Sustainable Design Principles in Construction Sector

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Abstract: Building construction affects each four topics of sustainable development that are ecological, economic, social and cultural development. Progress towards the sustainable construction requires novel technologies and policies; not only for the new buildings but also for the refurbishing processes. The industry has taken several steps to improve efficient use of resources, as well as the health and comfort of living surroundings.

Managing the performance of buildings and built environment from users' and societies' points of views is becoming more important due to market needs and due to the demands associated with sustainability. Approaches to adopt sustainable whole-building principles are under development. In this paper, some integrated approaches to adopt sustainability principles in building design are presented.

Aiming at a real progress in sustainable construction presupposes knowledge on the applicability and limitations of the evaluation methods. The subjective rating and valuation inside the current environmental assessment procedures complicates development of unanimous methods. Extension of evaluation to other sustainability aspects requires indicators that are even more dependent on the context. As the evaluation of sustainability remains characterised by local and value-driven factors, the future building design methods need a generic basis with flexibility in implementation.

1 INTRODUCTION

The fundamental goal of sustainable development is to preserve the ecological systems that globally are the basis for human life and biodiversity of the nature. However, the quality of life is recognised as the non-physical and non-ecosystem counterpart in any usable model of sustainable development (Ronchi, Federico and Musmeci 2002).

Building construction affects each four topics of sustainable development that are ecological, economic, social and cultural development. Environmentally, sustainable construction ensures more economical use of finite raw materials and reduces, and above all, prevents the accumulation of pollutants and waste.

Various expedient indicators to track the sustainable development have been developed by different fields of activities at local, national and global levels. In addition, different parameters and their observation and assessment methods are in use.

On the construction and real estate sector, the sustainability indicators demonstrate the influences of the whole sector as well as those of planning, design, construction and use of a building. They may be used in evaluation of a building, enterprise, sector or even a simple construction product, expressed by the aid of parameters. The methods and tools to use indicators as a basis for decision-making in design, product development and construction processes are under development. Indicators are also an essential part of life-cycle analysis (LCA) methods whose implementation in the design and construction processes proceeds promisingly.

The approaches to develop the sustainable design principles should be chosen in such a way that the all aspects of sustainability are taken into account. The construction and real estate sector has environmental impacts that are overwhelming but its importance to well-being, social development and business is also so crucial that there can be foreseen development of integrated methods and tools that cope with different demands.

2 DESIGN FOR A LIFE-CYCLE

2.1 Needs for a new design approach

Methodologies to manage construction projects from design to use are nowadays of greater importance than ever due to increasing complexity of buildings and building processes, rapid changes of user needs and market environment, goals of sustainable development and demands for faster delivery schedules.

The market expectations presuppose user-oriented approaches in all phases of building projects – and already in planning of new areas and sites. In business, the expectations concern high-performance facilities that even enhance the activities which they accommodate. The designers from architects to structural, mechanical and electrical engineers have to be educated and equipped to meet the challenges.

The construction and real estate sector has recognized that in the near future its products and processes will change from the traditional attitudes and methods towards a sector that is able and willing to fulfil users' needs at the long-term and also to pro-actively work for the sustainable development.

2.2 Managing performance of a building

Performance Based Building is an approach to building-related processes, products and services with a focus on the required outcomes (the 'end'). This approach would allow for any design solution (the 'means') which can be shown to meet the objectives of an actual project.

The comprehensive implementation of the performance approach is dependent on further advancement in the following three key areas:

- the description of appropriate building performance requirements
- methods for delivering the required performance
- methods for verifying the various performance aspects.

The main purpose for a generic hierarchical model is to provide a common platform to identify the desired qualities of a building and to develop a common language for different disciplines. The hierarchy and tools linked to it support a collaborative learning process that systematises decision-making and enhances results of a project definition phase. The choice of the objectives in the hierarchical presentation shows also to some extent the values of its developer (Koukkari and Huovila 2005).

Based on the hierarchy of performance objectives and their targeted qualities, alternate plans and technical solutions can be developed. Figure 1 represents a generic model of building's performance analysis developed at VTT Building and Transport. The sustainability aspects are embedded in the hierarchy.

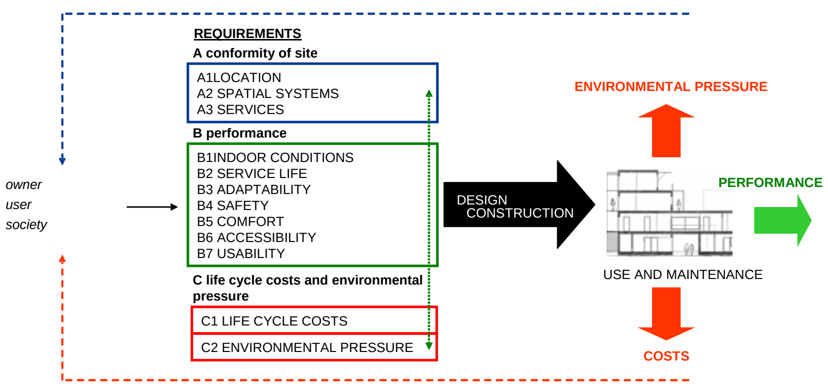

Figure 1 Generic model of a building's performance analysis

The capability of different solutions to fulfil the performance criteria can be studied with verification methods. They may be product information data from other industries and product manufacturers; or they may be simulation and visualization programs which handle large input data and use theoretically sound formulae. The level of consideration may also vary (building, system, single product). Verification methods of human and societal aspects are more value-bound, subjective and relative but some design guidelines can be found e.g. for accessibility.

The definition phase of a construction project is crucial for the realization of the sustainability goals because it includes the budget frame for construction, targets for operation costs (especially energy consumption) and quality specifications for example for the indoor climate and accessibility. The assessment of the ecological footprints of a building should be made using reliable and well-known methods, e.g. Life-Cycle-Analysis.

2.3 Environmental life-cycle analysis (LCA)

An assessment of environmental impacts of a process or a product is an analysis that is made by identification of what has been taken from the environment and what has been brought back, by recognition of the potential harms due to these actions and by rating the significance of the impacts. Consequently, the methods are developed to cope with the whole life-cycle of an object under review (Figure 2).

The Life-Cycle-Analysis (LCA) is internationally recognized as a usable approach to evaluate the environmental impacts of products or processes The method has been under development and in use since the early 1960s, but it was only in the mid-to-late 90s' that the protocol was standardized by the International Organization for Standardization (ISO14040-42). It is now being extended to construction.

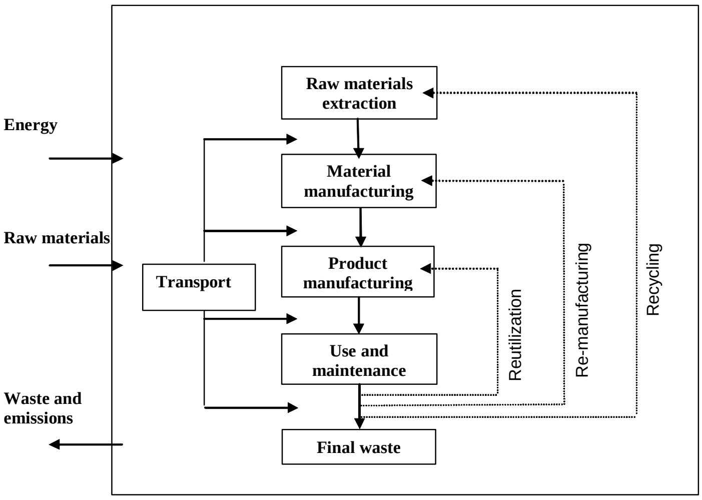

Figure 2 Life-Cycle of a product

The LCA includes three main steps that are inventory, analysis of potential effects and interpretation (valuation) of the results (figure 3).The life-cycle inventory (LCI) is an integral part of an LCA on which all subsequent steps are based. It means identification and quantification of the basic flows from nature to nature (inputs and outputs). It also includes definition of scope boundaries. The phase can be completed by assessing the potential environmental impacts that are climatic warming, acidification, eutrophication (excess thriving of aquatic flora), formation of photochemical oxidants, loss of ozone, harmfulness to health and ecotoxicity.

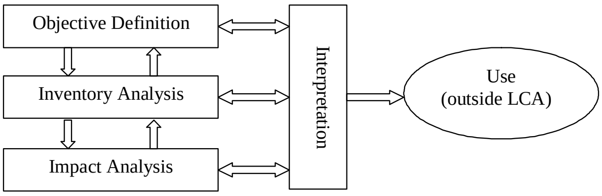

Figure 3 Phases of the LCA

Interpretation (valuation) of information may be done according to the standard ISO 14042. It presents methods to synthesize and assess the impact data. The first step is to categorize the various parameters based on their cause-consequence relations and link them to indicators. Steps to calculate an indicator factor of each impact category includes determination of weight factors. The weight attributed to each indicator is given based on the following criteria: spatial scale of the impact, severity of the hazard, degree of exposure and risk for being wrong. Based on a qualitative knowledge, the evaluation is converted into a quantitative scale.

In search for generally accepted parameters, it seems that the development leads to different weighting factors in different countries (Häkkinen et al 2002).

2.4 LCA in construction

The complete cycle of sustainable construction activities comprise the ways in which built structures and facilities are procured and erected, used and operated, maintained and repaired, modernised and rehabilitated, and finally dismantled and demolished or reused and recycled.

Assessment of environmental impacts over the lifetime of built facilities as well as estimates of life cycle costs (LCC) should be made available to the clients before a construction project begins. Clients, architects and consulting engineers will be more and more asked to take into account environmental aspects in their designs, especially LCA and LCC considerations. The different methods should be integrated with other tools such as quantity surveying or energy simulation.

Adoption of LCA in the construction sector is a cumbersome work as the buildings and works incorporates hundreds and thousands of individual products and in a construction project there are tens of companies involved. Further, the expected life time of a building is exceptionally long, tens or hundreds of years. The LCA fits best to the level of single product or material, and different approaches and tools to consider an entire building are under development. The feedback from real construction projects should be analyzed rationally and systematically in order to strengthen the evolution to generic transparent methods.

In principle, the LCA can be used to identify stages that have greatest environmental impacts in the life cycle of a product and to compare several products having similar technical properties. For this purpose, there ought to be a common understanding on the performance objectives and relevant criteria of a building. This kind of general view can also be utilized in order to widen the scope of the environmental LCA to other sustainability aspects. The evolution can be regarded as an alternative or as a complement to the performance analysis presented previously.

The functional performance aspects are in general not included methodologies and tools of environmental evaluation. As an unintentional consequence, it is common to regard sustainability only as “friendliness to the environment”. More over, most of the assessment programs are not design-orientated, despite claims to the contrary. They are constructed to give endorsement to a completed design rather than to assist the designer during the design process. While "environmental assessment" of new and renovated buildings is potentially one of the biggest future uses of computer simulation, the conceptual work on appropriate methodologies is still in its infancy (Soebarto and Williamson 2001).

3 DEVELOPMENT OF EVALUATION

3.1 General

Procedures and tools of the sustainability assessment of construction, buildings and built environment are being implemented or in the development phase. The methods typically presuppose previous knowledge and involve self-assessment or other subjective phases that complicate the application. The usefulness of tools may depend on the data incorporated as it is usually related with the particular aspects of the country of origin.

Applying any method to any market requires relevant information about the specific circumstances. The vulnerability of environment may depend upon different factors in different locations. In the case that the aspects of functionality, economy and society are to be considered, choice of sustainability indicators, parameters and weighting factors is even more demanding. The classification of indicators in relation to the main aspects depends on the hierarchy chosen as a basis. For this reason, the same indicator can be seen in different context in different methods. Various proposals for indicators to be adopted at sector, country or European level can be found in recent publications.

The performance of a solution can be assessed in each indicator (global indicators), allowing also assessment of each requirement of a project (Allard, Cherqui and Mora 2004). Each global indicator assesses one aspect of the solution's sustainability, for instance, the environmental performance, functional performance, social performance and economic performance.

3.2 Environmental parameters

Internationally, the interpretation of the results of the LCA is under rapid development. The methods of decision-making with decomposition and synthesis are in general applied in recent developments of the interpretation and valuation of the environmental indicators. In Portugal, the development of the interpretation and valuation phase of the LCA is an example of adoption of the list developed by the United States Environmental Protection Agency, EPA (EPA, 2000), presented in Table 1, and application of an multi-criterion methodology of analysis that is based on the theory known by the acronym AHP (Analytic Hierarchy Process) presented by Saaty (1990).

Table 1 Weight of environmental impacts according to EPA's list. The categories used in the Finnish application are shown with*.

Impact category	Current consequences
Global warming*	Low
Acidification*	High
Eutrofphication*	Medium
Fossil fuel depletion	Medium
Indoor air quality	Medium
Habitat alteration	Low
Water intake	Medium
Air pollutants	High
Smog	High
Ecological toxicity	Medium - Low
Ozone depletion*	Low
Human health	Medium - Low

In Finland, the Decision Analysis Impact Assessment (DAIA) has been used to categorize the emission effects on atmosphere and waters (see Table 1). In the DAIA and other methods for rating, the factors also develop due to updating of knowledge on the real effects.

With the help of an AHP process as comparison pair to pair (Pairwise Comparison Value), the numerical comparison is attributed to each one of the possible pairs in the list of the qualitative values. Thus it is possible to determine the number of times that the weight of a parameter must be higher than another one and establish a relation between all the parameters under study.

3.3 Functional parameters

The analysis and comparison of the functionality of construction solutions has to be carried out at the level of each element (interior walls, exterior walls, floor, roof, etc.), therefore each one of them presents distinct requirements.

The first step for the evaluation is to define functional parameters. The six essential requirements and durability according to the Construction Products Directive form a nationally regulated basis for consideration, e.g. thermal insulation, airborne and impact sound insulation, flexibility of natural illumination, structural stability, air permeability, etc.

3.4 Economic and social parameters

Economic and social indicators are often combined in sustainability evaluation. This tells on the one hand about their interrelation and, on the other hand, about the difficulties to find agreement. For example, the following social indicators are proposed: accessibility, security, sense of well-being, distance to school, movability and access to green areas, social services, health and comfort, cultural heritage.

Life-cycle cost analysis (LCCA) is a method for assessing the total cost of a facility ownership. It takes in account all costs of acquiring, owning, and disposing of a building or building system. LCCA is especially useful when project alternatives that fulfil the same performance requirements, but differ with respect to initial cost and operating costs, have to be compared in order to select the one that maximizes the net savings. The less are the costs foreseen for a construction solution, the better is its economical performance and more sustainable it is – within this aspect.

The construction solutions are very distinct at the level of the durability. It is essential to use the same study period for each alternative, whose LCCs are to be compared according to the stakeholder perspective. For example, a homeowner would select a study period based on the length of time he or she expects to live in the house, whereas a long-term owner/occupant of an office building might select a study period based on the life of the building.

3.5 Quantification of parameters

Once the list of indicators and their parameters is being set up, each parameter has to be quantified. The quantification is necessary in order to compare solutions, aggregate indicators and precisely assess the solution. Method of quantification should have been anticipated and different methods can be used: results from previous studies (databases), simulation tools, expert’s opinion and data base processing (Cherqui, Wurtz and Allard 2004).

Measuring the economic performance of a building is more straightforward than measuring, for instance, the environmental performance. Standardized methodologies and quantitative published data are readily available.

3.6 Aggregation of parameters

The aggregation of the different parameters shall be developed after the quantification of each one. The aggregation is normally established giving an equal importance to all the indicators. The choice may be not the most correct one once the indicators are not expressed in the same order of magnitude and/or in the same unit. For example, the contribution of a material for the greenhouse effect is presented in the amount of carbon dioxide emitted, the acidification in equivalent of hydrogen ions, the electro fission in nitrogen equivalent, etc. On the other hand, the way that each parameter influences the sustainability is neither consensual nor unalterable along the time.

The aggregation method used in the assessment methodology should be easy to understand and flexible in order to meet the solution's requirements. Each global indicator (I_j) could be assessed using a complete aggregation method, according to the following equation:

$$I_j = \sum_{i=1}^{n} w_i . \overline{P_i} \qquad (1)$$

In this formula, I_j is the result of the weighting average of all the normalized parameters $\overline{P_i}$; w_i represents the weight of the i^{th} parameter. The sum of all weigh must be equal to 1.

The objective of the indicators' normalization is to avoid the scale effects for the averaging and solve the problem of some indicators being the type "more is better" and others "less is better". Normalization could be done using the Diaz-Balteiro formula (Diaz-Balteiro and Romero 2004):

$$\overline{P_i} = \frac{P_i - P_{*i}}{P_i^* - P_{*i}} \forall i \qquad (2)$$

In this formula, P_i represents the value of the i^{th} parameter. P^*_i and P_{*i} are respectively the best and the worth value of the i^{th} parameter of sustainability. Using this normalization system, the indicators of sustainability have no dimension and are also bounded between 0 (worst value) and 1 (best value).This formula is valid when the parameter is of the type "more is better" and when it is of the type "less is better".

After evaluating the performance of the solutions in each global indicator (environmental, functional, social and economic) it is possible to define a single score (Sustainable Score) to evaluate the global performance. The sustainable score could be evaluated using the following formula (Bragança and Mateus 2004):

$$SS = \sum_{j=1}^{n} w_j . I_j \qquad (3)$$

In this formula, *SS* (Sustainable Score) is the result of the weighting average of the solution's performance in each indicator I_j and w_j represents the weight of each indicator in the sustainability. In order to obtain a Sustainable Score between 0 and 1 the sum of all weight of formula 3 weigh must be equal to 1.

Nonetheless, this single score should not be used alone to assess the sustainability, since the compensation between the values of each parameter could cause some distortions in the results. Moreover the solution has to be the best compromise between all different indicators: every indicator has to be represented.

3.7 Representation and assessment of the sustainability

A graphical representation of each indicator, once their values have been calculated, is a useful way to clearly notice the differences between the performances of the solutions assessed (Bragança and Mateus 2004). The Amoeba or “radar” diagram is one of the most used tools to graphically integrate and monitor the different indicators. In an Amoeba diagram it is easy to represent and monitor the performance of the solution at the level of each indicator and moreover two solutions could be easily compared, as shown in the example represented in figure 4. In this example is also represented the Sustainable Score (SS) of each solution.

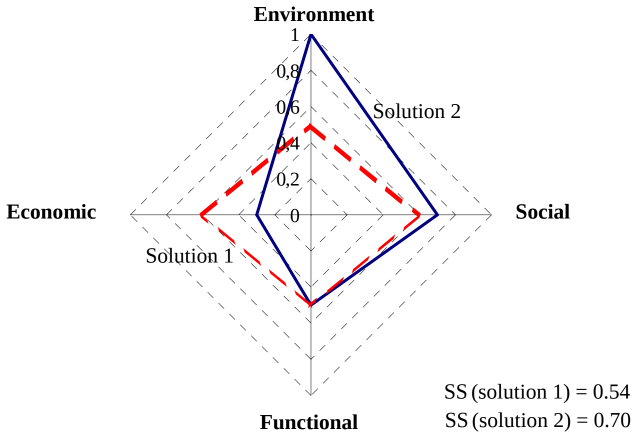

Figure 4 Comparison of two solutions using the Amoeba diagram

In an Amoeba diagram, the closer a solution is to the centre the worse it is. In the figure 4, it is possible to identify the stronger and weaker points of each solution. For instance, the strongest point for solution 2 is the environment performance while the strongest point of solution 1 is the economic performance. The weights used for the Sustainable Score in this evaluation were: environment indicator = 0.35; social indicator = 0.25; functional indicator = 0.25; economic indicator = 0.15. According to the requirements of this evaluation, solution 2 is more preferred.

4 DISCUSSION

The evaluation of sustainability consists of a wide range of technical, societal, economic and human issues that need to be identified, analysed and evaluated. Incorporation of performance indicators in a sustainable assessment is an attempt to prevent errors from the past, where the concept “sustainable solution” has been associated to construction solutions with good environmental performance, but without fulfilling the necessary functional requirements (comfort, durability, etc.).

The internationally standardized environmental Life-Cycle-Analysis is extensively adopted in different fields of activities. The methodology involves subjective rating and depends above all on the type of solution, as well as on socio-economic and cultural heritage of the subject. The definition of a worldwide accepted list of indicators and respective parameters is one way to proceed in order to turn the evaluation more objective.

The LCA methods provide useful support tools for the decision-making. Their application consumes however much time and money due to the amount of necessary information. Their appeal is also reduced due to the limited objectivity and thus their usefulness e.g. in marketing is remote. In the international scene, organisations for the technical standards are implementing the scientific understanding in the practical guidelines.

Relatively to the aggregation of the parameters considered in the evaluation, there are some difficulties in the choice of the aggregation method and in setting the weight of each parameter. It is possible to use different linear and non-linear aggregation methods. In the linear aggregation methods the weight has a major influence on the results. Therefore, most accurate values could be obtained using non-linear methods.

The weight of each parameter in the evaluation of the indicators and the weight of each indicator in the global performance is not consensual. Since the weights are strongly linked to the requirements of the evaluation, bigger values should be given to the weights of the most representative parameters and indicators. More reliable values could be obtained if the weights are determined by experts and through the application of a Multi-attribute Decision Analysis, p.e. the Analytic Hierarchy.

Some results of the sustainability assessment have shown that the most compatible solutions with the environment are generally the most expensive. However considering that the main goal of the concept "sustainable construction" is a bigger compatibility between the artificial and the natural environments, without compromising the functional performance, it can be concluded that the weights of the environmental and functional indicators shall be higher than the weight of the economic indicators in the sustainability evaluation.

5 CONCLUSION

The design methods of sustainable construction identify, support and recommend evolution of practices and technologies that deal with all the sustainability aspects of the sector. The evaluation methods should consider environmental pressure (related to the environmental impacts), functionality (related to the users comfort and the local building codes), social aspects (related to the social benefits) and economic aspects (related to the life-cycle costs). The fundamental object of sustainable design is a bigger compatibility between the artificial and the natural environments without compromising the functional requirements of the buildings and their respective costs.

Some integrated approaches to adopt sustainability principles in building design are presented in this paper. Despite the numerous studies about it there is a lack of a worldwide accepted methodology to assist the architects and engineers in the design, production and refurbishing phases of a building.

The future methodologies should be flexible enough to be adapted to the distinctive requirements of each evaluation. Moreover, they have to be more objective than the methodologies available and easy to understand by all construction market actors, in order to promote a better compatibility between the natural and the artificial environments. The methods are to be developed to comprehensively account for all parameters of environmental, functional, economic and social impacts.

6 REFERENCES

Allard, F., Cherqui, F., Wurtz, E. and Mora, L. 2004. *A methodology to assess the sustainability of rehabilitations projects in urban buildings, LEPTAB.* La Rochelle: University of La Rochelle.

Bragança, L., Mateus, R. 2004. Comparative assessment of exterior walls solutions' sustainability. In *Proc. on Improvement of Building's Structural Quality by new Technologies - COST C12 Final Conference, Innsbruck 20.-22.1.2005,* eds. C. Schaur, F. Mazzolani, G. Huber, G. de Matteis, H. Trumpf, H. Koukkari, J.-P. Jaspart and L. Bragança, 565-572. Leiden: Balkema.

Cherqui, F., Wurtz, E., Allard, F. 2004. Elaboration d'une méthodologie d'aménagement durable d'un quartier. *Annales du bâtiment et des travaux publics* 56(1) : 38-44.

Diaz-Balteiro, L., Romero, C. 2004. In search of a natural systems sustainability index. *Ecological Economics* 49(3): 401-405.

Häkkinen T. et al. 2002. *Eco-efficiency in the building and real estate sector*. Ministry of Environment, Housing and Building Department, the Finnish Environment 580. Helsinki: The Ministry of Environment.

ISO 14042:2000 – Environmental Management – Life Cycle Assessment – Life Cycle Impact Assessment.

Koukkari, H. & Huovila, P. 2005. Improving the Performance of Buildings. In *Proc. on Improvement of Building's Structural Quality by new Technologies - COST C12 Final Conference, Innsbruck 20.-22.1.2005*, eds. C. Schaur, F. Mazzolani, G. Huber, G. de Matteis, H. Trumpf, H. Koukkari, J.-P. Jaspart and L. Bragança, 495-502. Leiden: Balkema.

Ronchi, E., Federico A. & Musmeci F. 2002. A system oriented integrated indicator for sustainable development in Italy. *Ecological Indicators* 2(1-2): 197-210.

Saaty, T. L. 1990. How to make a decision: The analytic hierarchy process. *European Journal of Operational Research* 1(48): 9-26.

Soebarto, A.I. & T.J. Williamson, T.J. 2001. Multi-criteria assessment of building performance, theory and implementation. *Building and Environment* 36(6): 681–690.

United States Environmental Protection Agency (EPA), Science Advisory Board (SAB). 2000. *Towards integrated Environmental Decision Making.* EPA-SAB-EC-00-011. Washington D.C.: The United States Environmental Protection Agency.