A White Paper

A Cradle-to-Grave Carbon Index for Design, Construction and Operations of Site-Specific Buildings

Boggarm S. Setty, P.E., Fellow ASHRAE, Fellow AEE[1]

and

James E. Woods, Ph.D., P.E., Fellow ASHRAE[2]

12 May 2017

(Version 3.3)

Introduction

Industry is attempting to establish procedures that can be implemented so that Carbon Indices for buildings can be achieved throughout the processes of planning, design, construction, and operations. The desire for such indices has been driven, in part, by the evolution of standards for *energy use* and *high performance* in buildings, such as the ASHRAE Standard 90 series since 1975, and the 189 series since 2010.[3] As buildings have been designed and constructed to these higher performance standards, components and systems have become more energy efficient, and the calculated outcomes in indices, such as the Annual Building Energy Utilization Index or Intensity (e.g., EUI – Btu/GSF/year or kWh/GSM/year), have tended to decrease.[4] Accordingly, estimates of *carbon emissions*[5] from these outcomes have also tended to decrease (e.g., net-zero-energy buildings -NZEBs). This decrease is shifting the focus from reductions in carbon emissions associated with energy used during operations to energy and chemical processes used during other life cycle stages of projects (*embodied carbon*[6]), such as the carbon emissions during the

---

[1] CEO and Founder of Setty and Associates, bogisetty@setty.com.

[2] Indoor Environment Consultant, jewoods3@aol.com.

[3] For example, see current versions (3)and (2)

[4] This tendency is affected by operational factors, such as motivations and incentives of occupants and owners. See white paper on NZEB by Setty and Woods for more information on these factors (4).

[5] See Glossary for definition.

[6] See Glossary for definition.

manufacture of the materials, their transportation, the construction activities themselves, and the eventual demolition and disposal.[7]

A *Carbon Index* is being introduced and explored in this paper as a *cradle-to-grave*[8] design tool that indicates the total amount of embodied and operational carbon in greenhouse gases (GHG) emitted through five stages of a building's lifespan:

- Selection of sites for new buildings
- Design procedures that include reduction of carbon emissions as an additional design objective
- Construction in itself – including acquisition and utilization of materials and manpower
- Operation of systems, which includes: HVAC, electrical, and plumbing and water treatment, over an assumed 30-year life-cycle
- End-of life treatments, which include: reuse, recycling, and final disposal of buildings and their materials.[9]

A perspective of the relative impacts that the interactive processes of design and management are expected to have during the various stages of a building's lifespan on the proposed total Carbon Index for a typical commercial building is shown in Fig. 1:

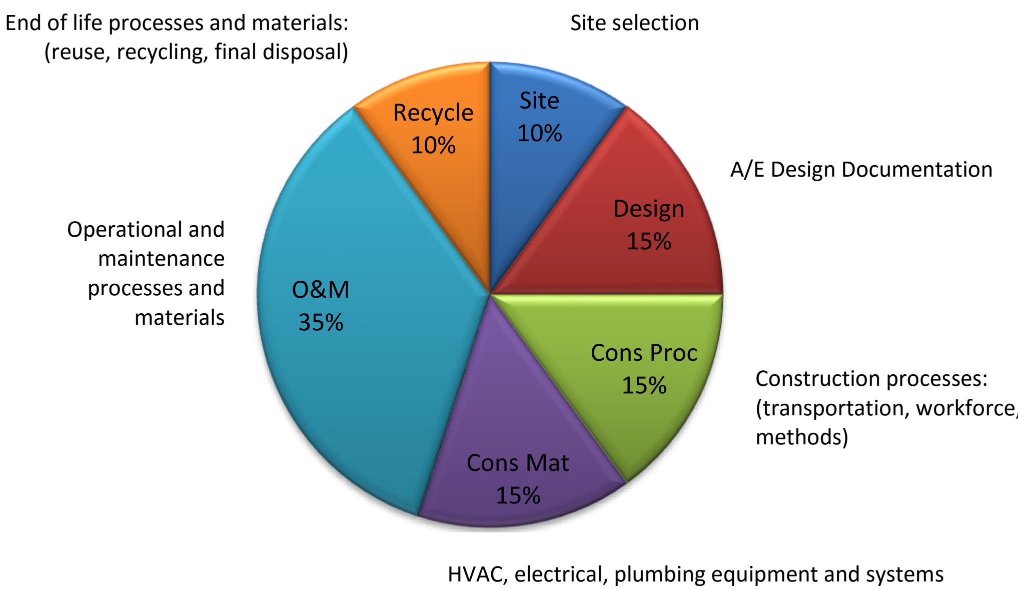

Figure 1. A perspective on cradle-to-grave impacts of building processes as percentages of a total Carbon Index for a commercial building (assumed values).

---

[7] For additional information, see (1) and (6).

[8] See Glossary.

[9] See (6) for additional discussion on "end of life" treatments.

The anticipated impacts, shown in Fig. 1, differ substantially from those in the RICS Information Paper (1), which were estimated at: 70 - 80% for operations, 15% for *embodied carbon*[10] during manufacture of products for buildings, and only minor influences from site selection, design, and construction.

These differences are fundamental. Based on experience in designing and evaluating building performance, Fig. 1 provides estimates from the perspective that designing and managing cradle-to-grave carbon emissions involve interactive decision-making during all stages of a building's lifespan. As indicated, planning, design, and construction activities (e.g., 55%) may have as much influence as operational activities (e.g., 45%) on the total carbon emission rate of a building over its lifespan (i.e., cradle-to-grave). Conversely, the RICS process passively estimates the embodied carbon emissions (e.g., 15%) from the energy used only in the *cradle-to-gate*[11] processes.

For the five stages of a building's lifespan, procedures are described below for developing a cradle-to-grave Carbon Index as a tool for interactive decision-making. Each of these procedures requires the determination of two sets of factors: 1) Primary Factors (PF) (e.g., distances to resources and amounts of materials to be transported); and 2) Carbon Impact Factors (CIF) (e.g., kg CO_2,e / mpg) that characterize the *embodied and operational carbon* in the PFs.[12] The sum of the products of the PF and CIF values will yield Carbon Indices for the five stages. While determining the quantitative values for the PFs is difficult enough, obtaining valid and reliable values for the CIFs is even more difficult.[13]

The sum of the carbon indices over the life-cycle, $\sum CO_2$, life-cycle, is defined in this paper as the Carbon Index:

$$\sum CO_2\text{, life-cycle} = \sum CO_2\text{, site} + \sum CO_2\text{, design} + \sum CO_2\text{, const} + \sum CO_2\text{, O\&M}$$

$$+ \sum CO_2\text{, end-of-life} - \sum CO_2\text{, recycling} \qquad [1]$$

Site Selection

Although architects and engineers may not be initially involved in selecting the site, it is important that they provide advice to the owner about the impact on the Carbon Index due to the building's location on the site, including:

1) Orientation of the building;
2) Proximity to resources:
    a. Grids for renewable and non-renewable electrical power;

[10] See Glossary.

[11] See Glossary.

[12] See (1) and (6) for additional discussions on Carbon Impact Factors. Examples of developing and using "Figures-of-Merit" such as "Impact Factors" were also described in (9).

[13] References (1) and (6) reveal that valid and reliable values are now just becoming available.

   b. Connection points for natural gas and other fossil fuels;
   c. Sources of water supplies;
   d. Disposal or recycling sites for sanitary and storm water; and

3) Routes and distances for transportation of materials and people to and from the site.

The Carbon Index for the site selection may be expressed as:

$$\sum CO_2, \text{site} = \sum CO_2, \text{orientation} + \sum CO_2, \text{resources} + \sum CO_2, \text{transportation} \quad [2]$$

Orientation

The placement and orientation of a proposed building on the selected site can affect: 1) the "massing" and material selections for the building enclosure/envelope; 2) the thermal, daylighting, and acoustic loads to be controlled; 3) the capacities of the HVAC and other systems; 4) the embodied carbon in the selected building components, equipment, and systems; and 5) the rates of energy and water utilization during operations.

To calculate $\sum CO_2$, orientation, the following preliminary information will be required for each placement and orientation of the building to be considered:

- Mass of each façade based on expected structural, thermal, daylighting, and acoustic loads (i.e., PFs); and the corresponding *embodied carbon*[14] impact factors (CIFs from *cradle-to-site*)[15] (e.g., kg CO_2 e / kg or m^3 material) from standardized reference sources.[16]
- Estimated sizes and material property characteristics of components and systems to provide for the health, safety, security, and functional requirements of the facility (PFs); and the corresponding embodied CIFs from cradle-to-site, such as kg CO_2 e / kg material, from standardized reference sources.
- Projected annual energy and water utilization rates and savings (PFs) over the life-span of the building structure (e.g., 30 years); and the corresponding *operational carbon*[17] impact factors (CIFs from cradle-to-site, such as CO_2,e / Btu or CO_2,e / kWh, and CO_2,e / gal H_2O or CO_2,e / liter H_2O) from standardized reference sources.[18]

Proximity to Resources

The placement and orientation of a proposed building on the selected site will also affect the amount of embodied and operational carbon in: 1) the wiring, cabling, conduits, and transformers between the connections to the building and the locations of the electrical substations; 2) piping or other means of transportation for natural gas or other fossil fuels; and 3) piping and pumps

[14] See Glossary.

[15] See Glossary.

[16] The development of these standard reference sources is just beginning. For example, see (1) and (6).

[17] See Glossary.

[18] Some standardized operational carbon emission factors have been proposed for primary energy conversion equipment for buildings. For example, see (6).

from sources of potable and other water supplies, sanitary and storm water sewers, and other sites of discharge or recycling.

To calculate $\sum CO_2$, resources, the following preliminary information will be required:

- The distances to the nearest available electrical, fuel, and water resources and disposal sites;
- The material property characteristics; and the corresponding embodied CIFs from standardized reference sources or site-specific calculations.
- Projected annual energy and water utilization rates and savings over the life-span of the building structure (e.g., 30 years); and the corresponding operational CIFs from standardized reference sources.

Transportation of Materials and People to and from the Site

The site selection will also affect access for construction, and for operations over the expected life-span of the building.

To calculate $\sum CO_2$, transportation, the following preliminary information will be required:

- Estimated distances to the site from employees' residences by private and public transportation over the life-span of the building (e.g., 30 years); and the corresponding embodied and operational CIFs from standardized reference sources.
- Estimated distances from sources of materials to the site for functional use in the building over the life-span of the building (e.g., 30 years); and the corresponding embodied and operational CIFs for transporting the materials, from standardized reference sources.

Design

The design process includes conceptual design, detailed design, and development of construction documentation. This active process is likely to have a significantly larger influence on the amount of *cradle-to-grave*[19] carbon emissions from a building over its life-span than anticipated in passive (i.e., survey) approach described in the RICS Information Paper (1). However, "designers of record" are not yet fully prepared to implement the Carbon Index calculations at the design phase, which is basically an expansion of building energy analyses. Calculations of on-site energy utilization (e.g., Btu/ft^2 or kWh/m^2) are common but results usually do not coincide with metered values, even though the methods of calculation and measuring have both advanced. Introduction of the Carbon Index will increase the complexity of these calculations, including the need to define limits-of-error and uncertainty analyses.[20]

During the design process, architects and engineers must design the architectural and other building systems such as HVAC, electrical, and plumbing systems for the health, safety, security of the occupants, and the functional requirements of the facility. These requirements impose certain

[19] See Glossary.

[20] For additional information on error and uncertainty analyses, see (7).

limitations on the design and on material and equipment selections. Therefore, in selection of the materials and equipment, architects and engineers must depend on valid and reliable embodied and operational CIFs for all the selected products.[21] These CIFs must be standardized in both the specifications and on drawings.

The Carbon Index for the design processes may be expressed as:

$$\sum CO_2, \text{design} = \sum CO_2, \text{arch} + \sum CO_2, \text{struct} + \sum CO_2, \text{civil} + \sum CO_2, \text{mech} + \sum CO_2, \text{elec} \quad [3]$$

Architectural

As the design progresses through the conceptual, detail, and documentation phases, types and quantities of materials, finishes, and furnishings are identified, detailed, and specified.

To calculate $\sum CO_2$, arch, the following information will be required:

- Specification of quantity and quality materials, components, and assemblies that comply with expected structural, thermal, daylighting, and acoustic loads.
- Optimization and/or selection of corresponding embodied and operational CIFs from standardized reference sources.

The architect should stipulate, in the specifications (e.g., Division 1 through 1b in the construction Section) and on the drawings, the Carbon Index requirements that have to be met during construction and procurement of the materials.

Structural

As the design progresses through the conceptual, detail, and documentation phases, types and quantities of materials are identified, detailed, and specified, such as concrete and masonry, steel and other metals, wood, and composite materials that support static and dynamic loads on the building,.

To calculate $\sum CO_2$, struct, the following information will be required:

- Specification and scheduling of the quantity and quality of structural systems that comply with expected static (e. g., weight) and dynamic (e.g., rain, wind, seismic) loads on the building.
- Optimization and/or selection of corresponding embodied and operational CIFs from standardized reference sources.

Civil

As the design progresses through the conceptual, detail, and documentation phases, types and quantities of materials are identified, detailed, and specified, such as concrete, metals, wood, and composite materials that support the development and maintenance of on-site streets, sidewalks, landscaping, water supply networks, sewers, and solid waste management.

To calculate $\sum CO_2$, civil, the following information will be required:

[21] See (6) for issues related to standardizing on carbon emission factors.

- Specification and scheduling of the quantity and quality of civil systems that comply with expected use of the site.
- Optimization and/or selection of corresponding embodied and operational CIFs from standardized reference sources.

Mechanical

As the design progresses through the conceptual, detail, and documentation phases, types and quantities of HVAC, plumbing, and other mechanical systems are identified, detailed, and specified.

To calculate $\sum CO_2$, mech, the following information will be required:

- Specification and scheduling of the quantity and quality of mechanical systems that comply with expected structural, thermal, daylighting, and acoustic loads.
- Optimization and/or selection of corresponding embodied and operational CIFs from standardized reference sources.

Electrical

As the design progresses through the conceptual, detail, and documentation phases, types and quantities of lighting, power, security, information technology (IT), and other electrical and electronic systems are identified, detailed, and specified.

To calculate $\sum CO_2$, elec, the following information will be required:

- Specification and scheduling of the quantity and quality of electrical and electronic systems that comply with expected electrical loads.
- Optimization and/or selection of corresponding embodied and operational CIFs from standardized reference sources.

Construction

The construction industry is not yet prepared to assume the responsibility and accountability for implementing the Carbon Index values, which will be specified in drawings and specifications, through the processes of bidding, constructing, commissioning, and delivering the project. Examples of issues to be addressed include:

- During pre-construction, shop drawing must be in compliance with architect/engineer's Carbon Index requirements stipulated in the project specifications and drawings. When conflicts arise, who determines compliance (e.g., the A/E) and on what basis? For example, the contractor finds materials or equipment with the values of embodied carbon at locations exceeding a specified distance of the source (e.g., > 500 miles radius) but with lower first costs.
- During construction, materials (e.g., construction forms and installed elements), power equipment such as robots, and transportation of materials and workforce must be in compliance with the specified embodied and operational CIFs and resultant carbon indices.

- During project delivery and acceptance by the owner, If Functional Commissioning or Acceptance Testing is within the scope of the project,[22] a demonstration of compliance with the specified operational CIFs and carbon indices must also be in compliance for the functional systems.

The Carbon Index for the three phases of construction includes: 1) transportation of construction materials, equipment, and workforce to the construction site; 2) well-being and productivity of the workforce; and 3) effectiveness of construction methods.

The Carbon Index for the construction processes may be expressed as:

$$\sum CO_2\text{, const} = \sum CO_2\text{, transportation} + \sum CO_2\text{, workforce} + \sum CO_2\text{, const methods} \quad [4]$$

Transportation

Manufacturers and suppliers should be prepared to provide their products from within a 500 mile radius of the construction site for each system, such as HVAC, envelope, plumbing, and electrical. When not feasible, however, alternatives should be included in the specifications and drawings so that offsetting embodied and operational CIFs can be provided.

Workforce

An educated and skilled workforce [23] can reduce waste and increase productivity on the construction site. These characteristics can be represented by embodied CIFs for the site. How these factors can be standardized should be defined by the workforce and construction industry.

Construction Methods

New techniques in structural, mechanical, electrical, and plumbing construction are leading to more modular construction and potential for lower embodied and operational CIFs. How these factors can be standardized should be defined by the workforce and construction industry.

Operations and Maintenance (O & M)

Once the building is accepted by the owner and all systems are in operation, the performance of the building is expected to provide an environment that protects the health, safety, security, and well-being of the occupants while meeting the owner's functional requirements. However, the functional and environmental requirements of the initial or subsequent owners are likely to change over the expected lifespan of the building's structure (e.g., 30 years or more). These subsequent changes are also likely to change the needs for: 1) energy and water resources; 2) maintenance, repairs and renovations; and 3) housekeeping procedures.

As carbon emissions are associated with each of these O & M functions, variations in the rates of emissions (i.e., embodied and operational carbon) will occur that will require a life-cycle approach to determining a Carbon Index for the entire operational period.

[22] For additional information on Functional Commissioning and Acceptance Testing, see (10).

[23] For examples of how an educated and skilled workforce can reduce waste and increase productivity during construction, see (5) and (7).

The Carbon Index for the operations and maintenance processes may be expressed as:

$$\sum CO_2\text{, O\&M (1-30)} = \sum CO_2\text{, energy and water} + \sum CO_2\text{, maintenance and repair} + \sum CO_2\text{, housekeeping} \quad [5]$$

Owners and facilities managers are not fully prepared to accept the responsibility and accountability for sustaining a life-cycle Carbon Index through operations and maintenance, as methods for determining them and assuring their accuracies are not yet available.[24]

Energy and Water Resources

HVAC, lighting, electrical power, and plumbing systems, which operate to satisfy occupant needs in commercial and institutional buildings over the life-cycle, currently account for approximately 20% of the annual energy use,[25] and approximately 17% of the annual withdrawals from public water supplies in the U.S.[26] These processes also emit substantial amounts of carbon (e.g., as CO_2,e) over the life-cycle of the building.

Calculating the values of operational Carbon Index, $\sum CO_2$, energy and water, at the building site or at the source is expected to be at least as controversial as calculating source- vs. site-energy indices, which have been debated by the various producers and suppliers for decades. Moreover, methods of generating power at central plants with different fossil fuels, nuclear reactors, or hydropower will result in substantially different CIFs if calculated at the building site or at the source of power generation.

The availability of on-site sources of power or potable water[27] adds another question about whether CIFs for energy and water at the source or site of delivery should be used in calculating carbon indices, as these on-site sources function are "demand-response" applications at the site.

> For thermodynamic consistency, it is rational that the operational Carbon Index for energy and water utilization should be calculated at the boundary of the building's footprint with appropriate embodied and operational CIFs for the on-site source equipment and materials.

Maintenance, Repair and Renovation

From the time of initial occupancy, the building, its systems, and its components will begin to degrade unless operational care is continuously provided. The first level of care is routine or

---

[24] For additional information on this issue, see (6) and (7).

[25] Commercial buildings represent just under one-fifth of U.S. energy consumption, with office space, retail space, and educational facilities representing about half of commercial sector energy consumption. See: http://buildingsdatabook.eren.doe.gov/ChapterIntro3.aspx; accessed 2 Nov 16.

[26] This sector includes: hotels, restaurants, office buildings, schools, hospitals, laboratories, and government facilities. See: https://www3.epa.gov/watersense/commercial/types.html, accessed 1 Nov 16.

[27] Examples of on-site sources of energy and potable water include: microgrids, ground-source heat/power systems, solar thermal and photovoltaic systems, wind turbines, and spring or deep-well water.

preventive *maintenance*; the second level is *repair*, and the third level is *replacement* or *renovation*. Each of these processes involves the use of energy, water, and chemicals.

To calculate $\sum CO_2$, maintenance and repair at each of the three levels, the following information will be required:

- Specification and scheduling of the quantity and quality of maintenance, repair, and renovation procedures that comply with expected functional requirements of the facility.
- Optimization and/or selection of corresponding embodied and operational CIFs from standardized reference sources.

Housekeeping and Environmental Services

In commercial and institutional facilities, the meaning of the term "housekeeping" is now often considered to also mean "Environmental Services," which includes cleaning and sanitizes public areas and private spaces to facility or hospital standards.[28] Environmental Services also includes other housekeeping duties, such as doing the laundry, assuring cleaning supplies are well stocked and available, and performing garbage pickup and disposal. Housekeeping and Environmental Services involves the use of energy, water, and chemicals.

To calculate $\sum CO_2$, housekeeping, the following information will be required:

- Specification and scheduling of the quantity and quality of housekeeping and environmental services that comply with expected functional requirements of the facility.
- Optimization and/or selection of corresponding embodied and operational CIFs from standardized reference sources.

End-of-Life and Recycling

When a facility is deemed to no longer safely or economically provide its function, it will likely be renovated, rebuilt, or demolished. A typical time for this occurrence is about 30 years after its initial construction. This so-called "end-of-life" stage will involve three processes: 1) de-construction; 2) waste disposal; and 3) salvaging, reclamation and recycling.

The Carbon Index for the end-of-life processes may be expressed as:

$$\sum CO_2\text{, end-of-life} = \sum CO_2\text{, deconstruction} + \sum CO_2\text{, disposal} - \sum CO_2\text{, recycling} \quad [6]$$

Owners, facilities managers, designers of record, and contractors, are not fully prepared to accept the responsibility and accountability for achieving an "end-of-life" Carbon Index, as methods for determining its values and assuring its accuracies are not yet available.[29]

---

[28] Based on information from: http://work.chron.com/definition-environmental-service-hospital-job-28675.html; accessed 2 Nov 16.

[29] For additional information on this issue, see (6) and (7).

Deconstruction

Depending on the complexities of the site and building, the process of deconstruction may involve planning, design, demolition and, potentially, reconstruction.

To calculate $\sum CO_2$, deconstruction, the following information will be required:

- Specification of quantity and quality materials, components, assemblies, and systems that must be removed for disposal, reuse, or recycling.
- Optimization and/or selection of corresponding operational CIFs for the removal processes, from standardized reference sources.

Waste Disposal

In the deconstruction process, decisions must be made regarding which materials are to be disposed as waste, and which materials are to be salvaged for reuse or recycling.

To calculate $\sum CO_2$, disposal, the following information will be required:

- Identification and separation of the materials, components, assemblies, and systems that are to be transported to waste disposal sites from those that are to be salvaged.
- Optimization and/or selection of corresponding PFs and operational CIFs for salvaging, from standardized reference sources.

Reclamation and Recycling

Materials, components, assemblies and systems, which are to be salvaged, will retain some of their characteristics, including embodied carbon. If the items are to be reused or recycled, use of additional energy and chemicals will likely be required, which will result in additional embodied and operational carbon. If the Carbon Index for reclamation/reuse/recycling, $\sum CO_2$, recycling is smaller than the Carbon Index for waste disposal, $\sum CO_2$, disposal, then the effect will be a net reduction in the Carbon Index for the "end-of-life" process.

To calculate $\sum CO_2$, recycling, the following information will be required:

- Determination of the embodied Carbon Indices from the existing PFs and CIFs for the items to be reused or recycled, from standardized reference sources;
- Calculations for the additional embodied and operational Carbon Indices from the new PFs and CIFs needed to reuse or recycle the items, also from standardized reference sources.
- Determination of the net differences in Carbon Indices between the processes for reuse/recycle and waste disposal.

Benchmarks or Targets

Public and private policy-makers typically set "benchmarks" to establish performance goals. The concept of benchmarking Carbon Indices for buildings may be considered analogous to benchmarking energy utilization, such as the US EPA's "Energy Star" program (i.e., ES > 75 to qualify the building for Energy Star Certification).[30] That program required several years of obtaining sufficient data from buildings to establish credibility. Yet, even today, much controversy persists regarding the accuracy of the ES benchmark.[31] It is anticipated that the development of a credible CI benchmark will require even more effort than for energy use benchmarks, due to the larger number of variables to be considered.[32]

Two Carbon Indices will result from the processes described above: 1) the *embodied* and the *operational* carbon in the materials and equipment that were designed and installed in the building; and 2) the *operational* carbon emitted during the life-span of the building. Both of these Carbon Indices should be displayed and compared to the appropriate benchmark:

- Within the completed construction documents, the designer of record should indicate the site-specific benchmark and corresponding Carbon Index that is to be achieved at the time of completion of the construction.
- As part of the project delivery process, the site-specific benchmark and corresponding life-span Carbon Index should be posted on the building to indicate the expected amounts of carbon emitted from energy and material utilization by the facility and its employees, and for traveling to and from their residences. As reported in some British articles, various forms of carbon indices are now being posted on some buildings.

Computerization

With the state of the art advancement in highly sophisticated computer technology, it is now feasible to extend privately and publically accessible software programs to include calculations for calculating a total cradle-to grave Carbon Index for a commercial or institutional building, including its systems and equipment, as indicated in Fig. 2. An issue will be validation of the calculated results with measured data from site-specific buildings.

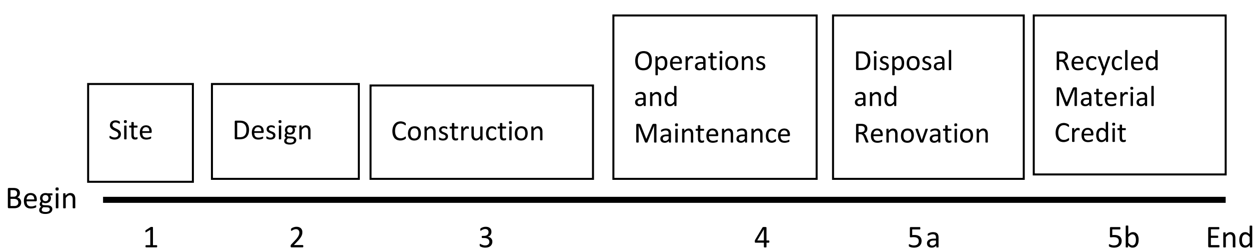

Fig. 2. Steps to development of a program to calculate a cradle-to-grave Carbon Index for a Building.

[30] For information on the EPA benchmarking tool, see: https://www.energystar.gov/buildings/about-us/how-can-we-help-you/benchmark-energy-use/benchmarking; accessed 30 Oct 2016.

[31] For an example of the concerns regarding the efficacy of Energy Star for buildings, see. (8).

[32] For additional discussion on the complexities of establishing credible CI Benchmarks, see (6).

Conclusions

The development of a Carbon Index as a "cradle-to-grave tool" for actively designing and managing building performance is a logical extension of current engineering practice for energy analyses of buildings. However, because of the increased number of variables to be considered, the procedures to determine valid and reliable values for site-specific Carbon Indices will be more complex.

It is anticipated that the development of credible benchmarks for the Carbon Index will require standardization of two major procedures for: 1) identifying and quantifying the Primary Factors (PFs) that characterize carbon emissions at each of the five stages in the building's life; and 2) establishing "Carbon Impact Factors" (CIFs) that accurately characterize the impact of the design or operational element on agreed upon target outcomes, such as "global warming potential" (GWP) and "sustainability."

While achieving standardization of the procedures for PFs may be difficult, it is feasible as it would be based on methods that are now used in planning, design, and construction practice, particularly those used for energy calculations. Standardizing on credible CIFs will be substantially more difficult. First, the target outcome or outcomes must be defined in measurable terms and within expected limits-of-error. Second, agreements on values must be obtained before benchmarks can be established.

If the industry and the Authorities having Jurisdiction (AHJ) pursue vigorously, perhaps it is possible to implement the "cradle-to-grave" Carbon Index for site-specific buildings. Introducing the *cradle-to-grave Carbon Index* enables transition of policies to reduce global warming and to enhance sustainability through the development of design tools with which planners, architects, engineers, contractors, and owners and managers can credibly evaluate the total amount of embodied and operational carbon in greenhouse gases (GHG) emitted through five stages of a building's lifespan. Setty® intends to lead in this effort.

Glossary

From RICS (1), with editorial modifications:[33]

- **Carbon Emissions**: Shorthand terms for the emissions of any of the number of greenhouse gases (GHG) that affect climate change. Carbon emissions are usually expressed as CO_2e (i.e. CO_2 equivalent), which is a ***calculated value*** based on the relative impact of a given gas on global warming (the so called global warming potential GWP). For example, if methane has a global warming potential of 25, it means that 1 kg of methane has the same impact on climate change as 25 kg of carbon dioxide and thus 1 kg of methane would count as 25 kg of CO, equivalent.
- **Cradle-to-Gate:** Carbon emissions between the confines of the 'cradle' (earth) up to the factory gate of the final processing operation. This includes mining, raw materials extraction, processing and manufacturing.

[33] The aim of the RICS information paper is limited to providing practical guidance to RICS Quantity Surveyors on how to calculate *cradle-to-gate* embodied carbon emissions associated with their projects in the UK.

- **Cradle-to-Grave**: Carbon emissions between the confines of the 'cradle' (earth) to gate (factory gate of the final processing operation), to site (delivery to the site of use), to-end of construction, plus maintenance, refurbishments, demolition, waste treatment and disposals ('grave').
- **Cradle-to-Site**: Cradle-to-gate emissions plus delivery to the site of use (construction/installation site).
- **Embodied Carbon**: Carbon emissions associated with energy consumption (embodied energy) and chemical processes during the extraction, manufacture, transportation, assembly, replacement and deconstruction of construction materials or products. Embodied carbon can be ***calculated*** from cradle-to-gate, cradle-to-site, cradle-to-end of construction, cradle-to-grave, or even cradle-to-cradle. The typical embodied carbon datasets are cradle-to-gate. Embodied carbon is usually expressed in kilograms of CO,e per kilogram of product or material.
- **Operational Carbon**: Carbon emissions associated with energy consumption (operational energy) while the building is occupied. This includes the so-called regulated load (e.g., heating, cooling, ventilation, lighting) and unregulated/plug load (e.g., IT equipment, cooking and refrigeration appliances). It also includes carbon emissions from embodied energy and chemicals for maintenance, repair, housekeeping, and renovation processes (Note: sentence added in this white paper).
- **Recycled Content**: The portion of a product that contains materials that have been recovered or otherwise diverted from the solid waste stream.

From this white paper:

- **Carbon Index:** A calculated value that indicates the total amount of embodied and operational carbon in greenhouse gases (GHG) that are emitted during the five stages of a building's lifespan.

References

1. **Embodied Carbon Working Group of the Royal Institution of Chartered Surveyors.** *Methodology to calculate embodied carbon of materials.* Coventry CV4 SJE, UK : Royal Institution of Chartered Surveyors (RICS), July 2012.
2. **ASHRAE.** *Standard 90.1-2016: Energy Standard for Buildings Except Low-Rise Residential Buildings.* Atlanta : ANSI/ASHRAE/IES, 2016.
3. —. *Standard 189.1-2016: Standard for the Design of High-Perfirmance Green Buildings Except Low-Rise Residential Buildings.* Atlanta : ANSI/ASHRAE/IES/USGBC, 2016.
4. **Setty, BS and Woods JE.** *Toward Fully Functional Net-Zero-Energy Buildings: An Engineerinng Perspective.* Fairfax, Virginia : Setty and Associates, 2014.
5. **Woods, JE.** The Future of an Educated and Skilled Workforce (ESW) in Buildings: Challenges and Opportunities. *TABB TALK.* 2014, Vol. 1, 1.
6. **Wu P, Feng Y, Pienaar J, and Xia B.** A review of benchmarking in carbon labelling schemes for building. *Journal of Cleaner Production.* http://dx.doi.org/10.1016/j.jclepro.2015.07.067, 2015.
7. **Woods, JE.** The Future of an Educated and Skilled Workforce: Availability and Use of Appropriate Instrumentation. *ICB/TABB Journal.* 2015, Vol. 2, 1, pp 19-32.

8. *ENERGY STAR Building Benchmarking Scores: Good Idea, Bad Science.* **Scofield, JH.** s.l. : ACEEE Summer Study on Energy Efficiency in Buildings, pages 3-267 to 3-282, 2014.

9. **Woods, JE.** Cost Avoidance and Productivity in Owning and Operating Buildings. [book auth.] Hodgson MJ. *Occupational Medicine: State of the Art Reviews, Vol.4, No. 4, pp. 753 770.* Philadelphia : Hanley & Belfus. Inc., October December, 1989.

10. *Total Building Commissioning: A Case Study of the U.S. District Courthouse, Salt Lake City, Utah, U.S.A.* **Setty, BS.** Prague, Czech Republic: Society of Environmental Engineers, Clima 2013 - 11th REHVA World Congress, paper 458.