor area should be calculated according to a standardized methodology produced by a professional organization.
D.3. The gross floor area of the Proposed and Reference Buildings should be within 1%.
D.4. For assessments that do not include operating energy in scope: operating energy performance equivalency may be demonstrated either of the following ways:
- a. Directly: Proposed Building and Reference Building energy simulation results are similar; or
- b. By proxy: Proposed Building and Reference Building enclosure elements have similar effective thermal resistances.

APPENDIX B: FURTHER RECOMMENDATIONS FOR THE REFERENCE BUILDING DESIGN

In this appendix, we present some high-level guidance on what in our opinion constitutes a proper Reference Building design. The recommendations presented are not exhaustive and are meant to provide a starting point for discussions on the matter. We anticipate that feedback we receive from the application of whole-building LCA in the green building programs will inform future modification and revisions.

Recommendation E: Reference Building Design

E.1. The design should be feasible and constructible.

E.2. The following design aspects should be reasonably similar to the Proposed Building:
  - a. Architectural complexity;
  - b. Number of above grade and below grade floors (e.g. 5 vs. 50 floors not acceptable);
  - c. Floor heights (e.g. 3.5m vs. 5.5m floor height not acceptable);
  - d. Design features (e.g. open-concept spaces);
  - e. Allowance for the size of structure (e.g. beam depth).

E.3. Relative to the Proposed Building, the building geometry of the design should not:
  - a. Excessively reduce the capacity to produce a reasonably efficient structure.
  - b. Excessively increase the following loads:
    - i. Snow loads;
    - ii. Overturning loads.
  - c. Excessively increase operating energy demand.

E.4. The building footprint of the design should provide sufficient site area for the project's external works.

E.5. Structural design unique to the Reference Building should have the following attributes reflecting typical practice:
  - a. A predicted service life equal to, or greater than, the building service life;
  - b. Spans generally within accepted useful ranges;
  - c. A layout that transfers loads to the foundation in a reasonably efficient manner;
  - d. A foundation system that is appropriate for the geotechnical conditions of the project site and the supported loading.

E.6. Enclosure design unique to the Reference Building should reflect typical practice and reasonably efficient use of constituent materials.

E.7. The total linear length of interior partitions (i.e. fixed + movable + glazed) and/or associated number of doors should be either:
  - a. The same as the Proposed Building design (early or final design iteration); or

b. The same as that of an existing building available to the project team, over an equivalent gross area, serving the same function.

E.8. The design should be comprised of materials, assemblies, and service systems that are considered contemporary, available, and reasonably economical for the project location.

E.9. Relative to the Proposed Building, the design should not include materials, assemblies, and service systems that have been used in an unconventional manner, including:

a. For a purpose other than what intended for;
b. In an unconventional context.

E.10. Relative to the Proposed Building, the design should not exhibit arbitrary, excessive material use, including:

a. Over-sized structural elements and non-structural materials;
b. Material use in excess of what is required, or not specifically required, to meet fireproofing, sound attenuation, vibration, etc. performance requirements;
c. Redundant material use.

APPENDIX C: RECOMMENDATIONS FOR CREATING THE REFERENCE BUILDING STRUCTURE BASED ON AN EXISTING BUILDING

This Appendix presents two methodologies for deriving the structural design of the Reference Building from an Existing Building. For the purpose of this document, an Existing Building is a building which has been recently constructed and whose construction documents are available to the project team.

The structural aspects that apply to this appendix include the following elements (including connections):

1. The foundation, including
    a. Spread, strip, mat footings
    b. Piles, caissons
    c. Piers, grade beams
    d. Tie-down anchors
2. Floor and roof structure, including:
    a. Slabs on grade, framed slabs, structural panels, decking, stairs
    b. Joists and trusses
    c. Structural sheathing and toppings
3. Structural framing, including:
    a. Columns, struts, bracing, etc.
    b. Beams, purlins, girts, lintels, etc.
    c. Trusses and frames
4. Above and below grade load-bearing and retaining walls, including:
    a. Stud walls, including structural sheathing, bracing, etc.
    b. Solid walls (e.g. concrete and masonry)
    c. Panel (e.g. cross-laminated timber) and composite panel (e.g. structural insulated panels) walls

It is important to remember that the Reference Building must be functionally equivalent to the Proposed Building. This requirement has the following consequences for structure:

1. The gross floor area of the Reference and Proposed Buildings must be the same.
2. The proportions of occupancy-related live loads imposed on the Reference and Proposed Building structures should be the same.
3. The Reference and Proposed Building structural designs should reflect the project's site conditions.

The loading a particular structure must resist is dependent on its location, geometry, occupancy, choice of assemblies, etc. Therefore, when the structural design of a Reference Building is derived from another building (e.g. an Existing Building), the design will not precisely reflect the actual loads imposed on it. Additionally, the characteristics of the materials that support the Existing and Reference Buildings (e.g. soil, bedrock) will often be different between sites. It is for this reason that the recommendations presented in this appendix include allowances for what in our opinion reasonably qualifies as a suitable Existing Building, and what requires redesign.

Please note that the rules presented in this appendix are intended to provide a starting point for discussions on the proposed approaches – we anticipate that the feedback we receive from their application will inform future modifications and revisions.

Option 1

This option entails approximating the Reference Building structural design using the entire structure from an existing design. This requires adjusting the structure of the existing design, normalizing the resulting material takeoffs on an area-basis, then applying the unit-area material takeoffs to the Reference Building geometry. Essentially, this option translates the material takeoffs of an existing design to the geometry of the Reference Building, as conceptually illustrated in Figure 4.

Once the basic Reference Building geometry is set, its structural design should generally be established according to the following procedure:

1. Select a qualified Existing Building (Recommendation F.1);
2. Adjust the Existing Building structure (Recommendation F.2);
3. Perform material takeoffs for the resulting Existing Building structure (Recommendation F.4a);
4. Calculate assembly areas for the Existing and Reference Buildings (Recommendation F.4b);
5. Translate the Existing Building takeoffs to Reference Building takeoffs (Recommendation F.4c).

While this option produces no actual Reference Building structure design, the effect of the structure on the Reference Building enclosure design should be accounted for. As such, it is required that the Reference Building envelope design assumes that it is supported by the various relevant Existing Building structural assemblies, at rates proportional to the Existing Building by area. For example, in the case where the total Existing and Reference Building perimeter wall areas are 1000 m^2 and 1250 m^2, respectively, a 25 m^2 section of Existing Building perimeter concrete wall should be assumed for 25*1250/1000 = 31.3 m^2 of the Reference Building.

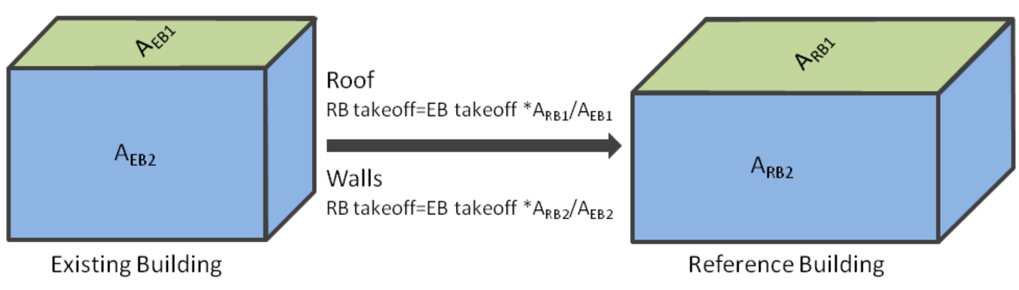

Figure 4: Use of an Existing Building for the Reference Building Structure, option 1 (elevation view)

Option 2

This option involves producing the Reference Building structural design using sections of structure from an Existing Building, adjusting the structure, and designing the remaining elements as required. For this option, a "section" is a part of the Existing Building structure and can be anything from a single structural member to a complete structural system.

Once the basic Reference Building geometry is set, its structural design should generally be established according to the following procedure:

1. Select a qualified Existing Building (Recommendation G.1).
2. Establish sections of qualified Existing Building structure (recommendations G.2, G.3).
3. Insert sections of Existing Building structure into the Reference Building geometry; infill the Reference Building with Existing Building structure to the extent possible (Recommendation G.4).
4. Adjust the Existing Building structure as required to conform to the Reference Building geometry (recommendations G.6, G.7).
5. Design the sections of the Reference Building which underwent a change of loading (Recommendation G.5), or where no section of Existing Building structure can be used to derive the Reference Building design (Recommendation G.8).

Figure 5 shows an illustrative example of some of the procedural concepts. Please note that other levels of the structure would undergo corresponding modifications.

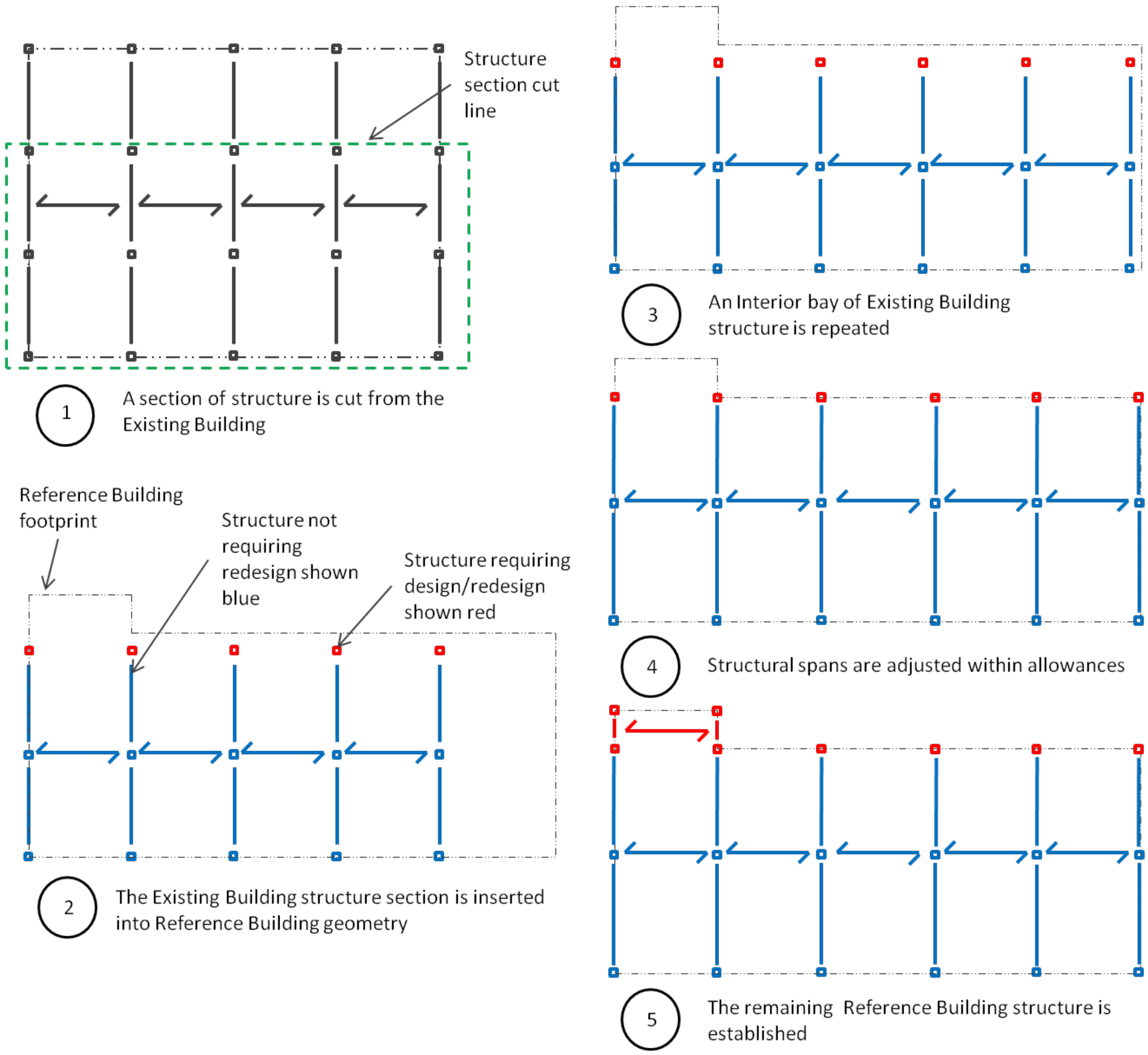

Figure 5: Use of an Existing Building for the Reference Building Structure, option 2 (plan view)

Recommendation F: Creating the Reference Building Structure Based on an Existing Building, option 1

F.1. For an Existing Building to qualify for this pathway, all of the following requirements should be met:
   a. The Existing Building is already constructed and construction documents are available to the project team;
   b. The Existing Building is in conformance with the relevant recommendations of Appendix B, Recommendation E.
   c. The Existing Building structure was designed in accordance with the same edition of the building code having jurisdiction as the Reference Building structure;
   d. The average Existing Building floor height is within 10% of the average Reference Building floor height.
   e. The average superimposed dead loads[1] are within 10% of the Reference Building;
   f. Either:
      i. The Existing Building is located in the same city as project site; or
      ii. The factored governing environmental loads (i.e. snow, rain, wind, earthquake) are each within 10% of the loads the Existing Building would experience at the project site.

F.2. The following adjustments should be made to the Existing Building structure:
   a. Floor heights should be adjusted to the average floor height of the Reference Building, without redesign.
   b. Structural elements should be redesigned as required such that the weighted average occupancy live loading is within 10% of the Reference Building.
   c. The foundation should be redesigned assuming the project site soil conditions if the soil bearing capacity supporting the Existing Building is not within 10% of the conditions at the Reference Building site.
   d. Composite panels (wall or roof, e.g. structural insulated panel, precast concrete insulated panel) providing structural support and thermal resistance within the enclosure should be redesigned assuming insulation in quantities required by the Reference Building.

F.3. It should be assumed that the Reference Building enclosure is supported by structural assemblies in the same proportions as found in the Existing Building.

F.4. The material takeoffs for the Reference Building structure should be calculated according to the following procedure:
   a. Perform material takeoffs for the adjusted Existing Building, broken down by the following assembly types:
      i. Foundation;
      ii. Lowest floor (i.e. slab on grade);
      iii. Upper floors (including support structure of the floor levels below);
      iv. Roof (including support structure of the floor level below);
      v. Above grade perimeter walls;
      vi. Below grade perimeter walls.
   b. Calculate the following assembly areas for the Existing Building and Reference Building:

i. Foundation: A = gross foundation area (same as the lowest floor area);
ii. Lowest floor: A = gross lowest floor area;
iii. Upper floors: A = gross total upper floor area;
iv. Roof: A = gross roof area
v. Below grade perimeter walls: A = net wall area
vi. Above grade perimeter walls: A = net wall area

c. Calculate the Reference Building material takeoffs according to the following equation:

$$TRB_{m,n} = TEB_{m,n} * ARB_m / AEB_m$$

where,

TRBm,n is the Reference Building material takeoff quantity for material n and assembly m
TEBm,n is the Existing Building material takeoff quantity for material n and assembly m
ARBm is the Reference Building area for assembly m
AEBm is the Existing Building area for assembly m

[1] For the purpose of this document, "superimposed dead loads" are all dead loads that are not the self-weight of structure
[2] net wall area = gross area - area of openings

Recommendation G: Creating the Reference Building Structure Based on an Existing Building, option 2

G.1. For an Existing Building design to qualify for use, the following requirements should be met:
  a. The Existing Building is already constructed and construction documents are available to the project team;
  b. The Existing Building structure was designed in accordance with the same edition of the building code having jurisdiction as the Reference Building structure.

G.2. Sections[1] of structure should be cut from the Existing Building at:
  a. The top or bottom of a floor level for vertically oriented structure;
  b. The support of any horizontally oriented structure;

G.3. For a particular section of Existing Building structure to qualify for use in the Reference Building, the following requirements should be met:
  a. General:
    i. All structure located on levels above (e.g. column above supported by a beam) and/or below (e.g. hanging structure) which the section supports is included in the section;
    ii. Each Existing Building floor height is within 10% of the corresponding Reference Building floor height.
  b. Roof (including columns and walls of floor level below):
    i. The governing factored live loading is within 10% of the loads the Existing Building would experience on the project site;
    ii. Superimposed dead loads[2] are within 10% of those supported by the Reference Building.
  c. Floors (including columns and walls of floor levels below):
    i. The occupancy live loading is applicable to the Reference Building;
    ii. Superimposed dead loads are within 10% of those supported by the Reference Building.
  d. Foundation:
    i. The bearing capacity of the soil is within 10% that of the Reference Building site.
  e. Perimeter wall:
    i. The factored weighted-average wind load is within 10% of the loads the Existing Building would experience when placed in the context of the Reference Building;
  f. Lateral load resisting structure:
    i. The applied factored loading on the structure should be within 10% of what it would experience when placed in the context of the Reference Building.

G.4. Sections of Existing Building structure should form the Reference Building structure to the extent possible and may be used more than once and/or aggregated.

G.5. Any section of Existing Building structure that undergoes a change in loading when placed in the context of the Reference Building should be redesigned.

G.6. The horizontal span(s) of qualified sections of Existing Building structure may be adjusted by up to 5%, without redesign, to account for differences in the geometry between the Existing Building and

Reference Building. The structure that supports the adjusted span(s) should be similarly adjusted, as required.

G.7. The lengths of all vertically spanning Existing Building structure should be adjusted to the Reference Building geometry, without redesign.

G.8. Any section of Reference Building structure that cannot be derived from the Existing Building should be designed by the project team.

[1] a "section" refers to a part of the Existing Building structure and can be anything from a single member to a complete structural system

[2] for the purpose of this document, "superimposed dead loads" are all dead loads that are not the self-weight of structure