Relating Sustainability Indicators to the Refurbishment of the Existing Building Stock

L.C. Havinga MSc.
Eindhoven University of Technology
l.c.havinga@tue.nl

prof. dr. B.J.F. Colenbrander **dr. ir. H.L. Schellen**
Eindhoven University of Technology

ABSTRACT

The construction sector and the associated built environment have an oversized footprint. They are responsible for more than a third of global resource consumption and an estimated 40% of the total waste generation, contribute up to 30% of global annual greenhouse gas emissions and consume a third of all energy. The retention, rehabilitation and reuse of the existing building stock play a pivotal role in the sustainable development of the city. However, there is an ongoing debate on evidencing the sustainability of refurbishment in contrast to demolition and new construction. On the one hand, a newly constructed building can achieve higher operating energy efficiency on the short term, on the other hand, when looking at lifespan, material use and waste generation, re-use or continued use of the buildings is more environmentally sustainable than to demolish and replace them. This paper provides a review of the role of sustainability in the built environment and reflects on this from the perspective of refurbishment; revealing the state of the art regarding the definitions of sustainability, the sustainability legislation on different scale levels and the assessment methods used to certify sustainable buildings. Subsequently, these different aspects will be put in relation to each other and assessed from the perspective of refurbishment.

INTRODUCTION

The construction sector and the associated built environment consume significant quantities of resources and energy, contribute to climate change, and affect the health and well-being of building users and others (Todd, 2012). In 2011 the United Nations Environment Program (UNEP) and the Sustainable Buildings and Climate Initiative (SBCI) released a report (United Nations Environment Programme, 2011) that notes:

1. The built environment is the single largest contributor to global greenhouse gas emissions (GHG), with approximately one third of global energy end use taking place in the operational use of buildings.
2. The construction sector is responsible for more than a third of global resource consumption, including 12% of all fresh water use, and contributes 40% of the generation of solid waste.
3. Constructing new green buildings and retrofitting existing energy- and resource- intensive

L.C. Havinga MSc. is a doctoral candidate in the Department of the Built Environment, Eindhoven University of Technology , the Netherlands. Prof. dr. B.J.F. Colenbrander is a full professor at the chair of Architecture, History and Theory in the Department of the Built Environment, Eindhoven University of Technology. Dr. ir. H.L. Schellen is an associated professor at the chair of Building Physics in the Departmennt of the Built Environment, Eindhoven University of Technology.

buildings stock can achieve savings of about one-third in energy consumption in buildings worldwide and significantly contribute in the reduction of CO_2 emissions.
4. Greening buildings will bring significant health and productivity benefits.

It is made clear that interventions are not only necessary, but possible. According to Petersdorff et al (Petersdorff, Boermans, & Harnisch, 2006), the main energy and CO_2 saving potential lies in the existing building stock. Most developed countries have regulations consisting of national performance standards for newly built houses. The demolition rate in the building stock can be estimated to be ∼½–1%, whereas new constructions to be 1% of the total living area per year, thus resulting in a slight increase of the existing building stock (Petersdorff e.a., 2006). Research in the UK (Power, 2008) suggests that even with ambitious new building programs and a high demolition rate, only 10% of the current stock will have been demolished by 2050, arguing the urgent need to upgrade the existing stock on the grounds that 70% of all homes that will exist in 2050 are already built. Consequently, existing buildings must be sustainably refurbished (Häkkinen, 2007),(Sev, 2011), minimizing the operational energy use while taking into account other sustainability aspects. This paper provides a review of the role of sustainability in the built environment and reflects on this from the perspective of refurbishment. Revealing the state of the art regarding the definitions of sustainability, the sustainability legislation on different scale levels and the assessment methods used to certify sustainable buildings. Subsequently these different aspects will be put in relation to each other and assessed from the perspective of refurbishment.

DEFINITION

In today's world, the term sustainable development is everywhere; over 500 definitions of sustainability and sustainable development have been spawned by various governments, professional bodies, institutions and organizations (Shah, 2012). The growth of sustainable awareness dates back many decades; from Silent Spring written by Rachel Carson (Carson, 2002) and first published in 1962, describing a world affected by pesticides and chemicals, through to James Lovelock's Gaia (Lovelock, 2000), first published in 1969, stating the role of 'mother earth'. One of the first definitions of sustainable development was made in 'Our common future', the report of the Brundtland Commission, calling for development "that meets the needs of the present without compromising the ability of future generations to meet their own needs"(World Commission on Environment and Development, 1987). Whilst this definition is still used today, a more commonly known terminology encompasses the environmental, social and economic principles captured as the 'triple bottom line' (Elkington, 1998), also referred to as the three P's; Planet, People, Profit.

The definitions of the terms 'sustainable building' and 'building sustainability performance' vary according to different actors of the construction industry. The internationally standard definition of a green building is provided by ASTM Standard E2114–04 (E06 Committee, 2004), that is, "a building that provides the specified building performance requirements while minimizing disturbance to and improving the functioning of local, regional, and global ecosystems both during and after its construction and specified service life". Furthermore, "a green building optimizes efficiencies in resource management and operational performance and minimizes risks, which threaten the human health and environment". By emphasizing performance requirements and human health, the principles of the triple bottom line are integrated within this definition of a green building. Also, it specifically mentions the importance of taking into account the different stages of a buildings lifespan, from construction and service lifespan, to what happens after a buildings service lifespan.

LEGISLATION

Worldwide Legislation

The United Nations Framework Convention on Climate Change (UNFCCC) was negotiated at "the

Earth Summit", the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992. The objective of this international environmental treaty is to "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". The Kyoto Protocol is an international agreement linked to the UNFCCC, which commits its Parties by setting internationally binding emission reduction targets. The main goal of the Kyoto Protocol is to contain emissions of the main anthropogenic (i.e., human-emitted) greenhouse gases (GHGs) in ways that reflect underlying national differences in GHG emissions, wealth, and capacity to make the reductions. The first round of the protocol was completed in 2012, but much greater emission reductions will be required in future to stabilize atmospheric GHG concentrations (Oberthür & Ott, 1999).

European Legislation

For meeting the commitments on climate change made under the Kyoto protocol, the EU has introduced legislation to ensure that buildings will consume less energy in the future. A key part of this legislation is the Energy Performance of Buildings Directives (EPBD). The first directive (Directive 2002/91/EC,EPBD), first published in 2002, requires that an energy performance certificate (EPC) is made available when buildings are constructed, sold or rented out. The certificate has to express the operational energy performance of the building. Also, every country had to insert legislation stating a minimum performance. Subsequently, the second Directive (Directive 2010/31/EU, EPBD) states, that "Measures are needed to increase the number of buildings which not only fulfil current minimum energy performance requirements, but are also more energy efficient, thereby reducing both operational energy consumption and carbon dioxide emissions. For this purpose Member States should draw up national plans for increasing the number of nearly zero-energy buildings and regularly report such plans to the Commission". Also, being more specific, Article 9 states: "Member States shall ensure that: by 31 December 2020, all new buildings are nearly zero-energy buildings; and after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings".

There are only very limited mandatory requirements related to building components and materials used in buildings, in practice energy-saving measures predominate. The mandatory requirements that currently exist in the EU countries studied by Reijnders & Van Roekel (Reijnders & van Roekel, 1999) deal only with very limited aspects of the interactions between buildings and the environment.

ASSESSMENT METHODS

As mentioned, an Energy Performance Certificate is obligated in Europe when a building is constructed, sold or rented out, therefore this type of certificate will be considered first. Subsequently, a wider range of building environmental assessment (BEA) tools, which are all voluntary and motivational in their application, will be considered. The field of BEA has matured remarkably since the introduction of the UK Building Research Establishment Environmental Assessment Method (BREEAM) in 1990, and the interim period witnessed a rapid increase in the number of tools (Cole, 2005). Reijnders and van Roekel (Reijnders & van Roekel, 1999) have made a rough division of BEA tools into two groups. The first group includes those, which are based on scores and a criteria system and are regarded as qualitative tools, the Criteria Based Tools (CBT). The second group includes the tools that use life cycle assessment (LCA) methodology with quantitative input and output data on flows of material and energy throughout the different stages of a buildings life cycle, from construction and use to demolition and recycling. For each category, the EPC, CBT and LCA, firstly the sustainability criteria and methodology will be introduced, secondly the pros and cons of their application will be elaborated, and thirdly they will be assessed from the perspective of refurbishment.

Energy Performance Certificate

Criteria & Method. The definition of the energy performance of a building is the amount of energy, actually consumed or estimated, necessary to meet the performance requirements associated with a standardized operational use of the building (Poel, van Cruchten, & Balaras, 2007). The criteria that are used in these calculations are: insulation values, technical and installation characteristics (including own-energy generation), design and positioning in relation to climatic aspects, solar exposure (taking into account the influence of neighbouring structures), and indoor climate factors that influence the energy demand. The Energy Performance Certificate is a document that indicates the operational energy performance of a building as a numerical output, calculated according to a methodology based on the general framework set out by the EPBD. Following the first EU directive, all EU countries have stated a minimum performance. There are many different software programs that allow these calculations to be made, most programs use an interactive model where the user can easily adjust for example the R-value (thermal resistance) of a wall, the type of ventilation system used or whether there are solar panels on the roof or not. These changes immediately result in a change in the Energy Performance, allowing for the user to compare the effect that different options have on the energy use of the building.

Pros & Cons. An EPC is based on the quantitative calculation of the operational energy consumption, creating an objective basis to assess and compare design solutions and buildings. These programs are relatively easy to use and allow for the user to integrate the outcomes at an early stage of the design process. Also, a study by Ronan Lyons (2013) has shown a positive impact of the Energy Performance Certificate on sales and rental prices of buildings on average in most of the Member States that were analysed, indicating that better energy efficiency is rewarded in the market. On the down side an EPC only covers the operational energy use of a building, disregarding not only the stages of construction, maintenance and eventual demolition and recycling, but also the resources that are being used and the environmental impacts that are related with them.

Refurbishment. Energy Performance Certificates are also applicable to existing dwellings and refurbishment projects. Although, since an EPC focusses on operational energy use and doesn't take into account sustainability factors like resource use and waste production, it could be considered easier to attain the best EPC rating th rough demolition and new construction rather than through refurbishment of an existing building.

Criteria Based Tools.

Criteria & Method. The Criteria Based Tools essentially consist of lists of suggestions for the environmental improvement of buildings linked with a score (Reijnders & van Roekel, 1999). Among the criteria-based tools (CBT) are Building Research Establishment's Environmental Assessment Method (BREEAM) and Civil Engineering Environmental Quality Assessment and Award System (CEEQUAL) (UK), SBTool (International), Leadership in Energy and Environmental Design (LEED) (USA), High Environmental Quality certification (HQE) (France), EcoProfile (Norway), PromisE (Finland), Green Mark for Buildings (Singapore), H K-BEAM and CEPAS (Hong Kong), Green Star (Australia). BREEAM is the leading and most widely used criteria based environmental assessment method for buildings (Nguyen & Altan, 2011). It was developed in the UK in 1990 and is the building environmental assessment method with the longest track record. The CBT's cover a wide range of criteria which are classified into categories (e.g. BREEAM): Energy, Transport, Water, Waste, Materials, Land Use & Ecology, Health and Wellbeing, Pollution, Management, Innovation. The method of a CBT typically consists of three major components (Cole, 2003).

1. Structure; a declared set of environmental performance criteria organized in categories.
2. Scoring; the assignment of a number of possible points or credits for each performance issue that can be earned by meeting a given level of performance.
3. Output; a means of showing the overall score of the environmental performance of a building or facility, usually involving a weighting system that is assigned to the different categories.

Pros & Cons. The Criteria Based Tools offer a wide range of sustainability aspects; there are even credits to be earned considering whether there is a bus stop nearby or not. On the downside, the coverage is rather superficial (Reijnders & van Roekel, 1999) and is not based on a systematic study of environmental impact related to the factors concerned; it is unclear whether the effects of the environmental improvements suggested are marginal, substantial or large (Reijnders & van Roekel, 1999). Additionally, weighting is inherent to the systems and when not explicitly, all criteria are given equal weights (Todd et al., 2001). According to Lee et al. (2002) weighting is the heart of all assessment schemes since it will dominate the overall performance score of the building being assessed. However, there is still no consensus on the assignment of weightings. The Green Building Challenge aims to provide a default weighting system, taking into account regional differences by encouraging users to change the weights. However, although sustainability issues differ from region to region, there is no consensus on regional weighting systems. There is a concern that it is possible to manipulate the results, if the default weighting system is altered in order to satisfy specific purposes (Larsson, 1999;Todd et al., 2001)(Ding, 2008).

The Criteria Based Tools are very complex, it requires training and certification to be able to use them (Nguyen & Altan, 2011). As a result, they are not accessible and are often used as a checklist at the end of the design stage instead of being used early in the design process while the most important decisions with regard to sustainability should be made at the beginning of the design process (Zeiler, 2011). Environmental issues are broad and difficult to capture, combining qualitative and quantitative data, a balance between completeness of coverage and ease of use remains one of the challenges in developing an environmental building assessment tool (Ding, 2008).

Lastly, developers and designers use the CBT's to attain an overall desired "score": a BREEAM "Excellent" or "Very Good," or LEED "Gold" or "Silver". The goal of achieving a high score may be considered to be more important than achieving a good overall product (Cole, 2003). In addition, the results of all categories are converted into a score. Each category has to attain at least a "pass", however, categories have very limited or no minimum requirements and a detraction of credits for polluting components does not exist. Therefore, a project can contain very environmentally unfriendly components in a specific category, and still achieve a high final score. This checklist approach, where the meeting of individual performance requirements is pursued in the quest for a certain overall rating, detracts the designer from the more fundamental issue of ethics and professional responsibilities. More skilled design teams recognize that the interrelationship between the different strategies and systems is key to successful sustainable design (Cole, 2003).

Refurbishment. Some CBT's (e.g. BREEAM) have developed a special tool for refurbishment, in which the criteria and weightings are adapted to suit refurbishment better. Refurbishment can thus be tested by means of these tools, however, cannot be compared to new construction, because it concerns separate tools whose scores are not comparable.

Life Cycle Assessment Tools.

Life Cycle Assessment (LCA) is "a method for analysing the environmental burden of products (goods and services) from cradle to grave, including extraction of raw materials, production of materials, product parts and products, and discarding them by recycling, reuse, or final disposal" (Guinée, 2002). LCA is defined as "the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle" (International Organization for Standardization (ISO), 1997). The most advanced and most used software tools for Life Cycle Assessment of products are Simapro (Netherlands) and Gabi (Germany). Life Cycle Assessment software tools that can be used to assess buildings include: ECOSOFT (Austria), EcoCalculator (Canada), Eco-bat (Switzerland), LEGEP (Germany), GaBi-Build-IT (Germany), SBS (Germany), ELODIE (France) EQUER (France) COCON (France), ECO-QUANTUM (The Netherlands), GreenCalc+ (The Netherlands), EcoEffect (Sweden), IMPACT (UK) and BEES (USA).

The indicator called "embodied energy", lies at the basis of Life Cycle Assessment. The so called "initial" embodied energy is the sum of the energy that is consumed by all of the processes associated with the production of a building, considered as if that energy was 'embodied' in the product itself. As buildings are designed to be more and more energy efficient during the operational phase of the life cycle, the initial embodied energy becomes relatively more significant. The initial embodied energy of a building is a significant multiple of the annual operating energy consumed, ranging from around 10 for typical dwellings to over 30 for office buildings (Ciravoğlu & Taygun, 2013).

The "gross life cycle embodied energy" consists of the total embodied energy during the life cycle of a building, taking into account not only the initial embodied energy that was used in initially construct the building, but also the operational energy, the embodied energy used during maintenance and/or refurbishment and the energy used to dismantle or demolish the building and dispose of- or recycle the materials (Ciravoğlu & Taygun, 2013). With the recycling and re-use of the materials, a part of the embodied energy of those materials can be detracted from the gross life cycle embodied energy. Based on LCA, a zero energy building consists of a building which will produce enough energy during its lifetime to recover this energy debt (Storey and Baird, 1999), while a zero energy building generally only accounts for the energy debt created during the operational use of the building.

The aspect of embodied energy, although it is vital to the ideology of Life Cycle Assessment, is only part of the actual assessment methodology. Following ISO 14040, an LCA consists of four components or steps (AIA Guide to Building Life Cycle Assessment in Practice);

1. Goal and Scope Definition,
2. Inventory Analysis,
3. Impact Assessment,
4. Interpretation.

In addition to the calculation of embodied energy, which is part of the inventory analysis, environmental effects and impacts are also assessed in LCA methods. These consist of (e.g. EcoQuantum v.2.00): Environmental effects; Material use, Energy consumption, Water consumption. Environmental Impacts; Depletion of abiotic resources potential (ADP) Global warming potential (GWP), Ozone depletion potential (ODP), Photo-oxidant formation potential (POCP), Human toxicity potential (HTP), Aquatic ecotoxicity potential (AETP), Sediment ecotoxicity potential (SETP), Terrestrial ecotoxicity potential (TETP), Acidification potential (AP), Eutrophication potential (EP)(Itard & Klunder, 2007).

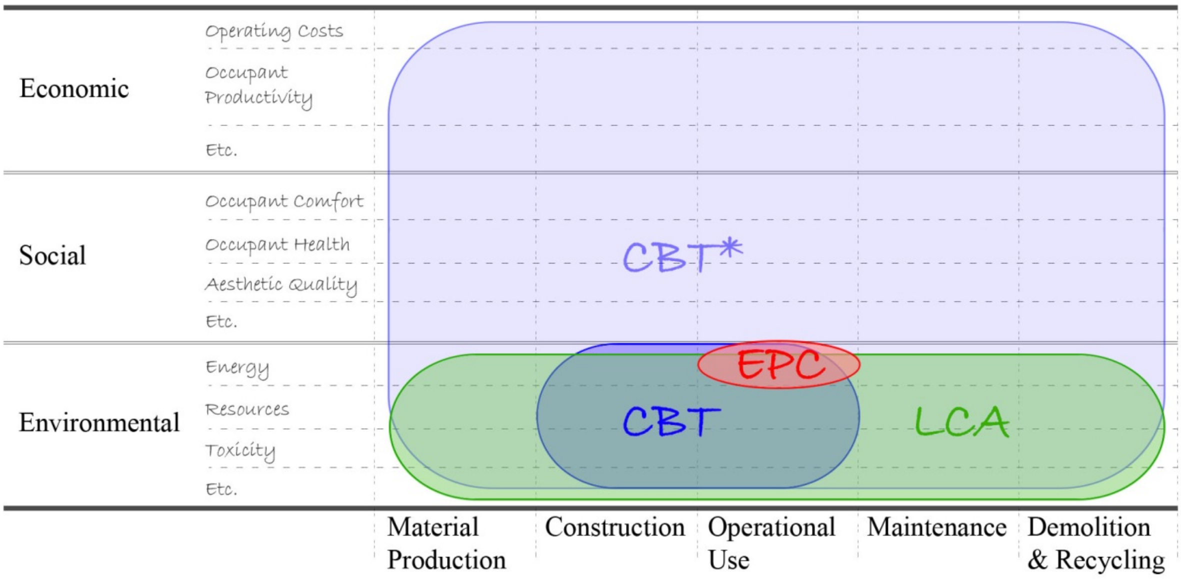
Pros & Cons. LCA is a scientific way of determining environmental impacts, based on international databases, calculation methods and ISO standards. The LCA-based methods have an in-depth coverage of environmental impacts associated with design and building materials. The latter is not unexpected because the methodology essentially builds on LCAs of products used in the building industry. Moreover, LCA-based instruments allow for estimates of the relative improvements associated with specified changes in design or the choice of building materials (Reijnders & van Roekel, 1999). LCA is based on a long-term vision, taking into account not only what is sustainable now, but also relating this to the past and the future of a product. Doing an LCA for buildings is very complex (compared to normal 'products') for four reasons; firstly buildings have a long and difficult to predict longevity, secondly a building usually undergoes many changes in form and / or function during its lifetime, thirdly a significant part of the environmental impact takes place during its use, fourthly, every building is unique and there are many different parties involved in the life cycle of a building. For these reasons, and because LCA is relatively new to the building industry (AIA Guide to Building Life Cycle Assessment in Practice), they are still less developed and less widely used than the CBT methods. Also, LCA contains no direct coverage of the indoor environment (Reijnders & van Roekel, 1999).

Refurbishment. LCA is ideal for evaluating a refurbishment process compared to other options. When taking into account the existing embodied energy already present in the existing building and the energy and materials used during demolition and construction of a new building, it is possible to compare the environmental impacts of refurbishment versus demolition and new construction through LCA.

CONCLUSION AND DISCUSSION

When the definition of sustainability, the existing legislation in the field of sustainability and the existing certificates and methods in the field of sustainability are put into relation with one another it becomes clear that these don't match. The legislation, and the consequent Energy Performance Certificate, concentrates on energy consumption during the operational use of a building. The commonly accepted definition of sustainability, the triple bottom line, focuses on environmental, social and economic health; planet, people, profit. These three categories are also reflected in the standard definition of a "green building", in addition, it specifically mentions the importance of taking into account the different stages of a buildings life, from construction and service life, to what happens after a buildings service life. The latter lies at the basis of Life Cycle Assessment methods: covering a much wider spectrum of environmental sustainability, taking into account different stages of the buildings life cycle and concerning a large range of environmental impact criteria in addition to energy. Social and Economic aspects, however, are not reflected in an LCA. The Criteria Based Tools do take into account economic, social and environmental sustainability aspects, although the main focus lies on the environmental sustainability impacts during the construction and operational use stages. These different areas of sustainability **are shown in Table 1**, clearly showing the extremely narrow part of sustainability that the legislation and the associated Energy Performance Certificates are focusing on. Also, the Criteria Based Tools have two separate indicated areas, one that stands for its main focus area, and one covering the wide range of rather superficial indicators covering the entire spectrum of sustainability.

Table 1. Spectrum of Sustainability in the Built Environment



The fact that legislation and regulations are concentrating on energy consumption during the operational use of a building has led to this principle being translated as "sustainable" in practice. A building is considered to be extremely sustainable when a zero energy value is achieved. The fact that in these cases other aspects of sustainability are completely ignored is problematic. Concepts such as "passive building" and "energy-neutral home" are popular, and national and international standards concentrate on attaining extremely high insulation values of the shells of buildings. That this insulation may often be environmentally polluting is completely disregarded. Also, there is for example the extensive use of solar panels to balance out the operational energy, while completely disregarding the embodied energy and environmental impact that was necessary to create the solar panels in the first place, a kind of deceptive sustainability. In relation to refurbishment, these regulations are also very problematic. Buildings that reach a certain age fall short of adequate operational energy efficiency to fill current standards, and are consequently threatened by large-scale demolition; to achieve the highest possible energy label demolition and new construction often are an easier option than refurbishment. The embodied energy present in these buildings will be discarded, the resources used in the new construction will not be accounted for, and the waste that is produced because of this is ignored. These things will not stand in the way of the newly constructed building achieving the highest energy certificate level, nor will it stand in the way of the newly constructed building being awarded sustainability prices and being promoted as “best practice”.

However, as described in the article, there are other assessment methods that try to provide a more complete assessment of sustainability. Unfortunately, they are very complex and require training and certification to be able to use them (Nguyen & Altan, 2011). As a result, they are not accessible and are often used at the end of the design stage instead of being used early in the design process while the most important decisions with regard to sustainability should be made at the beginning of the design process (Zeiler, 2011). They are therefore, and because they are completely voluntary in their application, far from standard in use.

The use of a different list of indicators in different approaches makes a definition of the term “Sustainable Construction” subjective and causes difficulties in comparing results from different tools. A case-study comparison by Zeiler (Zeiler, 2011) where eight different case studies were tested by four of the most popular assessment methods (LEED, BREEAM, Greencalc, Ecological Footprint), proved the outcomes to be completely different. A building could be considered most sustainable by one tool, and least sustainable by another. In order to overcome these constraints, both the International Organization for Standardization (ISO) and the European Committee for Standardization (CEN) have worked actively in the last few years to define standard requirements for the environmental and sustainability assessments of buildings (Mateus & Bragança, 2011). Both standards ISO/TC59 and CEN/TC350 take into account economic, social and environmental sustainability and aspects regarding a products life cycle from cradle to grave, they provide general definitions and principles regarding indicators and calculation methods for assessment tools. These standards do not set the rules for how building assessment schemes may provide valuation methods, nor does it prescribe levels, classes or benchmarks of performance (Technical Committee CEN/TC 350, 2010). Since these standards are not mandatory nor completed yet (especially on the part of social and economic sustainability), they haven’t been fully integrated in the assessment tools yet.

Efforts are being made to integrate LCA methodologies in CBT tools, trying to combine the measurability of LCA’s with the wide range of sustainability aspects covered in a CBT. Environmental issues are broad and difficult to capture, combining qualitative and quantitative data, a balance between completeness of coverage and ease of use remains one of the challenges in developing an environmental building assessment tool.

REFERENCES

Bayer, C. (2010). *AIA Guide to Building Life Cycle Assessment in Practice.* The American Institute of Architects

Bio Intelligence Service, Ronan Lyons and IEEP (2013) *Energy performance certificates in buildings and their impact on transaction prices and rents inselected EU countries,* Final report prepared for European Commission (DG Energy)

Carson, R. (2002). *Silent spring*. Boston: Houghton Mifflin.

Ciravoğlu, A., & Taygun, G. T. (2013). *Evaluation of the LCA approaches for the assessment of embodied energy of building products* (Vol. 22).

Cole, R. J. (2003). Building environmental assessment methods: a measure of success. *The future of Sustainable Construction,* ISBN 1-886431-09-4

Cole, R. J. (2005). Building environmental assessment methods: redefining intentions and roles. *Building Research & Information*, *33*(5), 455–467.

Ding, G. K. C. (2008). Sustainable construction—The role of environmental assessment tools. *Journal of Environmental Management*, *86*(3), 451–464.

E06 Committee. (2004). *Terminology for Sustainability Relative to the Performance of Buildings*. ASTM International.

Elkington, J. (1998). *Cannibals With Forks: The Triple Bottom Line of 21st Century Business*. New Society Publishers.

Guinée, J. B. (2002). *Handbook on life cycle assessment operational guide to the ISO standards*. Dordrecht; Boston: Kluwer Academic Publishers.

Häkkinen, T. (2007). Assessment of indicators for sustainable urban construction. *Civil Engineering and Environmental Systems*, *24*(4), 247–259.

Itard, L., & Klunder, G. (2007). Comparing environmental impacts of renovated housing stock with new construction. *Building Research & Information*, *35*(3), 252–267.

Lebel, G. G., Kane, H., & World Commission on Environment and Development. (1991). *Our Common Future: The World Commission on Environment and Development*.

Lovelock, J. (2000). *Gaia: a new look at life on earth*. Oxford; New York: Oxford University Press.

Mateus, R., & Bragança, L. (2011). Sustainability assessment and rating of buildings: Developing the methodology SBToolPT–H. *Building and Environment*, *46*(10), 1962–1971.

Nguyen, B. K., & Altan, H. (2011). Comparative Review of Five Sustainable Rating Systems. *Procedia Engineering*, *21*, 376–386.

Oberthür, S., & Ott, H. E. (1999). *The Kyoto Protocol: International Climate Policy for the 21st Century*. Springer.

Petersdorff, C., Boermans, T., & Harnisch, J. (2006). Mitigation of CO2 emissions from the EU-15 building stock: beyond the EU Directive on the Energy Performance of Buildings. *Environmental science and pollution research international*, *13*(5), 350–8.

Poel, B., van Cruchten, G., & Balaras, C. A. (2007). Energy performance assessment of existing dwellings. *Energy and Buildings*, *39*(4), 393–403.

Power, A. (2008). Does demolition or refurbishment of old and inefficient homes help to increase our environmental, social and economic viability? *Energy Policy*, *36*(12), 4487–4501.

Rawlinson, S., Weight, D. (2007). Sustainability: Embodied carbon. *Building*. 12 October 2007, p 88-91

Reijnders, L., van Roekel, A. (1999). Comprehensiveness and adequacy of tools for the environmental improvement of buildings. *Journal of Cleaner Production*, *7*(3), 221–225.

Sands, P., Galizzi, P. (2006) Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. *Documents in European Community Environmental Law*, Second edition. Cambridge University Press.

Sev, A. (2011). A comparative analysis of building environmental assessment tools and suggestions for regional adaptations. *Civil Engineering and Environmental Systems*, *28*(3), 231–245.

Shah, S. (2012). *Sustainable refurbishment*. Chichester, West Sussex, U.K.: Wiley-Blackwell.

Technical Committee CEN/TC 350 (2010). *NEN-EN 15643-1. Sustainability of construction works - Sustainability assessment of buildings - Part 1: General framework.* Delft: Nederlands Normalisatie Instituut.

Thormark, C. (2002) A low energy building in a life cycle—its embodied energy, energy need for operation and recycling potential. *Building and environment.* 37(4), 429–435

Todd, J. A. (2012). Buildings, Systems Thinking, and Life Cycle Assessment. In *Life Cycle Assessment Handbook: A Guide for Environmentally Sustainable Products* (pp. 311–328).

United Nations Environment Programme. (2011). *Towards a green economy: pathways to sustainable development and poverty eradication*. Nairobi, Kenya: UNEP.

World Commission on Environment and Development. (1987). *Our Common Future* (1St Edition edition.). Oxford ; New York: Oxford University Press.

Zeiler, W. (2011). Sustainable architecture and sustainable design assessment tools. In *PLEA 2011 - Architecture and Sustainable Development, Conference Proceedings of the 27th International Conference on Passive and Low Energy Architecture* (pp. 163–168).