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Comparison of methodologies for Whole Building Life Cycle Assessment: A Review

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EXECUTIVE SUMMARY

The main goal of this study is to review whole building life cycle assessment (WBLCA) methods and to distinguish the main differences and similarities among current guidelines available to comply with green building rating systems (GBRS), and existing product category rule (PCR). *The Leadership in Energy and Environmental Design V4 (LEED), Green Globes and the Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) System* are highlighted as the main GBRS for comparison. The PCR for building comparison include *the PCR UN CPC 531 Buildings (PCR 2014:02 Buildings, Version 1.0), International EPD system* and

Standards ISO 14040:2006 and ISO 14044:2006 are used as the basis for comparison. The findings show that methodologies integrated into current GBRS differ in goal and scope definition, as well as in the requirements for life cycle inventory and life cycle impact assessment stage. Furthermore, some of the methodologies do not address minimum requirements necessary to carry out LCA based on ISO standards.

Type of Document	Release Date
GREEN BUILDING RATING SYSTEMS (GBRS)	
LEED v4.0	2014
DGNB	2011
Green Globes	2013
IgCC 2012	2012
CALGreen 2010 and 2012	2010
ASTM E2921-13	2013
EN 15978:2011	2011
GUIDANCE to GBRS	
ATHENA WBLCA Guide	2014
Tally Guide for WBLCA	2017
DGNB Reference Guide	2015
PRODUCT CATEGORY RULES (PCR)	
PCR UN CPC 531 Buildings (PCR 2014:02 Buildings, Version 1.0), International EPD system	2012

SBK Stichting Bouwkwaliteit Calculation method for the assessment of the environmental performance of construction and civil engineering works (GWW) over their entire service life, based on EN 15804.	2014

INTRODUCTION

In the last two decades, green building rating systems (GBRS) have emerged in order to address the increased societal demand for more sustainable structures, which utilize fewer resources to build and use increasing the health and safety of its occupants (Collinge, et al. 2015). GBRS have emerged creating a new perception of building sustainability and marketability from the stakeholders point of view (Reed, et al. 2009).

With the evolution of sustainability assessment around the world, new methods to assess the broader impact of economic sector have been developed. Life Cycle Assessment (LCA) is a comprehensive method of evaluating the sustainability of products and processes. LCA is used to evaluate the resource consumption and environmental impacts of products and processes (goods and services) during their life cycle from cradle to grave (Ortiz, Castells and Sonnerman 2009)and is a considered sustainable method for comparing building assemblies and their ability to meet project goals (Initiative, G. B. 2013) (Cabeza, et al. 2014).

LCA methods have been used in the building construction sector for the last ten years (Buyle et al. 2013). Because LCA takes a comprehensive, systemic approach to environmental evaluation, interest is increasing in incorporating LCA method into building construction decision making for selection of environmentally preferable products, for evaluation and optimization of construction processes (Asdrubali et al. 2013), and for the evaluation of whole buildings, considering their complete life cycle (construction, operation, maintenance and end of life) (Simonen and Haselbach, 2012).

In recent years there has been a growing interest in including LCA to GBRS and metrics (Olander 2012) (Olinzock, et al. 2015) (Collinge, et al. 2015). LCA offers a quantitative comparison of materials across a range of environmental impact performance metrics, rather than using the imperfect prescriptive or qualitative measures common in green building assessment programs up to now (Lucuik 2014). WBLCA appears in GBRS and standards as 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 (Athena 2014). During the project's design phase, the assessment can inform decision making processes by allowing the environmental performance of different design options to be compared and opportunities to improve environmental performance throughout the life cycle to be identified (DGNB 2014). Understanding full life- cycle performance and impacts has also become critical for architects focused on conserving existing and historic buildings and places (AIA, 2015).

Previous reviews have looked at WBLCA case studies of residential and non-residential buildings and also the tools to carry out the assessment (Ortiz, Castells and Sonnerman 2009) (Cabeza, et al. 2014) and have found gaps regarding environmental indicators, easily understandable presentation of LCA results to users, simplification and adaptation of LCA to various purposes (Bribian, Uson and Scarpellini 2009). These previous reviews show that case studies found in the literature are difficult to compare because of their specific properties (Buyle et al., 2013). It has been increasingly documented that all decisions made during the LCA (functional unit choice, LCA system boundaries, inventory data, choice of the impact assessment method, etc.) influence greatly the LCA results (Van Den Heede and De Belie 2012).

While GBRS have increasingly developed guidelines for WBLCA, there are no reviews that analyze the different WBLCA methods described in GBRS and thus these differences have never been closely documented. The main goal of this review is to compare the WBLCA methods available for professionals and test their compliance with ISO standards.

DEFINITION OF WHOLE BUILDING LIFE CYCLE ASSESSMENT (WBLCA)

LCA is a methodology to estimate and evaluate the environmental impact throughout the product life cycle from cradle to grave (ISO 2006). WBLCA is an LCA exercise where the entire building project is considered holistically to help building designers focus their efforts when a reduced footprint is desired (Athena 2014). WBLCA shows promise for evaluating and motivating lower impact buildings (Simonen, 2015).

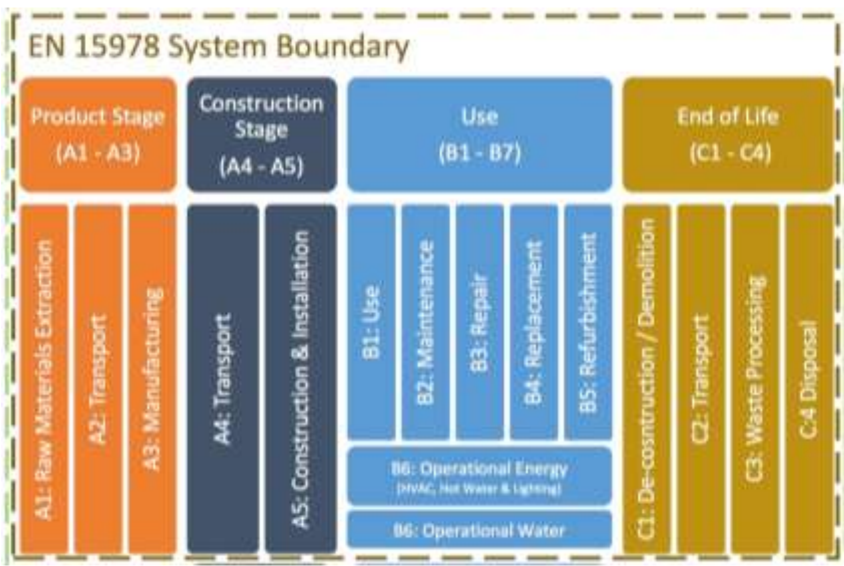
In all of the GBRS studied the use of WBLCA represents different scores according to each system weighting. Under LEED V4 (option 4), the use of a comparative core and shell WBLCA is worth 4 points. (US Green Building Council 2014). In Green Globes for New Construction the comparative core and shell WBLCA is worth 33 points (Initiative, G. B. 2013). In Living Building Challenge projects must account for the total embodied carbon footprint from construction through a one-time carbon offset tied to the project boundary (ILFI 2014). Under DGNB a comparative WBLCA is conducted using local climate data, and a five out of a maximum of ten points are awarded if the proposed building's environmental impact is equal to that of the reference building. More points will be awarded if the environmental impact of the proposed building is less than that of the reference building (DGNB 2014).

LCA METHODOLOGIES USED FOR WHOLE BUILDING LIFE CYCLE ASSESSMENT

Most WBLCA found in the literature follow the traditional process based LCA approach (Cabeza, et al. 2014), this is based on four steps established by the International

Organization for Standardization (ISO) in ISO 14040 and 14044 (Ortiz, Castells and Sonnerman 2009). These four steps are: **1) Goal and Scope Definition** , defines the objectives and the reasons for carrying out the study the scope also includes functions, functional unit, system boundaries, allocation procedures, data requirements and limitations; **2) Life Cycle Inventory (LCI)** is the stage for data collection of emission and resource use data from life-cycle databases. This is a comprehensive and critical phase since LCA results rely on the quality of LCI (Collinge, et al. 2015) ; **3) Life Cycle Impact Assessment (LCIA)** – models the LCI data and translates this into quantifiable environmental impacts. Three sub stages of the LCIA include the definition of impact categories, classification and characterization. Finally the for stage is 4) **Interpretation** - LCI and LCIA results are interpreted and improved to present meaningful information for decision-makers (ISO 2006).

The European EN 15978 is an LCA standard that is increasingly becoming the common method for describing the system boundary of whole-building LCA (Athena 2014). The system boundary defined by the standard encompasses four life cycle stages- Product stage, Construction Stage, Use Stage, and End of Life divided into 16 substages (EN BS 2011) (Fig. 1)



1.1

Fig 1. EN 15978 System Boundary (Source: eTool)

Goal and Scope

All GBRS use LCA as a basis for comparison, however the goals varies greatly. In DGNB the objective of the assessment is to quantify and document the environmental performance of the building and to compare the results against a defined benchmark. The system requires the use of both LCA for building components and life cycle energy modelling (LCEM) of building's energy demand during the operation phase. In LEED, in order to achieve credits the proposed building must demonstrate at least a 10% reduction in global warming potential and a 10% reduction of two of five other impact measures when compared to a baseline building, without increasing any measure by more than 5%. Under Green Globes, at least two alternative design options for the project building should be evaluated using an LCA tool to influence the design process. The intent of this criterion is for this LCA comparison to occur prior to the Construction Document Phase.

The different GBRS also differ in scope since each one is based on a different standard. DGNB references the system boundaries established in EN 15978, LEEDv4 references ISO 21930 and GreenGlobes only addresses ISO 14040 and ISO 14044. The scope of the WBLCA under DGNB encompasses environmental impacts of production, use and end-of life phases and does not include external works. LEEDv4 requires a cradle-to-grave core& shell WBLCA, which includes environmental impacts associated with all the life-cycle stages for the building structure and enclosure: resource extraction or harvest, building product manufacture, on-site construction, product maintenance and replacement (where warranted), and deconstruction or demolition and disposal. Green globes scope and boundaries include complete building structure, envelope, foundation, and footings. Below grade or an attached parking garage shall also be included. Surface parking, excavation and other site development work, and HVAC, plumbing and electrical components shall be excluded.

In terms of building function, all GBRS WBLCA emphasize the building's use into consideration (office building, commercial building, school, etc.) in establishing and evaluating the building's environmental quality, and compares the result with values for other reference buildings with same function. Functional unit requirements vary, however, in each system. Under DGNB the building to be evaluated must be described in terms of its material and time-dependent qualities. In addition a clear description of the technical and functional properties of the building, the building type and use (e. g. number of users) must be recorded in a documentation data sheet, this description represents the functional equivalent for the evaluation. LEED v4 requires a description of function, gross floor area, orientation, and operational energy usage. Green Globes does not address a functional unit.

One of the greatest difference among all the GBRS in this stage is the reference period. Under DGNB the reference period is set down specifically for each DGNB scheme, for example 50 years for new offices. In LEED v4 the LCA uses an assumed building service life of at least 60 years—long enough to capture the replacement cycle of enclosure materials, such as roof systems and curtain walls, but short enough that its basic structure is unlikely to be replaced. Under Green Globes, the LCA time span should be equivalent to the expected life of the building, with a minimum of 60 years and a maximum of 120 years, unless otherwise approved by the Green Globes assessor.

Life Cycle Inventory Analysis

Data requirements under the different GBRS differ greatly. DGNB requires a WBLCA conducted using local climate data and provides auditors and consultants with access to the ESUCO LCA databases which include both generic and specific data. The methodological consistency, conformity and completeness of specific data from other
1.2 sources must be verified by independent external experts. LEED v4 and Green Globes encourage the use of simplified LCA tools that provide the background data sets that form the basis of the assessment. Simplified LCA process for their users by providing aggregate data, makes the LCA less time-intensive and costly but might sacrifices accuracy (Bendewald and Zhai 2013).

Life Cycle Impact Assessment

While all GBRS address Climate Change: Global Warming Potential (GWP) as a main
1.3 impact category to be reported, the rest of the impact categories requirements vary. In addition to GWP, DGNB addresses the impact assessment categories from EN 15978, Ozone Depletion Potential (ODP), Photochemical Ozone Creation Potential (POCP), Acid Potential (AP), and Eutrophication Potential. LEED v4 incorporates ozone depletion potential, acidification potential, eutrophication potential, formation of tropospheric ozone and depletion of nonrenewable energy resources. Green globes addresses acidification potential, eutrophication potential, ozone depletion potential, smog potential and fossil fuel use.

	Indicator	Unit
Impact Assessment	Global warming potential, GWP	kg CO_2 equiv
	Depletion potential of the stratospheric ozone layer, ODP;	kg CFC 11 equiv
	Acidification potential of land and water; AP;	kg SO_{2-} equiv
	Eutrophication potential, EP;	kg $(PO_4)_{3-}$ equiv
	Formation potential of tropospheric ozone photochemical oxidants, POCP;	kg Ethene equiv
	Abiotic Resource Depletion Potential for elements; ADP_elements	kg Sb equiv
	Abiotic Resource Depletion Potential of fossil fuels ADP_fossil fuels	MJ, net calorific value
Resource use	Use of renewable primary energy excluding energy resources used as raw material	MJ, net calorific value
	Use of renewable primary energy resources used as raw material	MJ, net calorific value
	Use of non-renewable primary energy excluding primary energy resources used as raw material	MJ, net calorific value
	Use of non-renewable primary energy resources used as raw material	MJ, net calorific value
	Use of secondary material	kg
	Use of renewable secondary fuels	MJ
	Use of non-renewable secondary fuels	MJ
	Net use of fresh water	m^3
Waste	Hazardous waste disposed	kg
	Non-hazardous waste disposed	kg
	Radioactive waste disposed	kg
Output Flows	Components for re-use	kg
	Materials for recycling	kg
	Materials for energy recovery (not being waste incineration)	kg
	Exported energy	MJ for each energy carrier

Fig 2. EN 15978 Impact Assessment and Indicators (Source: eTool)

The impact category characterization methods addressed in each GBRS studied also differ. While DGNB does not mention specific characterization methods, LEED v4 specifically refers to TRACI 2.1 CML 2002, and ReCiPe. Green globes does not mention specific characterization methods but it can be inferred from the use of Athena Impact Estimator LCA tool that characterization methods accepted are similar to the ones accepted in LEED v4.

Interpretation

GBRS studied do not address this stage of the general LCA methodology. DGNB, LEEDv4 and Green Globes establish specific requirements for documenting the credit under the
1.4 scope of each rating system, but does not mention the requirements established by the ISO standards. In terms of verification, only DGNB establishes requirements for verification of results and indicates that all the information used, options or decisions made must be presented in transparent form in order to be verifiable including completeness and verification of the completeness for the quantification at the building level, traceability of the data used for the products; conformity of the data to the requirements of EN 15804. Green globes GBRS does not address this phase.

SUMMARY AND CONCLUSION

WBLCA has been a complex exercise practiced by experts, and although it has been incorporated into GBRS, currently there is no standardized methodology accessible for building designers. The methodologies presented are diverse and use a variety of standards as main reference. This causes differences in goals and scope, particularly in the description of the functional or reference unit and system boundaries. None of the GBRS analyzed, mention critical scope aspects defined by ISO standards, such as allocation procedures, assumptions, limitations, and types of critical review. In the same way, different GBRS fluctuate greatly in data collection methods for life cycle inventory stage and requirements for classification and characterization of impacts.

The different approaches to WBLCA available in different GBRS will become a barrier for precise comparisons between buildings assessed with different tools. In order to continue the advancement of holistic environmental assessment in buildings, more robust databases and a large body of knowledge there is a growing need to enhance the dialogue between the different GBRS developers and improve a standardized WBLCA methodology.

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