Using the SBTool System as a platform for education in sustainable built environment

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ABSTRACT: For a number of the well-known rating systems, the number of registered projects greatly exceeds those certified. Part of this is due to time lags in the process and the high cost of certification, but it also reflects a desire by users to learn about sustainability issues raised in these systems. In professional development settings, formal courses related to sustainability assessments tend to focus on specific rating systems, and result in credentials being given only for the specific system. In formal educational settings the study of large number of existing systems presents a problem, since each one contains very specific and different criteria. In this context, it is suggested that the generic SBTool system, which has a generalized framework and contains a broad spectrum of generic criteria and benchmarks, could be used as an effective educational platform. In this scenario, instructors and students could collaborate to determine the scope of enquiry (multi-issue, or focused on a particular issue area) and then concentrate the discussion on the issues related to the validity and appropriate implementation of specific criteria. The paper will illustrate some options related to the issues outlined above, and will demonstrate the great diversity of results that are possible within the consistent overall framework.

1 INTRODUCTION

Curricula for academic programs in Masters of Architecture or Civil Engineering that emphasise sustainability have become very complex and extensive. Such programs have to ensure that traditional topics related to design and construction continue to be covered, but must now extend to at least some of related issues in the fields of ecology, climate science, sociology, materials science, construction technology, urban planning and management theory.

This situation presents both instructors and students with several dilemmas: is it better to follow a broad but shallow survey approach, or a more in-depth but narrower program consisting of individual courses? And, if an in-depth approach is followed, how can the various components be tied together?

Another approach is to use an existing performance rating system (e.g. LEED, BREEAM, CASBEE etc.) as the basis for an educational program. Such systems do link together many separate technical and environmental issues, but in a way that is applicable to a particular building type in a specific region, and this works against the need to inculcate students with ideas that they will be able to apply to different building types in other regions.

The issue to be resolved is two-fold: how to ensure that the increased amount and breadth of information can be absorbed to an acceptable depth and focus, and how to integrate the rapidly proliferating special areas of study.

2 WORKING DEFINITION OF SUSTAINABLE BUILDING PERFORMANCE

The authors define sustainability in the built environment sector as including four major factors: environmental, social, economic and functional. The first three elements will be familiar to many, but over more than a decade of dealing with these issues, we have found it impossible to make meaningful progress, at least at the scale of buildings, without referring to functionality (or serviceability) in addition to the well-known triad. This definition is not universally.

There have been many other suggestions for a clear definition. Lau (2010) emphasizes the complexity of trying to address sustainability issues within the sector. By the mid 1990s, there were over 300 definitions of sustainability Dobson (1996). With such a highly contested definition, Andres Edwards (2005) took a different tack in trying to understand sustainability by examining the principles that underlie the actions of various different sustainability organizations. The focal categories of groups examined included community, commerce, natural resources, ecological design and the biosphere. After reviewing 39 sources spanning the period from 1978 to 2003, Edwards (2005) found seven common themes:

1. Stewardship;
2. Respect for limits;
3. Interdependence;
4. Economic restructuring;
5. Fair distribution;
6. Intergenerational perspective;
7. Nature as model and teacher.

These themes are useful in the way that they begin to paint a picture of this new paradigm from which sustainability may emerge. Every one of these themes runs counter to the technological world view and the idea of unlimited material progress.

The meta-themes outlined above are, of course, very general and must be supplemented by more specific goals. One good example of an attempt to define sustainability at a more explicit level is found in the curriculum for a graduate course for engineers developed at the University of Florida, and described by Yeralan (2009). The course contents proposed by these authors are the following:

1. The history of industrialization and trade technology
   Industrial revolutions, effects of, large-scale commerce, positive feedback, monopolies, globalization.
2. Environmental issues
   Effects of production on the environment, the carbon and water cycles, monitoring and evaluating environmental health.
3. Energy, food and water
   Types of energy, energy models, exergy and emergy, food-chain, relationship between food and other production, virtual or embodied water, fossil fuels and bio-fuels, renewable and alternative energy.
4. Global climate change
   Global warming; climate models, trends; evaluating the effects of natural disasters.
5. Environmental ethics
   Ethics and morality. Normative, descriptive, and meta-ethics. Conflicts, conflict mitigation and conflict resolution. Anthropo-centric versus ecocentric views.
6. Sustainability - definitions and principles
   The principles of sustainability; various definitions; historical studies.
7. Systems issues
   Systems thinking, systems modelling of the production with its environment.
8. Modelling techniques for complex systems
   Philosophical foundations and issues of modelling. UML (unified modelling language), industrial dynamics, signal flow diagrams, state space models, state transition diagrams. Shortcomings of the scientific method.
9. Economics of globalization
   Economic principles of large-scale international production, transport, and consumption; the macro and micro views of globalization, entropy.

10. International efforts towards sustainability
    Historical treaties and their content. Major philosophical views. Difference between developed and developing countries.
11. Sustainability models
    Models of sustainable production systems, economic and operational research models, decision making in a sustainable environment. Shortcomings of the analytical method.
12. Incorporating sustainability issues into industrial engineering models
    Examples of optimization models that contain sustainability concerns.

The curriculum above is more specific than other examples, but is still quite general. A better understanding of the isolation between disciplines can be obtained requires an investigation of the existing curricula in architectural and engineering education.

3 LIMITATIONS OF TRADITIONAL COURSE STRUCTURES IN MEETING NEW CHALLENGES

The field of architectural and engineering education related to buildings and urban design has developed from several different traditions. Architectural education has been variously based on a fine arts / visual design approach, a less academic vocational approach and, more recently, elements of building science and sociology. Engineering education was traditionally originated in the field of Civil Engineering and Structural Engineering. Engineers who become practitioners in mechanical engineering for buildings have usually come out of general mechanical engineering courses.

During the last few decades, both disciplines have faced the need to address environmental issues. Within the engineering discipline efforts have mainly focused on including ecological and environmental management issues, as well development of more sophisticated technical skills such as CAD (computer-assisted design) and computer-based analytic and predictive methods.

Within the architectural stream, the picture is more complex. In North America, the UK, Australia and some other parts of Europe, concepts of “green building” have been introduced, sometimes over the opposition of more traditional visual-arts oriented instructors. Where accepted, such expanded programs have introduced many energy and environmental issues to students, at least at senior undergraduate or graduate levels. In North America, at least, this has often been augmented by linking course work or studio projects to the requirements of LEED (Leadership in Energy and Environmental Design). In North America, this is appropriate, since LEED is designed for conditions there, with the only limitation being that LEED is focused on green (environmental) and not sustainability issues.

All of these developments have been somewhat complicated by the trend towards problem-based learning. As Grierson (2011) put it: “Case studies have suggested that a shift is needed from more traditional teaching delivery methods to problem-based learning.” and later in the same paper, with reference to a survey of 304 postgraduate students, “When asked how these skills could be incorporated into the curriculum there was a clear emphasis on ‘skills training workshops aligned with sustainability’ and ‘live projects in collaboration with industry’…”

When turning to issues of sustainability in the built environment sector there is an even greater need to link issues such as social, economic, urban and community factors to the core engineering or architectural programs. This vastly increases the burden for instructors and students alike, and it is this massive problem of integration that the authors try to address in this paper. Grierson (2011) recognize this dilemma by proposing a draft programme that requires the student to select one of four curriculum packages: Business for Sustainability, Engineering for Sustainability, Humanities and Social Science for Sustainability, and Science for Sustainability. For the purposes of this paper, this is just a re-presentation of the old dilemma of separate streams, since sustainability in the built environment requires all of these streams to be integrated.

4 CHANGES NEEDED IN HIGHER EDUCATION TO ADDRESS SUSTAINABILITY ISSUES

What changes in curricula are needed to provide a graduate-level student with sufficient breadth and integration to develop an understanding of sustainable building and construction?

A comprehensive analysis of the Australian higher education system with regard to its approach to sustainability issues, by Lyth (2007), has produced some interesting proposals:

1. The research indicated that professionals understand the need for climate change adaptation but not the practical implications. Therefore, professional development that focuses on 'what we should be doing on the ground' is needed, supported by quality assured resources and processes to support tertiary teachers, trainers and practitioners;
2. It was acknowledged that there will be an increasing need for built environment professionals and students to work in cross-disciplinary teams to be able to understand problems related to climate change, collectively solve them, and share best practice case studies. This is likely to require partnerships between professional institutions and increased resources (financial and time) to facilitate collaborative teaching and learning initiatives;
3. The professional institutions opposed the idea of a sole focus on specialised courses on climate change. It was agreed that such an approach would limit the ability to embed core competencies across the professions and might foster an inequitable distribution of competency across Australian communities, thus limiting adaptive capacity in some places and sectors.

Further on in the document, Lyth (2007) explains: "The architecture profession's teachers are a diverse group and many know nothing about climate change and some may see it irrelevant to architecture. For those who are teaching in the area, some focus on the architectural science aspects of climate changes/ sustainability while others address cultural/society/ philosophy/ design aspects. Therefore some agreed structure within architectural education that begins to frame the key issues might be useful. The matter is too important and too complex to be left to a few enthusiasts within each school of architecture."

It should be noted that this paper, and most others reviewed, have addressed the issue separately for architectural design and engineering professions. There seems to be a move to expand towards the central space between the two cultures, without giving up home ground. This will probably be a difficult perspective to maintain in the long run.

The most positive indication that serious attempts are being made to integrate architectural education with a broad range of sustainability issues is an EU-funded project called EDUCATE, described by Altomonte (2009).

The EDUCATE Action (Environmental Design in University Curricula and Architectural Training in Europe) has been built on a consortium of seven European academic partners, with a mission to "foster knowledge and skills in sustainable environmental design aiming to achieve comfort, delight, well-being and energy efficiency in new and existing buildings. This will be promoted and demonstrated within a culturally, economically and socially viable design process, at all stages of architectural education".

To these aims, EDUCATE is set to achieve the following objectives:

- Remove pedagogical barriers to the integration of environmental design principles within a creative architectural discourse;
- Define and test a curriculum and pedagogical framework which bridges current divides between sustainability-related technical information and the design studio at different levels and stages of architectural education to meet current professional demands and expectations;
- Develop an intelligent portal on sustainable environmental design that facilitates such integration in higher education and supports continuing professional development for building practitioners;
- In concert with Chambers of Architects, propose homogeneous criteria for accreditation of architectural curricula and professional registration that clearly establish the level of awareness, knowledge, understanding and skill in sustainable environmental design expected of graduates qualifying as architects;

- Promote and disseminate environmental know-how and exempla of best practice amongst students, educators, building professionals and the public, fostering change of behaviour and expectations towards the integration of sustainable design in architecture.

5 A POSSIBLE SUPPORT FOR INTEGRATION OF CURRICULA

As the previous sections have shown, universities, professional associations and governments are still struggling to find a way to integrate the traditional approaches to architectural and engineering education, and to expand both to include consideration of key sustainability issues.

A partial step towards a solution may be to use a broad framework that outlines all or most of the key issues in a way that shows linkages between them and may provide indications of how to integrate these widely differentiated topics into one coherent whole.

Some authors, as Vanegas (2004), suggest a study of LEED as a component in a broader sustainability-oriented curriculum but, although there is much to learn from LEED, it is a closed system that is oriented to North American conditions and, its inclusion as a stand-alone course would not provide the overall integration that is needed.

The international and generic Sustainable Building assessment method and tool "SBTool", developed by the International Initiative for a Sustainable Built Environment (iiSBE), may provide a better platform for the integration of specific and broader sustainability issues in a platform that will support an integrated educational approach. The SBTool system includes a methodology for the evaluation of the building sustainability, which is thoroughly explained in the SBTool technical document, by Larsson & Macias (2012), excerpts are shown in Figures 1-4.

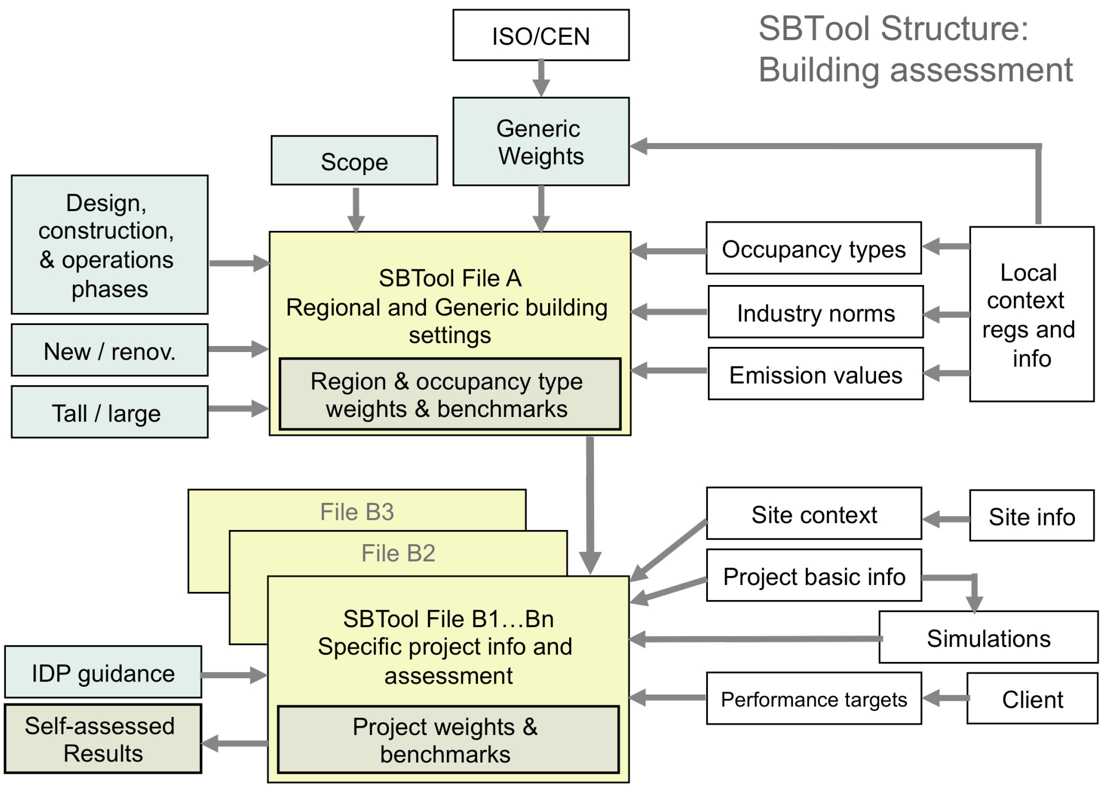

Figure 1. Description of the system structure from the SBTool Assessment Guide.

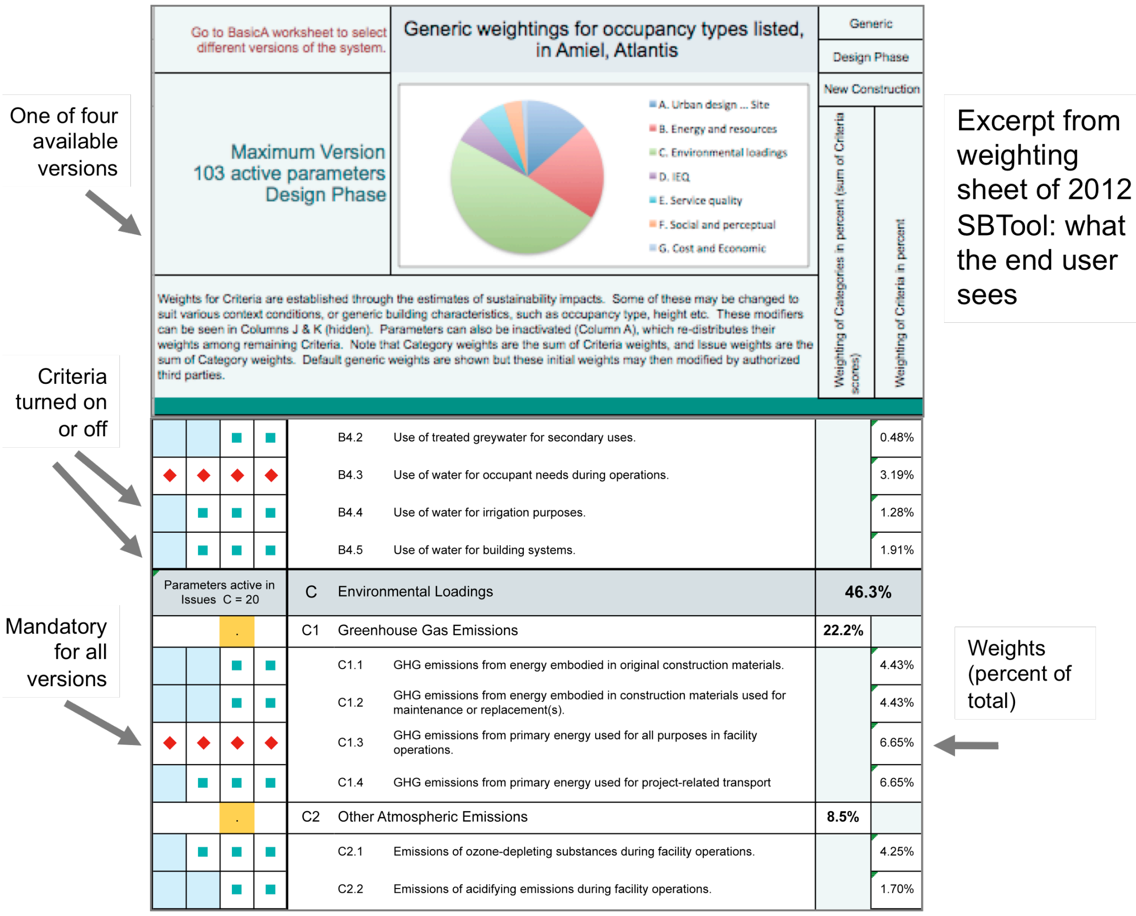

Figure 2. Example of the weight calculation of the in SBTool.

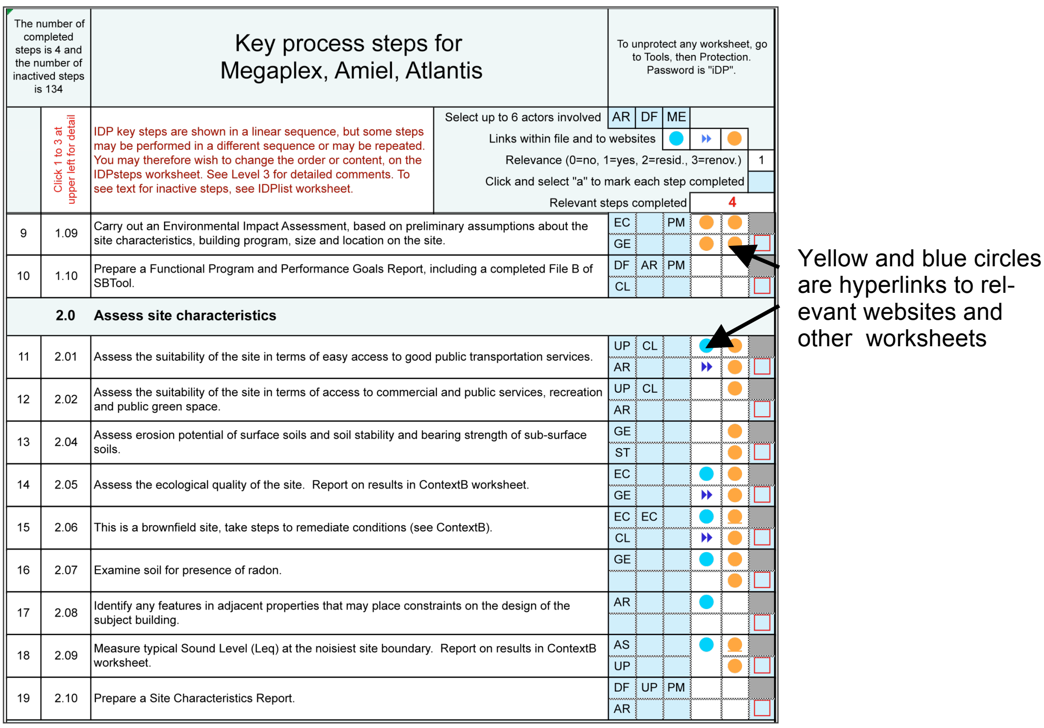

Figure 3. Example of the user process guide embedded in the SBTool system.

The SBTool system is a generic framework for assessment that may be used by third parties to develop rating systems that are relevant for a variety of local conditions and building types. It may also be thought of as a rating system toolbox. The system is designed as a generic framework, with local non-commercial organizations being expected to define local context conditions and to develop appropriate weights and benchmarks. SBTool has therefore been designed to facilitate such a regional calibration; in fact, the system requires the insertion of regionally meaningful benchmarks. This feature makes SBTool quite different from other well-known rating systems, such as LEED, BREEAM, CASBEE, etc.

The main features of the SBTool system are the following:

- The system covers a wide range of sustainable building issues, not just green building concerns, but the scope of the system can be modified to be as narrow or as broad as desired, ranging from 100+ criteria to half a dozen;
- It takes into account region-specific and site-specific context factors and these are used to switch off or reduce certain weights, and to provide background information.
- SBTool is able to carry out assessments at four distinct stages of the life-cycle and the systems provides default benchmarks suited to each phase (Pre-design, Design, Construction and Operations);
- The framework provides separate modules for Site and Building assessments, with Site assessments carried out in the Pre-design phase and Building assessments carried out in Design, Construction or Operations phases;
- The system handles large projects or single buildings, residential or commercial, new and existing construction, or a mix of the two;
- Designers can specify performance targets and can score self-assessed performance;
- Assessors can accept or modify self-assessed performance scores submitted by designers.
- Parameters can be calibrated for up to three occupancy types, within a single building or as separate structures in a large project;
- The system allows third parties to establish parameter weights that reflect the varying importance of issues in the region, and to establish relevant benchmarks by occupancy type, in local languages. Thus, many versions can be developed in different regions that look quite different, while sharing a common methodology and set of terms. The main advantage, however, is that a SBTool version developed with local knowledge is likely to be much more relevant to local needs and values than other systems.

The system is designed to permit authorized third parties to select one of four scope options, which determine the number of active generic criteria. All of these have been developed as generic defaults, and all users must review and modify or replace these as required to produce locally relevant versions. For example the criteria can be turned off in the Weights worksheet to further reduce the number of potentially active generic criteria, with the exception of a small number of mandatory criteria. The generic criteria potentially active are shown in Figure 4. These criteria can vary from the "Minimum Scope" to the "Maximum Scope", as follows:

- SBTool Minimum Scope
  The minimum scope version contains what the development team considers to be the minimum number of criteria to cover key issues. Clearly, this may be too limited for some, but it does offer a quicker and less complex route to assessment.
- SBTool Mid-size Scope
  The Mid-size version is suggested as a version that covers most important performance issues, while remaining reasonably workable for those who are faced with the task of modifying the generic criteria with others that are specifically suited to their region.
- SBTool Maximum Scope
  The Maximum version contains all criteria that have been fully developed with benchmarks and that could be used in assessments.

SBTool is a flexible and comprehensive framework (Fig. 4) that provides coverage of almost all issues related to the sustainability of building or civil engineering projects. As important, the framework structure provides logical linkages between a broad range of issues during various phases of the life cycle. This feature suggests that the system could provide a useful platform that would enable students and researchers to better understand the relationships between these separate issues. Another important feature of the system is its consideration of various contextual issues, and that makes it suitable for application in a wide variety of different regions.

Issue area	Scope	Pre-design	Design	Construction	Operation
Site Location, Available Services and Site Characteristics	Max.	35			
	Mid.	20			
	Min.	8			
Site Regeneration and Development, Urban Design and Infrastructure	Max.		22	0	21
	Mid.		12	0	11
	Min.		2	0	2
Energy and Resource Consumption	Max.		10	6	10
	Mid.		8	4	7
	Min.		4	2	3
Environmental Loadings	Max.		19	7	18
	Mid.		6	1	6
	Min.		2	0	2
Indoor Environmental Quality	Max.		18	0	19
	Mid.		10	0	10
	Min.		2	0	2
Service Quality	Max.		20	9	25
	Mid.		10	4	13
	Min.		2	1	2
Social, Cultural and Perceptual Aspects	Max.		10	2	10
	Mid.		5	1	5
	Min.		1	0	1
Cost and Economic Aspects	Max.		4	1	4
	Mid.		3	1	3
	Min.		1	0	1
Total System	Max.	35	103	25	107
	Mid.	20	54	11	55
	Min.	8	14	3	13

Figure 4. Number of active criteria by issue and phase in SBTool 2012 Generic (excluding Developer version).

An impression of how compact the system can be may be gained by reviewing Figure 5, which shows the criteria suggested for the Minimum Scope version. It should be noted that the red diamonds (◆) indicate criteria that are mandatory, and must be present in all versions. The Minimum version shown in Figure 5 includes a few other key criteria.

Criteria selected for the Minimum scope version in Design phase		
A2.3		Impact of orientation on the passive solar potential of building(s).
A3.13		Provision of on-site parking facilities for private vehicles.
B1.1		Embodied non-renewable energy in original construction materials.
B1.3	◆	Consumption of non-renewable energy for all building operations.
B3.1	◆	Degree of re-use of suitable existing structure(s) where available.
B4.2	◆	Use of water for occupant needs during operations.
C1.3	◆	GHG emissions from primary energy used for all purposes in facility operations.
C5.1		Impact on access to daylight or solar energy potential of adjacent property
D1.5	◆	CO2 concentrations in indoor air.
D3.1	◆	Appropriate daylighting in primary occupancy areas.
E1.8	◆	Occupant egress from tall buildings under emergency conditions.
E4.5		Adaptability to future changes in type of energy supply.
F1.1	◆	Access for mobility-impaired persons on site and within the building.
G1.5	◆	Affordability of residential rental or cost levels.

Figure 5. Criteria selected for the Minimum Scope version in the Design phase.

6 USE OF SBTOOL AS A PLATFORM FOR EDUCATION IN SUSTAINABLE BUILT ENVIRONMENT

Sustainability is an important part of architecture and such it is creative design, both dimension should be thought together in order to improve results. In that moment of design process, the architect or engineer may account for the lack of skills to integrate sustainable concepts and it is in that moment that SBTool can support students, providing sustainable concepts and considerations for an environmental-responsible design. In this educational scenario, the SBTool framework becomes a roadmap that can enable students to integrate their learning to the maximum extent possible. Specifically, the system shows users which set of design assumptions can result in the most sustainable overall result for the particular set of performance benchmarks that have been developed.

SBTool provides a fast and detailed contact with sustainable dimensions, as well as its parameters permits a general and broad approach of criteria and principle implied in sustainability scope. Each parameter is properly studied and contains information that permits student to general understand the goal that is under study and its importance to achieve sustainability. However it is necessary the access to all the information under parameter development to provide a correct teaching.

The discussion above is somewhat theoretical, but detail and specific examples will help to make the point.

A first example is whether an improvement in daylighting performance has a more important impact on overall performance than a reduction in the concentration of indoor levels of CO_2. It could be argued that both aspects of performance are important, but the SBTool system provides weights for each criterion, and the students will have developed benchmarks that are appropriate for the region and building type.

Figure 6 illustrates the basis of the SBTool weighting system. The system of weighting used in SBTool is based on sub-default weights being assigned to each criterion, partly based on ISO indicators, linked to other indicators that categorize issues of “Extent” (the effect or impact confined to the building, the site or a larger geographic area), “Intensity” (how intense) and “Duration” (how long). The authorized user (in this case the instructor) can then modify the results up or down by a maximum of 10%. This approach to weighting may be called quasi-objective, and will provide students with a challenging task, to debate whether the weights are appropriate or should be changed, and why.

Adjustable ←→ | Pre-set values ←→

Potential effects of Loadings and Qualities	Extent of potential effect (1 to 5 points)	Duration of potential effect (1 to 5 points)	Intensity of Potential Effect (1 to 3 points)	Primary system directly affected (1 to 5 points)
1 Much less	1 Building	1 1 to 3 years	1 Minor	1 Servicability
2 Less	2 Site / project	2 3 to 10 years	2 Moderate	1 Cost & economics
3 OK	3 Neighborhood	3 10 to 30 years	3 Major	2 Human comfort & well-being
4 More	4 Urban / Region	4 30 to 75 years		2 Non-energy resources
5 Much more	5 Global	5 >75 years		3 Energy resources
				3 Water resources
				4 Human health
				4 Ecological systems
				5 Life safety
				5 Climate system

Figure 6: The basis of weighting for criteria in the SBTool system

Considering the use of the SBTool platform as a means for students to better understand the relationship between their individual courses, an example that may clarify this is the relationship between the energy embodied in construction materials, the estimation of operating energy, and the SBTool requirement to estimate the longevity of the building. Both embodied and operating energy have to be estimated using external tools, but the SBTool system requires the results to be entered into the system. The embodied energy results are amortized over the predicted life-span of the building by SBTool, and the system then adds the annualized embodied energy result to the operating energy, to result in an overall annualized energy consumption. In such calculations, students learn about the inter-relationship between embodied and operating energy, since a high-mass building will have more embodied energy but may have a better operating performance. The importance of longevity then also becomes evident to the student. Thus, the interaction of three variables is demonstrated, each of which may relate to a different course in the curriculum.

A final example will demonstrate the value of the SBTool structure. The system requires, where applicable, that students establish appropriate benchmarks for different phases. For example, the criteria for control of indoor pollutants exist within the system, in a generic form, for both the Design and Operations phases. Students must decide what benchmarks and procedures will describe the most appropriate way of predicting good air quality at the Design stage, and then develop different benchmarks and procedures for actually measuring pollutant levels for the Operations phases. The SBTool structure, targets and references to standards are the same for both phases, which facilitates this task and helps the student to understand how the same issue may be addressed differently in each phase.

In summary, SBTool covers a wide range of sustainable building issues and, therefore, is an adequate platform for the education in sustainable built environment.

The SBTool system allows third parties to establish parameter weights, which is very useful for the students to understand that sustainability is not a subjective matter that allows manipulation to “greenwash” whatever is under evaluation.

The system provides separate modules for Site and Building assessments, which is fundamental for students to understand that not only the building is important but also the site where it is built.

The system takes into account region-specific and site-specific context factors, which is of great importance if sustainability issues are to be understood in a variety of different environments. This is quite unlike commercial rating systems that are designed to be relevant to single regions and with, at most, a minor degree of adjustment possible. This is not just a matter of practicality, but is a critical factor in ensuring that generations of students and professionals are not be led to have false impressions of the importance of various issues or appropriate benchmarks for criteria.

Assessments can be carried out at four distinct stages of the life-cycle, using a common overall structure. Thus, students will learn how the specific benchmarks for a certain issue, such as impact on the site, may be quite different in benchmarks for the Design or Operations phases, while addressing the same general issue.

Parameters can be calibrated for up to three occupancy types, and this reflects the reality that many modern buildings contain two or three different occupancies.

The system handles large or small projects and tall or mid-rise buildings, reflecting the wide variety of project and building forms that may occur in large urban areas or smaller communities.

Designers can specify performance targets and can score self-assessed performance. This feature is vital if students are to see outcomes after the scores for individual criteria are blended, based on their weights.

Assessors can accept self-assessed performance scores submitted by designers, or can modify them. In an educational environment, the student may take on the role of the designer, while the instructor plays the role of a third-party assessor.

The framework in Figure 7 shows the relationship between the issues identified in SBTool with a typical range of engineering and architectural courses, to make the point that there is a strong relationship between the two. The first row covers topics that are applicable to all or most SBTool issue areas. It should be noted that the range of SBTool issues is considerably broader than those covered by mainstream assessment and rating systems.

Issue area	Issues dealt with in SBTool	Relevant courses
General / all	Setting performance targets; Facility management; Construction management; Site & ecology impact assessment; Use of integrated design process; Design for new or renovation projects; Design for rural or urban settings; Design for residential, public and commercial uses; Design for mid-rise / very tall buildings; Design for large / small projects; Design for passive solar; Post-occupancy evaluation.	Energy policy; Environmental policy; Facility management; Construction management; Site & ecology impact assessment; Architectural design studio; Building science theory; Building information modelling.
Site Location Available services and Site Characteristics	Geophysical analysis; Ecological analysis; Transportation analysis; Soil pollution analysis; Urban context.	Land use analysis; Urban planning; Traffic analysis.
Site Regeneration and Development, Urban Design and Infrastructure	Site pollution analysis; Remediation of soil pollution; Protection of ecology during construction; Site planning for micro-climate & ecology; Site planning for project; Landscaping, trees & shading; Pedestrian walkway design; Design for bicycling; Design for vehicle traffic & parking.	Environmental bioremediation; Water pollution engineering; Soil and water quality management; Environmental impact assessment; Environmental management system;
Energy and Resource Consumption	Embodied energy analysis; Operational energy simulation; Renewable analysis & design; Material LCA analysis; Minimization of virgin materials use; Minimization of potable water use; Re-use of structures and materials; Material re-use and recycling; C & D waste management & recycling.	Structural engineering; Materials science & LCA; Embodied energy analysis and modelling; Operation energy simulations and modelling; Concrete materials; Steel in very tall buildings; Durability of structures.
Environmental Loadings	Greenhouse gas emissions; Other atmospheric emissions; Impacts on site terrain or ecology; Greywater re-use and treatment; Wastewater treatment design; Solid waste recycling and disposal; Impacts on adjacent lands; Pollution of aquifers or water ways; Heat island effect.	Environmental bioremediation; Water pollution engineering; Soil and water quality management; Environmental impact assessment; Environmental management systems.
Indoor Environmental Quality	Design for natural ventilation; Design for hybrid ventilation; Design for mechanical vent/cool; Electrical system design; Daylighting design & prediction; Artificial lighting design (indoor); Artificial lighting design (outdoor); Noise and acoustic design; Computer-base building information systems;	Physiology and indoor environment; Physics for building science, lighting and acoustics; Air pollution engineering; Chemistry and biology for indoor air quality; Mechanical engineering for HVAC systems; Electrical engineering for distribution & control sys; Building automation; Computer fluid dynamics modelling; Daylight modelling & design; Advanced acoustic design.
Service Quality	Construction safety; Occupant egress from tall buildings; Plan and volumetric efficiency; Operation during outages; Skills and knowledge of operating staff; Adaptability to future energy systems; Flexibility and adaptability; Planning for commissioning.	Architectural design; Structural engineering; Fire safety design; Building and equipment monitoring systems; Facility management; Commissioning planning & execution.
Social, Cultural and Perceptual Aspects	User and occupant satisfaction; Access and use for mobility-impaired persons; Access to and use of public open space; Access to and use of private open space; Maintenance of heritage value of existing structures;	Heritage conservation; Sociology.
Cost and Economic Aspects	Capital cost; Operating cost; Life-cycle cost; Affordability for residential occupants; Economic impact on urban area; Economic viability of commercial activities.	Economics for project planning; Project financing; Life-cycle costing (aka whole-life costing).

Figure 7. Possible links between typical courses of Architecture / Engineering and SBTool.

7 CONCLUSIONS

SBTool provides a cross-disciplinary / multi-criteria view of sustainability, showing the importance and constituting the basis for a broad comprehension. If a methodology like this is implemented during student learning, it will allow the ability to embed sustainable issues into core competences, resulting naturally, in sustainable buildings and cities. SBTool methodology also supports an integrated design/learning process, which, integrating several issues, provides a successful final assessment of sustainability.

The authors therefore propose that the SBTool framework should be used as a central resource in graduate courses on sustainable building and construction, with specific engineering or architectural courses being referenced to the framework to identify the relationship between such courses. In such an application, individual and specialized courses would still be needed, but students and instructors would have a clear understanding of what gaps in coverage are left by their course curriculum and the relationship between courses.

Using SBTool in such a scenario offers much more flexibility than would the use of pre-set commercial rating systems such as LEED or BREEAM, because of the generic nature of the SBTool framework which forces students to develop benchmarks for all the criteria that are relevant to their region and to a range of common building types. This task constitutes an intensive and excellent learning process.

Students and instructors still face formidable challenges in trying to cover all the subject matter that is relevant to sustainable building and construction, but the authors consider that the approach suggested will greatly facilitate the process.

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