Sustainability Assessment and Standardisation – Steel Buildings

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ABSTRACT: This paper aims at evaluating in what extent are the existing sustainability assessment methodologies capable of truly reward the benefits of steel-intensive buildings in comparison with other building construction solutions. This evaluation consists in describing the more common sustainability assessment methodologies from the steel construction point of view and in comparing existing assessments to steel buildings. The pros and cons of each will also be pointed out, in order to determine the best practices of each methodology.

1. INTRODUCTION

With the construction and real estate evolution some materials have emerged. Steel, although not a new material, is getting more and more attention, especially because it is unique among other major construction materials, as it is fully recyclable (Living Steel 2010, Gervásio 2008). This call of attention to steel intensive buildings has also been driven by the following facts: adaptability and flexibility, since parts can be easily added or taken off or demounted; steel allows low operation as well as effective embodied energy (Santos et al. 2010, Gervásio et al. 2010); foundations can be extracted from the site and also can be lightweight; high ratio strength- weight; fabric/offsite manufacture, allowing just in time deliverables, better safety and health conditions for workers, higher product quality and quicker production and building construction; bigger life span, accomplished by gathering the other characteristics; multicycling products, as steel can be continuously recycled without losing its quality and properties; recyclable and re-usable; great thermal mass performance, etc.

Several case-studies have been published assessing buildings sustainability, environmental or even energy performance; others, had reviewed and compare sustainability assessment systems as e.g. by Forsberg & Malmborg (2004), Haapio & Viitaniemi (2008), or Ding (2008). However neither of them has specifically focused steel buildings nor a comprehensive critical review of steel-intensive buildings sustainability assessment. This papers aims to offer information to compare and contrast different sustainability assessment methods especially in relation to steel buildings in early design phases.

2. INTERNATIONAL STANDARDS: ISO AND CEN

Several documents, laws and standards have been developed by public and international policy makers, to tighten environmental mitigation (Grecea & Szitar 2011, Ilomaki et al. 2008) and to improve the sustainable development. Also, private organisms and academia are committed to ensure a sustainable built environment (Czarnecki & Kaprón 2010). At an international scale complementary works are being carried out in the International Organization for Standardization (ISO Standards) and in the European Committee for Standardization (CEN).

2.1. ISO Standards

In what regards the ISO standards, there are different Technical Committees (TC) responsible for the development of several standards related to Life-Cycle and Sustainability. However, only ISO/TC59 "Buildings and civil engineering works" has been specifically addressing buildings' sustainability in an integrated manner between environment, society and economics. The standards that have been developed by ISO/TC59/SC17 (Sustainability in Building Construction) are listed in Table 1 (ISO 2011).

ISO 15392:2008 identifies and establishes general principles for sustainability in building construction, throughout their life cycle - from cradle to grave. However this standard does not provide benchmarking for assessment.

The ISO 21929 series – 21929-1 (ISO 21929-1, (under development) and 21929-2 (ISO 21929-2, (under development) – intend to provide the framework, recommendations and guidelines for the development and selection of appropriate sustainability indicators for buildings and construction works. The framework includes a list of environmental, social and economic impacts key indicators, describing also how they should be used. Some of them are mandatory, while others are just mentioned as helpful for and when assessing sustainability of buildings. Rules are provided to aid the indicators selection. Both standards, however do not give guidelines for the indicators weighting or for the aggregation of results. The proposed indicators are collected and presented in Table 1. All of them can be applied to steel-framed buildings.

The elaboration of environmental product declarations (EPD) to building products is standardised by ISO 21930:2007. According to it the indicators presented in Table 1 shall be used to express the impacts and the environmental aspects of the building products.

Table 1. Core indicators of ISO 21929-1 and Environmental indicators in ISO 21930

Core indicators of ISO 21929-1		Environmental indicators in ISO 21930
Public transportation	Potential impact on climate change	Climate change (greenhouse gases)
Personal modes of transportation	Potential impact on the depletion of stratospheric ozone layer	Depletion of the stratospheric ozone layer
Green and open spaces	Aesthetic quality	Acidification of land and waste sources
User relevant basic services	Accessibility	Eutrophication
Building site	Indoor condition	Depletion of non-renewable energy resources
Building	Indoor air quality	Depletion of non-renewable material resources
Adaptability	Land	Use of renewable material resources
Adaptability for changed use purpose	Non-renewable resources	Use of renewable primary energy
Adaptability for climate change	Fresh water	Consumption of fresh water
Waste	Safety	Waste to disposal
Serviceability	Costs	Emission to water, soil and to indoor air
Maintainability		Other additional environmental information

2.2. CEN Standards

CEN trough TC 350 "Sustainability of Construction Works" has been developing voluntary horizontal standard methods to assess and promote sustainable construction for both new and existing construction works and also for EPD of construction materials.

CEN/TR 15941:2010 provides the methodology to use the generic data needed to elaborate an EPD. It specifies where and how it should be used, which the reliable sources are and how its quality should be assessed. However, the requirements and core rules for the use of generic data are described in prEN 15804 (prEN 15804, (under approval). This later provides a structure to ensure that all the EPD of construction products, construction services and construction processes are derived, verified and presented in a harmonised way.

EN 15643-1:2010 provides the general framework, principles and requirements, for the assessment of buildings in terms of the three sustainability dimensions, considering technical characteristics and functionality of the buildings. The proposed framework and methods can be applied to all building typologies and to relevant environmental, social and economic aspects. The life-cycle phases covered by this standard vary depending on the buildings stage; if a new building is assessed, the entire LC should be considered; if the assessment is preformed to an existing building, then it should cover the remaining service life and end of life stage. EN 15643-1:2010 drove the development of three other standards: EN 15643-2:2011, prEN 15643-3 and prEN 15643-4. These three standards regard respectively the framework for the assessment of environmental, social and economic performance.

EN 15643-2:2011 beyond presenting the requirements for the environmental assessment, as the life-cycle phases considered and their constraints, it also sets the indicators that should be included in the assessment (Tab. 2).

prEN 15643-3 aims to evaluate the social impacts and aspects of the building and its site and to aid the decision-making process when addressing sustainability. This standard regards social aspects as, for instance health and wellbeing or functionality (Tab. 2).

Table 2. Environmental indicators considered in EN 15643-2:2011and Social indicators considered in prEN15643-3

Environmental indicators considered in EN 15643-2:2011	Social indicators considered in prEN 15643-3
Abiotic depletion potential	Thermal performance
Acidification of land and water resources	Humidity
Destruction of the stratospheric ozone layer	Quality of water for use in buildings
Eutrophication	Indoor air quality
Formation of ground-level ozone	Visual comfort
Global warming potential	Acoustic performance
Use of non-renewable and renewable primary energy	Accessibility for people with specific needs
Use of secondary materials and fuels	Noise
Use of freshwater resources	Resistance to climate change
Components for reuse	Fire safety
Materials for recycling and for energy recovery	Security against intruders and vandalism
Non-hazardous waste to disposal	Security against interruptions of utility supply
Hazardous and radioactive waste to disposal	Maintenance Requirement
Exported energy	

Finally, prEN15643-4 addresses the economic performance assessment which shall include all relevant information on the costs. This cost information must be related to the building fabric – before and during the use phase and at the end of life – and cost information regarding the building information as energy and water costs or taxes that occur during the operation phase. Some of the costs information related to the building fabric is listed below:

- Land costs;
- Professional fees;
- Initial adaptation or fit out of asset;
- Subsidies and incentives;
- Repairs, replacement of components or refurbishment;
- Cleaning;
- Redecoration;
- Deconstruction/ Dismantling, Demolition;
- Transport costs associated deconstruction and disposal;

- Costs from reuse, recycling, and energy recovery at end of life.

3. SUSTAINABILITY ASSESSMENT TOOLS

Pre-design and design phases are regarded as crucial to the sustainability performance of a building throughout its life-cycle. Unfortunately, the development of supportive decision-making methodologies is poorly developed.

Sustainability assessment methodologies can be oriented to different scales of analysis: building material, building product, construction element, independent zone, building and the neighbourhood, or even to different life-cycle phase.

This paper will focus in the comparison of BREEAM (BREEAM 2011), LEED (LEED 2010), ATHENA (ATHENA® 2008), SB Tool (iiSBE 2009), Eco-Quantum, CASBEE (IBEC 2009) and EcoProP (EcoProp 2004), taking into account the following criteria:

- Relevance: Has the methodology a holistic approach?
- Coverage: Do the methods cover all sustainability dimensions? Which are the sustainability indicators focused by the methodology?
- Applicability: which building typologies can be assessed? Which life-cycle phases are included in the assessment?
- Adaptability: Are the methodologies easily applicable to steel-framed buildings? Do they truly acknowledge the steel sustainability potential?

Relevance

Early design phases are crucial for the buildings life cycle sustainability (Hanna & Skiffington 2010, Bunz et al. 2006). Holistic and systemic approaches are hence most effective when used in these phases. According to Ding (2008) it is important to separate project design and project assessment, as the assessment process is usually carried out when the project's design is almost concluded. In this way, sustainability assessment methods to be truly useful must be introduced as early as possible, allowing interrelation between designing and assessing teams. Analysing the most well-known and used methodologies it is possible to divide them depending on their scope, into three main groups (Trusty 2000, Bragança et al. 2010):

- Systems to manage overall building performance (Performance Based Design);
- Life-cycle assessment systems with additions of social, cultural and economic issues;
- Sustainable building rating and certification systems.

From the methodologies under assessment, only EcoProP is a Performance Based Design system; Eco-Quantum and ATHENA are life-cycle assessment systems, while BREEAM, LEED, SBTool, CASBEE and DGNB correspond to Level 3 – Rating and Certification Systems. Moreover, accordingly to Trusty (2000) performance based design methods are more likely to be used in early design phases, while LCA and rating and certification systems are usually used in the later-design, construction or operation phases.

Coverage

Sustainability assessment is nowadays widely mentioned; however it is most of the times just regarded as an environmental issue and not giving so much attention to the functional, social and economic performance. Weighting is inherent to all systems and, according to Lee (Lee et al. 2002), it is the heart of all assessment systems, as it is responsible for establishing the overall performance score. However, its establishment is not unanimous there is not yet a consensus-base method to guide the weightings assignment (Ding 2008).

Figure **1**Figure 1 shows schematically the weighting factors given to sets of sustainability indicators in each of the methodologies assessed. EcoProP was not included in this comparison since weighting factors were not available. ATHENA and Eco-Quantum address environmental aspects only and interim weighting factors are not publicly available, so they were also out of the plot drawing. Regarding CASBEE, it is not possible to determine the weight of the two main indicators groups to the final score – the "building environmental quality (Q)" and the "building environmental load (LR)" – since they rely on the interim scores of each addressed category; still, their contribution is shown in Table 3. (IBEC 2008).

Table 3. CASBEE weighting factors (IBEC 2008)

Building environmental quality		Building environmental load	
Q1 Indoor environment	0.4	LR1 Energy	0.4
Q2 Quality of Service	0.3	LR2 Resources & Materials	0.3
Q3 Outdoor Environment on Site	0.3	LR3 Off-site Environment	0.3

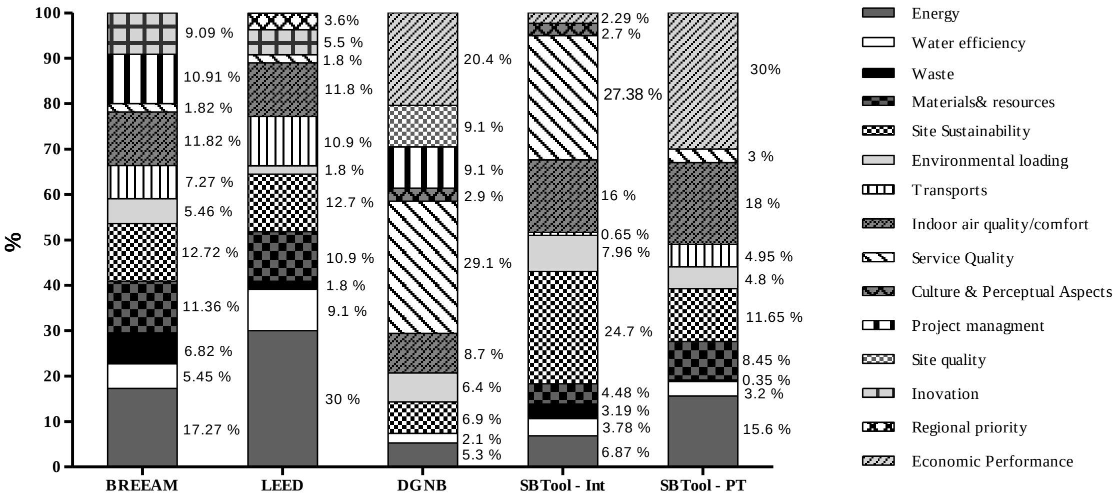

Figure 1. Sustainability methodologies weights distribution

From all the assessing methodologies, just SBTool, DGNB and EcoProP consider the three main sustainable dimensions: environment, social and economy. Neither LEED nor BREEAM consider cost issues, instead both systems focus on the eco-friendly aspects such as energy, water, and indoor environment. Cultural and/or aesthetic aspects – that are normally added to the social field – are just considered in SBTool (International 2011 version) and DGNB. Project Management is just regarded in BREEAM, DGNB and EcoProP, accounting about 10% to the final score in the first two approaches. In the social field, all the rating systems assessed, as well as EcoProP, consider indoor comfort and health aspects, though service quality is barely accounted in BREEAM, LEED and $SBTool^{PT}$ (version 2009/2 - homes). On the contrary, SBTool International and DGNB give an important position to service quality. Concerning ecological aspects, all the methodologies concentrate a great effort in this field. Aspects related to energy and site sustainability have the highest percentage in the ecologic weight.

A more detailed comparison, at the indicators level, is presented in Table 4.

Table 4. Main issues accounted in the sustainability assessment methodologies

	BREEAM	LEED	SBTOOL INT	SBTOOL PT	DGNB	ATHENA	Eco-Quantum	EcoProP	CASBEE
Energy									
Low CO_2 emissions	x		x		x			x	
Renewable energy		x	x	x	x	x	x	x	x
Natural/local energy		x							x
Efficiency	x	x		x	x			x	x
Electrical Demand	x	x	x		x				x
Low or zero carbon	x		x		x			x	
energy monitoring	x	x					x		x
Drying space	x								
Water Efficiency									
Re-use/recycling	x	x	x	x				x	x
Water consumption	x	x	x	x	x			x	x
Water monitoring	x								
Leak detention	x								
Waste									
Construction waste management	x	x	x						
Non-hazardous waste	x		x				x		
Hazardous waste	x		x	x			x		
Liquid effluents			x		x				
Materials and Resources									
Materials reuse	x	x	x	x	x				x
Recycled content		x		x					x
Renewable sources		x	x			x	x		x
Responsible sourcing	x	x		x	x				x
Robustness	x				x				
Ease of disassembly, re-use or recycling			x		x			x	
Site Sustainability									
Site Selection	x	x	x	x	(x)			x	
Site development		x	x						
Land use			x	x	x		x		
Heat Island effect		x		x	x				x
Noise control	x			x	x				x
Development of community		x			(x)				
Stormwater design	x	x							
Local ecology/ biodiversity	x		x	x					x
regional impacts	x		x		x				x
Access to daylight			x						x
Influence in other constructions			x						x
Light pollution	x	x	x						x
Environmental loading									
Atmospheric emissions	x	x	x	x	x	x	x	x	x
Refrigerant management -	x	x	x	x	x	x	x	x	x

	BREEAM	LEED	SBTOOL INT	SBTOOL PT	DGNB	ATHENA	Eco-Quantum	EcoProP	CASBEE
LCA									
Transports									
Public transports	x	x	x	x	(x)				
Cycling accessibility	x	x			x				
Parking	x								
Travel plan	x								
Indoor air quality									
Thermal comfort	x	x	x	x	x			x	x
Visual comfort	x	x	x	x	x			x	x
Acoustics	x		x	x	x			x	x
Hygiene	x	x	x	x	x			x	x
Ventilation	x	x	x	x				x	x
Water quality	x								
Service Quality									
Flexibility/adaptability			x		x			x	x
Disable persons access					x				
Safety and security	x		x		x			x	
Earthquake resistance									x
Maintenance management			x		x			´x	x
Spatial efficiency			x		x			x	x
User controllability			x					x	x
Functionality			x					x	x
Fire prevention					x			x	
Cultural & Aesthetics									
Culture & heritage			x						
Aesthetic quality			x		x				
Integration of public art					x				
Project Management									
Planning	x				x				
Construction phase					x				
Stakeholders participation	x				x				
Construction site impacts	x				x				
Economic issues									
Construction Costs			x		x			x	
LCC			x		x		x	x	
Value Stability					x				
Local economy			x						
Innovation									
Innovation issues	(x)	(x)							
Regional priority									
Regional priority issues		(x)							

(x) – consider as extra points or separately from the assessment

Applicability

Sustainability assessment methodologies can be used in different life cycle phases (Table 5) and also in several buildings typologies or even building products (Table 6). The ATHENA methodologies classification states that Level 1 methodologies (performance-based) are more likely to address products comparisons and supply information, while Level 2 (LCA-based) and Level 3 (Rating and Certification Systems) systems mainly the building as a whole (Trusty 2000).

There are different building typologies and all the systems assessed, with the exception of Eco-Quantum, are able to analyse more than one. Methodologies like BREEAM, LEED, CASBEE or DGNB have different versions for the different buildings types and also for its stage (new construction, existing building or refurbishment). CASBEE has under development a tool version to assist planning/pre-design of the project (IBEC 2009) (Tab. 5).

Table 5. Assessed buildings typologies

	BREEAM	LEED	SBTool	ATHENA	Eco-Quantum	CASBEE	DGNB	EcoProP
Pre-Design						*		x
Existing buildings	x	x		x	x	x		
New buildings	x	x	x	x	x	x	x	
Refurbishment	x	x	x	x		x		
Building product					x	x		
Residential building (multi story)	x	x	x	x		x	x	x
Homes (single family)	x	x	x	x	x	x	x	x
Offices	x	x	x	x[1]		x	x	x[1]
Schools	x	x				x	x	
Hospitals	x	x				x		
Retail	x	x	x			x	x	
Industrial	x	x					x	
Prisons	x							

* under development | 1 – and other types of buildings but without specification

All methodologies have different approaches to life-cycle phases. None of them is cable of addressing all phases, but BREEAM, LEED and SBTool present a better coverage. ATHENA, for example accounts for construction, demolition and disposal, but it does not consider the operation phase; BREEAM, although considers disposal does not includes demolition. SBTool addresses demolition, but not disposal. CASBEE only takes into account construction, operation and maintenance. Despite considering mainly the same phases, the approach to them may vary from system to system (Tab. 6).

Table 6. Life Cycle Phases considered

	BREEAM	LEED	SBTool	ATHENA	Eco-Quantum	CASBEE	DGNB	EcoProP
Project/design	x		x				x	
Production	x	x	x	x				
Construction	x	x	x	x	x	x	x	x
Use/Operation	x	x	x		x	x	x	x
Maintenance	x	x	x	x	x	x		x
Demolition		x	x	x	x			x
Disposal	x	x		x	x			x

4. APPLICATIONS TO STEEL-FRAMED BUILDINGS

In order to examine the sustainability methodologies and standards potential within steel construction it is necessary to determine which issues included in its approach regarding buildings' properties can be associated with the steel building technology and acknowledge its potential towards sustainability.

As already stated, being steel construction or other construction solution, early design stages are the most effective to achieve the buildings' sustainability throughout its entire life-cycle. Hence, approaches like EcoProP, which are specially developed to be applied in early project phases, are of great value towards good decision-making support.

LCA-based methods have an in-depth coverage of environmental impacts associated with design and building materials (Kohler 1999). ATHENA and Eco-Quantum approaches, although not directly related to steel construction, can easily promote it. One of steel construction's advantages is its recycled content rate or even the fact that iron is one of the most abundant materials on earth. Hence, by accounting the steel making process and the end-use solutions, these systems can certainly declare the environmental potential of this technology.

Concerning the standards from ISO and CEN, it is important to bear in mind that the proposed frameworks and indicators should be followed when assessing steel construction. For example, social indicators proposed by prEN15643-3:2010 as fire safety, or security against vandalism or interruptions in energy supply, are barely mentioned in the sustainability assessment systems. The development of EPD's for steel products using ISO 21930:2007 or FprEN 15804:2011 frameworks and methods can also promote the environmental potential of steel-framed buildings.

When taking a closer look to the steel main sustainable factors together with the assessment approaches and the main issues considered by them (following the categories presents in Figure 1) it is possible to identify its specific applicability.

For example, steel's off-site manufacture can contribute positively for achieving a great score in site sustainability, waste, project management or materials and resources categories. Steel just in time delivery and faster construction can lead to fewer impacts on the site and locality, as reducing location traffic congestion, contributing to more workable conditions in difficult urban sites. LEED's 'Development density and community connectivity' credit, SBTool's 'Impact of construction process on local residents and commercial facilities users' and 'Impact on private vehicles used by building population on peak load capacity of local road system' indicators, or CASBEE's 'Load on local infrastructure' item can address this benefits. Also, the less waste production reduces the need of outputting them from the site, leading to less energy spent in transportation. This issue can also be addressed in BREEAM's 'construction site impacts' credits. The use of steel also provides the opportunity for management systems that reduce site disturbance. This can be accounted in LEED, BREEAM, SBTool and DGNB "site development" aspects, in BRREAM's "responsible construction practices" credits and also in EcoProP 'impacts in surroundings' item. Also for indicators related to site development or sustainability, steel properties as its lightweight, lighter and smaller foundations or flexibility, which enable difficult urban sites to be more readily exploited, can be regarded as positive contributions towards the whole building sustainability.

The lightweight steel solutions are a great benefit when, for example, re-developing contaminated sites, as these structures require less ground works. Moreover, large scale prefabrication using steel components can reduce disturbance of the polluted ground. These facts can be accounted in LEED 'Brownfield redevelopment', BREEAM's 'site selection', EcoProP's "location", SBTool 'Use of previously contaminated land for development' and DGNB 'site location conditions' items. Lightweight solutions also contribute for reducing the amount of materials used and to less exploitation of natural resources; these facts are considered for instance, in CASBEE 'Reducing usage of materials'.

The most mentioned property of steel when talking about sustainability, is its recyclability and multi-cycling, which contribute both for reducing demolition or production waste and to improve the recycled content of the building. Among all the methodologies referred, LEED is the one that best addresses this important property of steel. It is dealt with in several items from the materials category, as 'Construction waste management', 'Recycled content' and 'Regional materials'. SBTool also considers this matter in 'use of virgin non-renewable materials' and in

'Easy of disassembly, re-use or recycling'; CASBEE acknowledges steel's recyclability by 'Use of recycled materials as structural frame materials' and DGNB by 'Ease of dismantling and recycling'.

Besides being easily recycled steel can also be easily re-used. Due to its bolted connections, steel structures can simply be detached from each other and demounted without generating dust, dirt and high noise levels. This re-usability turns steel structures into very flexible and adaptable structures, allowing them to be demounted in one place and re-mounted in another, even if the goal of the building is quite different from the first one. Steel is also very adaptable and flexible as it connects well with existing structures or façades in the site, allowing them to be included in the new building. This reduces materials usage and contributes, for example, to keep a location aesthetics and heritage. Re-use, flexibility and adaptability of steel structures can be addressed in the different methodologies in items as BREEAM's 'Materials life cycle impacts', LEED's two credits regarding building reuse and 'Material re-use' and SBTool's 'Degree of re-use of suitable existing structures where available'.

Regarding indoor air quality, service quality and functionality aspects, although not directly related to steel construction, as good results can also be achieved by other construction solutions, steel construction easily achieve great scores when being assessed by the above mentioned methodologies. For instance, indicators related to the indoor air conditions contain issues such as visual, thermal and acoustic comfort, which are related not only to the flexibility of steel structures but also the wide variety of materials that can be easily included in the structure during the building design; good thermal and acoustic insulation materials can be added and highly glazed areas have a great affinity with steel buildings. Service quality and functionality of steel buildings can be rewarded by its flexibility allowing a great spatial efficiency and suitability to desired function, by ensuring easy access to the structure components, facilitating maintenance operations. The fire prevention aspect assessed by DGNB also contributes to promote steel construction since it is a good fire delayer. SBTool is the only approach accounting safety and health aspects during the construction phase. The off-site manufacture of steel also contributes to a more controllable and safer work period, reducing the workers' exposure to risks.

Finally, the faster construction period, the long life span, the easy maintenance operation without big material loses and the great performance regarding thermal needs, contribute to less expenses and hence to obtain a greater economic performance in SBTool and DGNB assessments.

5. CONCLUSIONS

Steel construction has been proving its sustainable potentitb al and taking big steps towards the built environment sustainability. For this reason, it is essential to assess into what extent the existing sustainability assessment systems can acknowledge steel sustainable facts and promote its development. In the research presented in this paper, different methodologies were assessed and compared, when been applied to steel buildings. Although, all the methodologies evaluated can recognise some of the benefits of this construction solution, none of them is capable of addressing all the facts. If some can best recognise the functional or service qualities of steel buildings, as SBTool, others like LEED are more effective rewarding the steel recycling potential. BREEAM and DGNB showed a great coverage of the steel benefits, but in a superficial way. Also, early design support approaches should be preferable, as EcoProP, since they contribute in a more efficient way to accomplish the buildings' sustainability.

Overall, to deal with all sustainable construction aspects in early design phases, and in particular with steel construction, a systemic approach is needed, defining the sustainable building concept through tangible goals in order that, as a result of the sustainable design process, it is be possible to achieve the most appropriate balance between socio-cultural, economic and environmental fields.

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