Sustainability **2014**, *6*, 8775-8795; doi:10.3390/su6128775

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

A Simplified Method for Evaluating Building Sustainability in the Early Design Phase for Architects

Jernej Markelj [1,*], Manja Kitek Kuzman [2], Petra Grošelj [2] and Martina Zbašnik-Senegačnik [1]

[1] Faculty of Architecture, University of Ljubljana, Zoisova cesta 12, 1000 Ljubljana, Slovenia; E-Mail: martina.zbasnik@fa.uni-lj.si

[2] Department of Wood Science and Technology, Biotechnical Faculty, University of Ljubljana, Rožna Dolina, cesta VIII 34, 1000 Ljubljana, Slovenia; E-Mails: manja.kuzman@bf.uni-lj.si (M.K.K.); petra.groselj@bf.uni-lj.si (P.G.)

* Author to whom correspondence should be addressed; E-Mail: jernej.markelj@fa.uni-lj.si; Tel.: +386-1-2000-777.

External Editor: Marc A. Rosen

Received: 2 September 2014; in revised form: 20 November 2014 / Accepted: 25 November 2014 / Published: 2 December 2014

Abstract: With society turning increasingly to sustainable development, sharper demands are being made concerning energy efficiency and other properties that mean reductions in the negative effects of the building on the environment and people. This means that architects must have a suitably adapted solution already in the early design phase, as this has the greatest influence on the final result. Current tools and methods used for this are either focused only on individual topics or are too complex and not adapted for independent use by architects. The paper presents a simplified method for evaluating building sustainability (SMEBS) which addresses these needs. It is intended as a tool to aid architects in the early project planning phases as it allows a quick evaluation of the extent to which the demands of sustainable building are fulfilled. The method was developed on the basis of a study of international building sustainability assessment methods (BSAM) and standards in this field. Experts in sustainable construction were invited to determine weights for assessment parameters using the analytical hierarchy process (AHP). Their judgments reflect the specific characteristics of the local environment.

Keywords: building; architect; sustainability; evaluation; analytic hierarchy process

1. Introduction

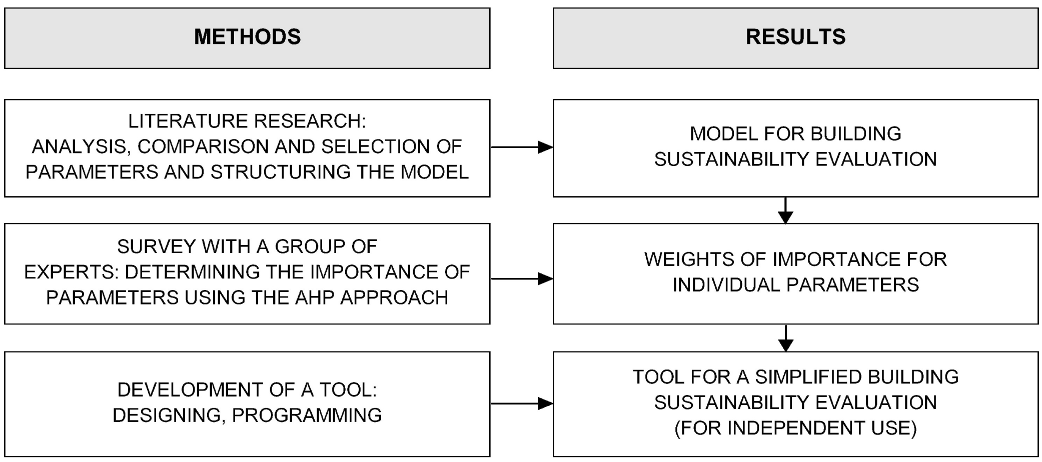
We are becoming increasingly aware that the quality of building design, manner of construction and operation of buildings are key factors that influence the implementation of sustainable development. This is why in the past two decades numerous building sustainability assessment methods (BSAM) have been developed throughout the world [1]. They are used to assess and present the quality of the building with the help of criteria from different fields. Initially, most emphasis was placed on the evaluation of environmental topics such energy consumption, pollution from emissions, water use and biodiversity. However, in recent years, with the development and defining of international standards in this area, BSAM increasingly take into account other aspects: functionality, economical aspects, accessibility and technical characteristics. The building is increasingly being treated in the entirety of its life-cycle: from the phase of acquisition of raw materials, the production of construction materials and components, the actual construction process of the building, its use and maintenance and if applicable also its demolition and disposal. Due to the comprehensive and clear analysis of a particular building, BSAM are becoming increasingly popular, and in certain countries even compulsory, in public procurement, where funds must be very efficiently invested and a high level of transparency is demanded. Chambers and institutes of engineers and architects throughout the world increasingly recommend using BSAM in their guidelines for optimal project planning. They are also demanded by numerous private investors in building projects who demand that the principles of sustainable construction are clearly complied with (and hence that the targets of sustainable development are pursued). In certain countries, the use of BSAM for projects financed by public funds is already compulsory. In practice, this means that architects must have a suitably adapted project plan already in the early design phase, as this has the greatest influence on the final result. In early design phase the most important building design decision that influence the sustainability are set: position and orientation of the building on the parcel, its form, type of structure with material, internal layout, building envelope with its transparent parts as well as the type of mechanical systems for heating, cooling, ventilation and air-conditioning. In order to optimize the project according to the principles of sustainable construction and energy efficiency, these early stages of design should comprise the following [2]:

(1) The form should be chosen depending on the site-specific characteristics, functional requirements, orientation and sunlight, the thermal hierarchy of spaces and the potential for natural ventilation.
(2) Building envelope design should be optimized (heat insulation, window openings, illumination of spaces and shading, thermal mass) and the choice of active systems should be given special consideration (heating, cooling, mechanical ventilation, solar collectors, PV modules).
(3) Tools for checking the suitability and performance of the design solution should be used (acquisition of key information about the planned building and its characteristics in the phase of use).
(4) The acquired results should be properly interpreted and the design optimized accordingly (back to Step 1).

In the phases that follow the early design stage, some aspects can be improved, but only to a certain extent. Alongside the environmental indicators, such as the amount of energy that will be needed for the construction and operation of the building, the level of harmful gas emissions, water use *etc.*, it is also necessary to include social and economic aspects in evaluating the quality of the design solution [3,4]: the living comfort inside the building, its functionality, the total cost for the entire life cycle of the building, integration in the neighborhood, public involvement and location. However, maintaining control over all the aspects connected with sustainability in building construction and estimating their influence on the final result while still in the early design phase is quite challenging. There is, therefore, a need for an information tool that will show in a comprehensive manner how a particular design is addressing a variety of different criteria important for achieving a more sustainable solution. It should be simple enough to allow the architect himself to perform a quick evaluation of the sustainability of the design in the early planning stages. As such it would be an important aid for architects, as leaders of the building planning teams, to optimize the design solution during process.

The main purpose of this article is therefore to present the development of a simplified method for evaluating building sustainability (SMEBS) in the early planning phases for architects. The stages of the research are outlined in Figure 1. In the first stage (Section 2) we analyzed the literature about building performance tools that are a support in planning and comprehensive building sustainability assessment methods (BSAM). The advantages and disadvantages of existing BSAM are explained and the reasons for a simple method for evaluating building sustainability are presented. On this basis a model of structured parameters for building sustainability evaluation in the early design phases is developed (Section 3). For determining the significance of individual parameters in the model experts from the field of sustainable construction are surveyed (Section 4). In the survey, the analytical hierarchy process (AHP), which enables complex decisions to be made by simplifying the decision-making process, is used for allocating parameter weights. The model and acquired parameters' weights (Section 5) are used to develop a SMEBS, which allows a quick evaluation of the extent to which the demands of sustainable building are fulfilled. Based on these results the architect can optimize the design project accordingly. It is made as an Excel based tool and is intended for use in the local context (Section 6).

Figure 1. Workflow diagram.



2. Available Methods and Tools for Assessing the Building during the Planning Phase

There are various methods and tools that are available to help us test the influence of different parameters on the design and functioning of the building. They are usually focused on testing individual parameters such as energy use in operation phase [5,6], analyzing the environmental impact [7,8], checking the level of daily illumination in rooms [9], foreseeing the expenses in the building's entire life-cycle [10] and other or specific combinations of parameters [11–15]. Tools that are aimed at testing the influence of individual design parameters are useful but deficient. We wish to acquire as comprehensive an assessment of a planned building as possible. Tools for testing specific parameters are therefore often included in the comprehensive BSAM. There are already a large number of these. In Europe alone, over 60 BSAM have been recorded [16]. We have examined in greater detail the methods that are most in use globally: BREEAM, LEED, DGNB, CASBEE, HQE, SBTool [17–22]; some methods developed for use in Central European countries: BEAS and TQB [23,24]; recent European research projects: OPEN HOUSE and ENERBUILD [25,26]; European standards EN 15643-2, -3, -4: The sustainability of construction works–Assessment of buildings [27] and international standard ISO 21929-1: Sustainability in building construction–Sustainability indicators [28].

We find that there are numerous advantages in using BSAM. The standards in methods act as guidelines for planning and help investors choose the desired quality of building when preparing the project brief. Therefore, to achieve a desired certification level, the building must be planned accordingly. This leads to a reduction of negative effects of the building on the environment, higher quality of living in the building, lower expenses in the building's operational phase and a higher market value because of its proven quality. The transparency of the planning procedure is also greater as the standards are clearly defined and can be verified. It is also possible to compare the quality of buildings on the basis of the final assessment result. However, there are also some negative aspects of using BSAM. The procedure for assessing and certifying is long and demanding. Checking the broad spectrum of content demands much time and requires the use of different tools for testing the results. Most of the existing BSAM are either not adapted for an independent use by the architects (with most BSAM it is obligatory to include a licensed assessor in the process of certification [29]) or are the requirements for criteria fulfilment quite complex and require specific knowledge of an expert consultant (Life-cycle cost analysis, Life-cycle assessment, simulation of energy flows and thermal indoor environment …). We believe this is one of the reasons why BSAM is not used more frequently. The process of evaluation and certifying a building also entails additional cost: registering the project with a certification institution, hiring a licensed assessor and other consultants [30]. Different BSAM are adapted for use in specific regions or countries so their use in other environments can be unsuitable due to local conditions [31]. Every region has a specific climate and the materials and technologies that are locally available are different, as are cultural and political preferences. The use of BSAM outside the intended region is also limited due to other obstacles such as language, legislation and local rules, different systems of measurement, *etc*. There is therefore a need for assessment methods that consider the local context—that address the country's geographical and economic situation in terms of importance given to certain evaluated parameters [32]. Coming to the local situation–in Slovenia no local BSAM method has yet been developed nor has an international one been suitably adapted [33].

BSAM are intended above all to show the quality of the building when it is finished and for later comparison with other buildings. Less attention is given to the optimization of the building with the help of BSAM in the planning phase. Some BSAM do allow the early testing of the level of fulfilment of criteria and the foreseen final score. This means that in the early design phase of the project a licensed assessor uses the available information and the support of building designers to give a rough estimate regarding the fulfilment of individual demands–the so-called pre-assessment [17,29]. Certain BSAM allow a preliminary score to be acquired on the basis of a smaller number of core criteria, which are assessed according to the usual procedure [25]. In both cases a licensed assessor is involved in the procedure, as BSAM are not adapted for independent use by architects. Berardi [34] states that methods must be simple enough if they are to be used as design tools. In order to introduce the sustainability assessment methods early in the design process, they must be structured in such a way that detailed information is not a prerequisite. On the basis of a review of existing literature, we found that there is a need for a method that evaluates the project solution in a comprehensive manner in the early design phase and is at the same time simple enough for independent use by architects. The developed SMEBS tried to address these questions and at the same time respond to the particularities of the local environment.

3. Selection of the Parameters and Structuring the Model for Evaluating Building Sustainability

A selection of parameters for evaluating was created on the basis of comparable analysis of the above mentioned BSAM [17–24], recent European research projects and international standards in this field [25–28]. Due to the large number of different selected parameters, the model is hierarchically structured in four levels (Figure 2): level 1–assessment of the building's sustainability, level 2-aspects, level 3–categories, and level 4-criteria. On level 2 we have divided the building sustainability score into three aspects: burden on the natural environment (environmental aspect), the quality of the built environment (user aspect) and the economic efficiency of the project (financial aspect), as prescribed by standard ISO 21929: Sustainability in building construction. The aspects are further subdivided into categories that stem from thematically connected criteria chosen at the fourth level. The environmental aspect consists of the categories of pollution and waste, energy, water use, materials and sustainable land use. The user aspect consists of the categories of well-being, functionality and technical properties. The financial aspect consists of the categories of costs and property value. At the fourth level we determined 33 criteria (Table 1), on the following basis:

- criteria are recognized as core indicators for building sustainability assessment [27,28];
- the building is considered in its entire life-cycle, from the phase of acquisition of raw materials, production of materials and components, construction, operation and maintenance of the building and its demolition and disposal;
- the frequency of apparition of certain criteria (or their content) in foreign BSAM;
- inclusion of a variety of criteria to cover all three distinct aspects of sustainability [28] and take into account regional particularities.

With some BSAM, the planning process is an integral part of the final score while with other methods it is dealt with in the form of recommendations regarding the professional preparation and management of the project (e.g., the organization of an architecture competition aimed at acquiring the best possible solutions, interdisciplinary planning, checking the references of contractors, inclusion of the public in the planning process). We believe the final score of the building's level of sustainability is not necessarily influenced by the way the project is prepared so we have included this content amongst the recommendations, but no points are allocated.

Figure 2. Model for evaluating building sustainability.

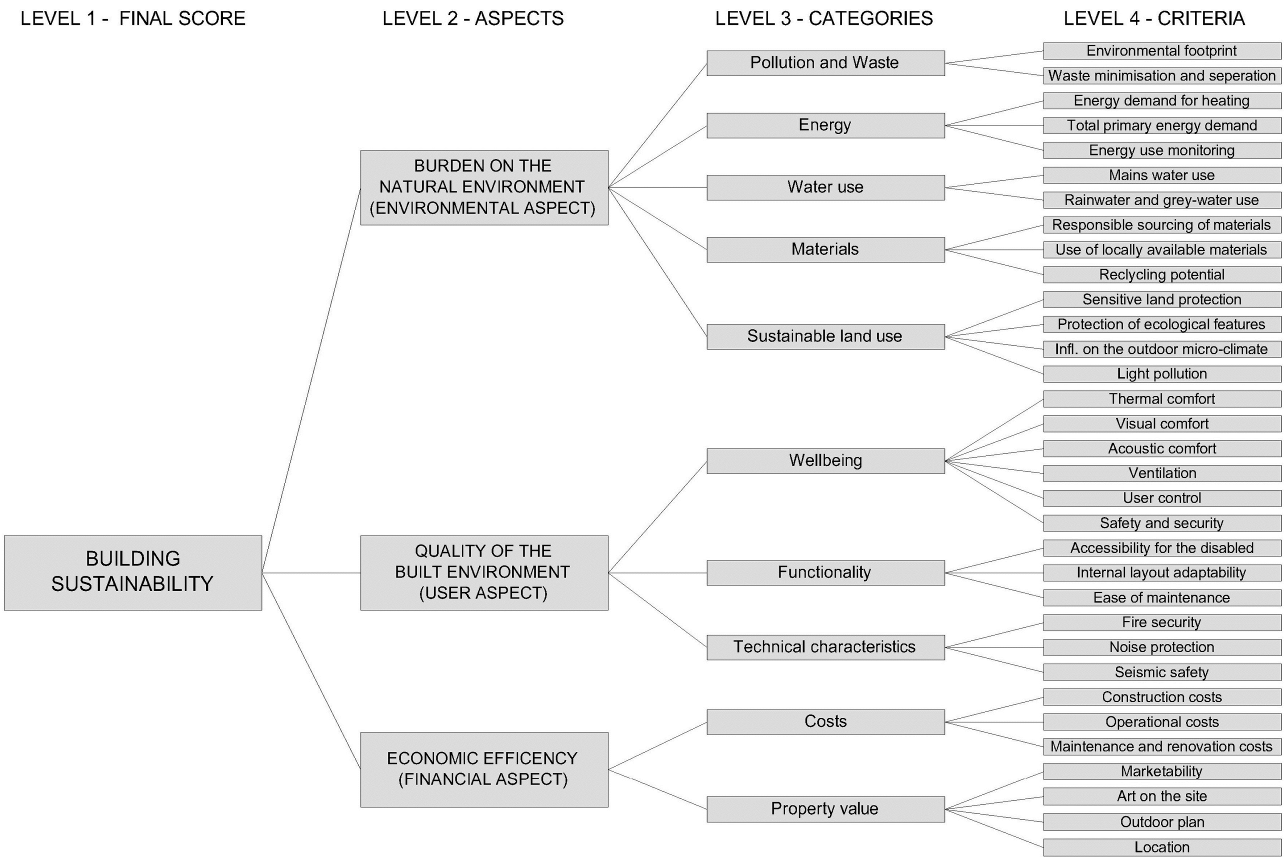


Table 1. Short descriptions of chosen criteria.

Environmental footprint	**Protection of ecological features**	**Ease of Maintenance**
the reduction of negative influences of the building on the environment and people due to harmful emissions resulting from the combustion of fossil fuels during the building's entire lifecycle (embodied and operational emissions)	keeping records of local ecological characteristics, protection of existing plant and animal habitats	maintenance and replacement of technical appliances and systems should be simple to implement
Waste minimization and separation	**Influence on the outdoor micro-climate**	**Fire security**
encouragement of the use of recycled construction materials; waste reduction, sorting and composting	measures planned on the building and around it to reduce the heat island effect	appliances such as smoke detectors, fire alarms and sprinkler systems are included for higher fire security
Energy demand for heating	**Light pollution**	**Noise protection**
the lowest possible heating needs for the building	measures planned to minimize the light pollution through the use of appropriately directed sources of light to illuminate the building and surrounding facilities illumination	protection against outdoor and indoor noise through the implementation of specific measures

Table 1. *Cont.*

Total primary energy demand	**Thermal comfort**	**Seismic safety**
the lowest possible use of primary energy in the entire life-cycle of the building with the lowest possible energy use from non-renewable energy sources *i.e.*, the highest possible proportion of energy use from renewable sources	providing an appropriate level of hygro-thermal comfort in the interior of the building throughout the year	high level of earthquake safety to reduce danger and damage in the event of an earthquake
Mains water consumption	**Acoustic comfort**	**Operational costs**
adaptation of sanitary appliances to reduce water use	providing suitable acoustic properties	low operational costs (heating, cooling, ventilation, water supply, electricity, cleaning) suited to the building user financial capabilities
Rainwater and grey-water use	**Ventilation**	**Maintenance and renovation costs**
use of rainwater and grey-water to reduce the consumption of mains water consumption	providing suitable levels of ventilation inside the building and prevention of draughts	low maintenance and renovation costs (repair, replacement, refurbishment of building parts and technical systems) suited to the building owner aspirations
Responsible sourcing of materials	**User control**	**Marketability**
reduction of burden on the environment and health risks through the use of verified materials	the possibility of controlling temperature, ventilation, lighting, protection from the sun	maintaining the building's value for a longer period of time
Use of locally available materials	**Safety and security**	**Art on the site**
reduction of negative effects due to transport and stimulation of the local economy	design of premises, equipment and signs that reduce risk of injuries, accidents and criminal acts	artworks in the building create added value
Recycling potential of components and materials	**Accessibility for the disabled**	**Outdoor plan**
promotion of recycling of obsolete parts of the building and the return of materials in the biological or technical life cycle	common areas and other parts of the building are specially adapted for use by physically impaired persons	spatial arrangement around the building to enable interaction, relaxation or recreation and secure parking for bicycles
Sensitive land protection	**Internal layout adaptability**	**Location**
avoiding construction on agricultural and undeveloped land (meadows, fields, forests)	the possibility of adapting the building's plan layout to the needs of the user	proximity of public transport, green spaces and amenities (convenience store, day-care and education, public administration, post office, bank, healthcare)

Table 2 shows the frequency of apparition of selected criteria in examined BSAM and international standards. Each assessment method uses different forms of criteria arrangement and different terms for evaluating different demands so it is quite difficult to constitute a comparison [3]. In addition, when certain criteria appear not to be included in a BSAM, they may indirectly be included in other criteria. Some BSAM include various criteria that are unique or rarely found in other methods. These are not included in the comparison, because it would be practically impossible to include all of them. For the purpose of comparison, therefore, our developed criteria were chosen. We used three options in the comparison. The criteria demands are either directly included (x), are indirectly covered by other criteria (o) or are not evaluated in the BSAM. The comparison shows that almost all chosen criteria are evaluated in the majority of the examined BSAM and international standards. The exceptions being seismic safety (this criteria is chosen because it is relevant in this region) and art on the site (this criteria was chosen to form a part of the property value category). With inclusion of the majority of the criteria that are also represented in international BSAM, the building planner and the investor are already reminded to address them at the beginning of the project. This means the project is more adapted for a possible certification with an international BSAM later on in the process.

Selected criteria in the SMEBS also address the issue of future-proofing. The impact of possible higher average temperatures and more frequent extreme weather is compensated by a good quality building shell, adequate shading, appropriate technical systems or good thermal mass with night-cooling which are evaluated in thermal comfort, ventilation, energy demand for heating and total primary energy demand. Rainwater and grey-water use decrease mains water use in the event of droughts and ensures a certain level of autonomy. Seismic safety and internal layout adaptability address the resilience in events of natural disasters and societal changes. Marketability includes the evaluation of risk in case of floods or landslides. These and also other criteria help shape the building design to successfully respond to future challenges and not become prematurely obsolete.

4. Determining the Importance of Parameters Using the AHP Approach

Once the criteria have been chosen and the model has been given its structure, the second, essential step is to determine the weights of importance of the parameters. Often this is determined on the basis of the shared opinion of an appropriate interest group [35]. The group usually consists of experts in the field and future method users. The analytic hierarchy process (AHP) is very frequently used to determine the shared opinion of the group [36–42] as it is one of the most frequently used methods for multiple-criteria decision-making. AHP allows the experts to make decisions concerning complex content by simplifying the natural decision-making process on the basis of pairwise comparisons between two parameters [42]. The AHP method for ascribing weights to parameters using the model for assessing building sustainability was executed in the following order [39]:

- the problem was defined and modelled in a hierarchical structure;
- the group of experts to carry out the comparisons was formed;
- judgments were made between parameters on a scale of 1–9, as proposed by Saaty [43], by each expert individually;
- the pairwise comparisons of individual experts were entered into a matrix;
- the consistency ratio was calculated to establish whether the judgments of experts were sufficiently consistent;
- individual judgments were aggregated into a group judgment using the geometric mean method to derive local weights of parameters;
- local weights of parameters were derived according to Saaty's eigenvector method [43];
- global weights of parameters were calculated from the hierarchical structure.

Table 2. Frequency of the criteria in examined BSAM and international standards.

	Environmental footprint	**Waste minimization and separation**	**Energy demand for heating**	**Total primary energy demand**	**Energy use monitoring**	**Mains water consumption**	**Rainwater and grey-water use**	**Responsible sourcing of materials**	**Use of locally available materials**	**Recycling potential of materials**	**Sensitive land protection**	**Protection of ecological features**	**Influence on the outdoor micro-**	**Light pollution**	**Thermal comfort**	**Visual comfort**	**Acoustic comfort**	**Ventilation**	**User control**	**Safety and security**	**Accessibility for the disabled**	**Internal layout adaptability**	**Ease of Maintenance**	**Fire security**	**Noise protection**	**Seismic safety**	**Construction costs**	**Operational costs**	**Maintenance and renovation costs**	**Marketability**	**Art on the site**	**Outdoor plan**	**Location**
BREEAM	o	x		o	x	x	o	x		o	x	x	x	x	x	x	x	x	x	x	x		o		o		x	x	x			x	x
LEED	o	x		o	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			o			o							x	x
DGNB/BNB	x		o	x		x	o	x		x	x	x	x		x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x
HQE	x	o	o	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x		x	x		x							x	x
CASBEE	x	x	x	o	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	o	x	x				o	x	x	x
TQB	x	x	x	x		x	x	x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	o				o	o	x	x
BEAS	x	x	x	o	x	x	x	x	x		x	x	x	o	x	x	x	x	o			x			x							x	x
SBTool	x	o		x	x	x	x	x			x	x	x		x	x	x	x	x		x		x				x	x	x	x		x	x
OPEN HOUSE	x	x	o	x	x	x	o	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		o	x
ENERBUILD	x		x	x	x			x			x	o			x	x	x	x	o						x		x	x	x				x
EN 15643	x	x		x		x	o			x					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
ISO 21929-1	x	x		o		x	o	o			x	x	x	o	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x		x	x
DIRECT (x)	10	8	4	7	8	11	6	10	6	7	10	9	9	5	12	12	12	12	9	8	8	8	8	5	9	4	7	7	7	5	2	9	11
INDIRECT (o)	2	2	3	5	0	0	5	1	0	1	0	1	0	2	0	0	0	0	2	0	0	1	1	1	2	1	0	0	0	2	1	1	0
TOTAL	12	10	7	12	8	11	11	11	6	8	10	10	9	7	12	12	12	12	11	8	8	9	9	6	11	5	7	7	7	7	3	10	11

The goal was to obtain weights for individual parameters in the model as they can be used to acquire the collective estimate of the building's sustainability. We sent an invitation to fill out the internet questionnaire via e-mail to 40 prominent experts that have experience in sustainable construction. The chosen experts were predominantly architects, since they were our major target group as future users of the developed method. We received their replies between 9 and 24 November 2013. Seventeen of the questionnaires were satisfactorily filled out and the respondents all quoted years of experience in the field of sustainable building. The majority of the respondents have an architectural education, while others have educational background in civil engineering, mechanical engineering, physics or economics. They are active in different fields (planning and consulting, educational and research institutions, public or state administration, development agencies and interest groups, production and sale of materials and building components). The respondents are already acquainted with the existing BSAM. They are most familiar with DGNB, BREEAM and LEED (Figure 3).

The questionnaire consisted of pairwise comparisons of the individual parameters (aspects, categories, criteria) on the same hierarchy level within a group of parameters. Each parameter also contained a short description to explain the content. The descriptions were of comparable length and quality. When allocating judgments in pairwise comparisons experts used the number scale 1–9, as proposed by Saaty [43] (Table 3). There were 61 pairwise comparisons to be determined by the experts in the questionnaire. Table 4 shows a part of the questionnaire for the experts.

Figure 3. (**a**) Educational background of the respondents (n = 17); (**b**) Fields of activity of the respondents (n = 17); (**c**) Respondents' acquaintance with existing BSAM.

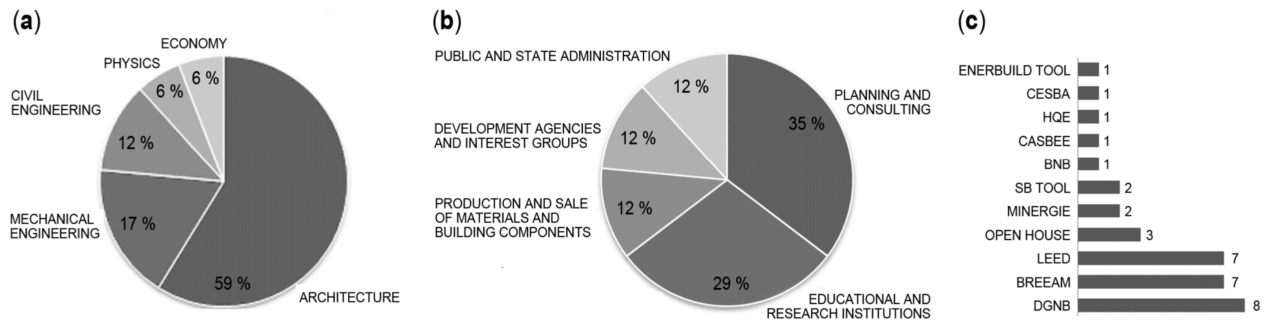


Table 3. Explanation of numerical value in allocating judgments.

Intensity of Importance	Definition	Explanation
1	Equal importance	Parameters i and j are equally important.
2	Weak or slight difference in importance	
3	Noticeable difference in importance	Parameter i is moderately more important than j.
4	Medium difference in importance	
5	Large difference in importance	Parameter i is much more important than j.
6	Very large difference in importance	
7	Strong difference in importance	Parameter i is proved to be more important than j.
8	Very strong difference in importance	
9	Extreme difference in importance	Parameter i absolutely more important than j.

Table 4. Part of the questionnaire for experts: pairwise comparisons between categories within the aspect of quality of the built environment.

Circle a Number to Show Which of the Parameters You Believe is More Important		
	Wellbeing	Functionality
1	thermal, light and acoustic comfort, quality of ventilation, user control over systems for local settings of desired comfort, security	accessibility for the disabled, internal layout adaptability, ease of maintenance
	9 8 7 6 5 4 3 2 1 2 3	4 5 6 7 8 9
	Wellbeing	Technical properties
2	thermal, light and acoustic comfort, quality of ventilation, user control over systems for local settings of desired comfort, security	fire security, noise protection and seismic safety of the building
	9 8 7 6 5 4 3 2 1 2 3	4 5 6 7 8 9
	Functionality	Technical properties
3	accessibility for the disabled, internal layout adaptability, ease of maintenance	fire security, noise protection and seismic safety of the building
	9 8 7 6 5 4 3 2 1 2 3	4 5 6 7 8 9

In the AHP method all judgments are recorded in a matrix of pairwise comparisons $A=(a_{ij})_{n\times n}$, in which the dimension of matrix n means that we compared n parameters. The element of the matrix a_{ij} denotes a pairwise comparison of parameter i with parameter j; we gave the inverse comparison (comparing parameter j with parameter i) the reciprocal value: $a_{ji}=1/a_{ij}$. We can employ the eigenvector method [43] to derive the parameter weights from the matrix of pairwise comparisons A, which means that we must solve the equation:

$$Aw=\lambda_{max}w \tag{1}$$

where λ_{max} is the maximal eigenvalue of matrix A. For every matrix of pairwise comparisons A we must also calculate the consistency ratio, which measures the level of inconsistency between pairwise comparisons:

$$CR=\frac{CI}{RI} \tag{2}$$

where $CI=\frac{\lambda_{max}-n}{n-1}$ is the consistency index, n is the size of matrix A and RI is the average consistency index. We assumed that if $CR \le 0.15$, then the inconsistency level of matrix A is still acceptable [44].

In the case of group decision making where m is the number of decision makers, we aggregate the individual judgments into one joint judgment a_{ij}^{group} applying the geometric mean method:

$$a_{ij}^{group}=\sqrt[m]{\prod_{k=1}^{m}a_{ij}^{k}} \tag{3}$$

where a_{ij}^{k}, $k=1,\ldots,m$ are the individual judgments of m decision makers.

Aczel and Saaty [45] showed that the geometric mean method Equation (3) is the only appropriate method for aggregating individual judgments into group judgments as it satisfies some necessary axiomatic conditions like preserving reciprocity.

For the analysis of the acquired data we used an Excel template [46]. The template allows judgments of up to 20 respondents to be entered and aggregated separately for each group of parameters at the same hierarchical level. After the pairwise comparisons of individual respondents were entered in the template, we discovered that some pairwise comparison matrices were not acceptably consistent ($CR \leq 0.15$). For pairwise comparisons in these matrices we asked the respondents to make appropriate corrections with minimal alteration as suggested by the template. The experts then decided by themselves how these slight alterations in pairwise comparisons were to be made, establishing acceptable consistency, while maintaining the previous criteria weight allocation as much as possible. In order to deduce the combined local weights from all the experts we joined the judgments gathered from pairwise comparisons of individual experts using the geometric mean Equation (3).

We derived the global weight of an individual parameter Equation (4) by multiplying local parameter weights with hierarchically higher ones according to the following equation:

$$GW_{P,i} = LW_{A,j} \times LW_{CA,k} \times LW_{CR,i} \quad (4)$$

where GW_P = global weight of the parameter, LW = local weight, A = aspect, CA = category and CR = criteria that represent the level on the hierarchical structure; indexes i, j, $k = 1,\ldots,n$ denote the individual criteria, category or aspect at each hierarchical level.

5. Results and Discussion of Weight Allocation

The final results of parameter weights allocation using the AHP method are shown in Table 5. Experts ascribed the greatest importance to the quality of the built environment (user aspect), whose weight is 41.08%. The aspect of burden on the natural environment (the environmental aspect) scored 34.41%, and the financial aspect 25.52%. For the environmental aspect, the highest local priority was given to the energy category (23.02%) followed by materials (21.99%), water use (21.89%), pollution and waste (17.08%) and the lowest weight in the category was scored by sustainable land use (16.02%). For the user aspect, the greatest local priority was given to well-being (39.60%), followed by functionality (32.68%), and the lowest weight was given to technical characteristics (27.72%). In the financial aspect, the costs category scored 56.79% and property value 43.21%.

The results show that for the respondents, the most important aspect of sustainable building is a high quality of the built environment with a high level of well-being for users and appropriate functionality and technical characteristics. When it comes to the user aspect, building designers should pay special attention to thermal comfort, ventilation, accessibility for the disabled, internal layout adaptability, fire security and seismic safety as these criteria were given the highest levels of priority. The environmental aspect with 34.4% does not stand out in particular in terms of priority weighting. We can interpret this by saying that the respondents recognize that the natural environment in Slovenia is well preserved and not under significant threat from the existing construction approaches. The reasons for a relatively good preservation of biodiversity in Slovenia are the limited impact of economic factors and given natural characteristics: the transitional location on a junction of biogeographical regions (Alpine, Mediterranean, Pannonian and Dinarides), agitated topographic relief and various geological and hydrological conditions [47]. This can be supported with the fact that

35.53% of land in Slovenia is part of the European Natura 2000 nature protection areas [48] which is the highest percentage among all EU member states. For comparison, Austria with 14.70% and UK with 7.22% of land area part of Natura 2000, give much greater priority weight to the issues regarding environmental aspect in their BSAM: TQB (Austria) 49.0% and BREEAM (UK) 66.6% (if we redistribute their criteria with weights to our assessment structure (Figure 2)). On the basis of the allocated weights, we can say that the most important criteria within the environmental aspect are the environmental footprint, total primary energy demand and water use. Although the financial aspect scored lowest, this does not mean that individual economic criteria are also the least important. In fact, the criteria of operational costs, maintenance and renovation costs, and location are amongst the ones with the highest weight. This is why they should be given special attention when planning a sustainable building.

Table 5. Results of the allocation of weights to individual criteria, categories and aspects.

Aspect	Local Weight	Category	Local weight	Criteria	Global Weight	Global Weight	Global Weight
Burden on natural environment–Environmental aspect	0.1708	Pollution and waste	0.7473	Environmental footprint	0.0439	0.0588	0.3441
			0.2527	Waste minimization and separation	0.0149		
	0.2302	Energy	0.3501	Energy demand for heating	0.0278	0.0792	
			0.5220	Total primary energy demand	0.0412		
			0.1278	Energy use monitoring	0.0101		
	0.2189	Water use	0.5310	Mains water consumption	0.0400	0.0753	
			0.4690	Rainwater and grey-water use	0.0353		
	0.2199	Materials	0.3874	Responsible sourcing of materials	0.0293	0.0757	
			0.2657	Use of locally available materials	0.0201		
			0.3469	Recycling potential of components and materials	0.0262		
	0.1602	Sustainable land use	0.2776	Sensitive land protection	0.0153	0.0551	
			0.2490	Protection of ecological features	0.0137		
			0.2935	Influence on the outdoor micro-climate	0.0162		
			0.1800	Light pollution	0.0099		

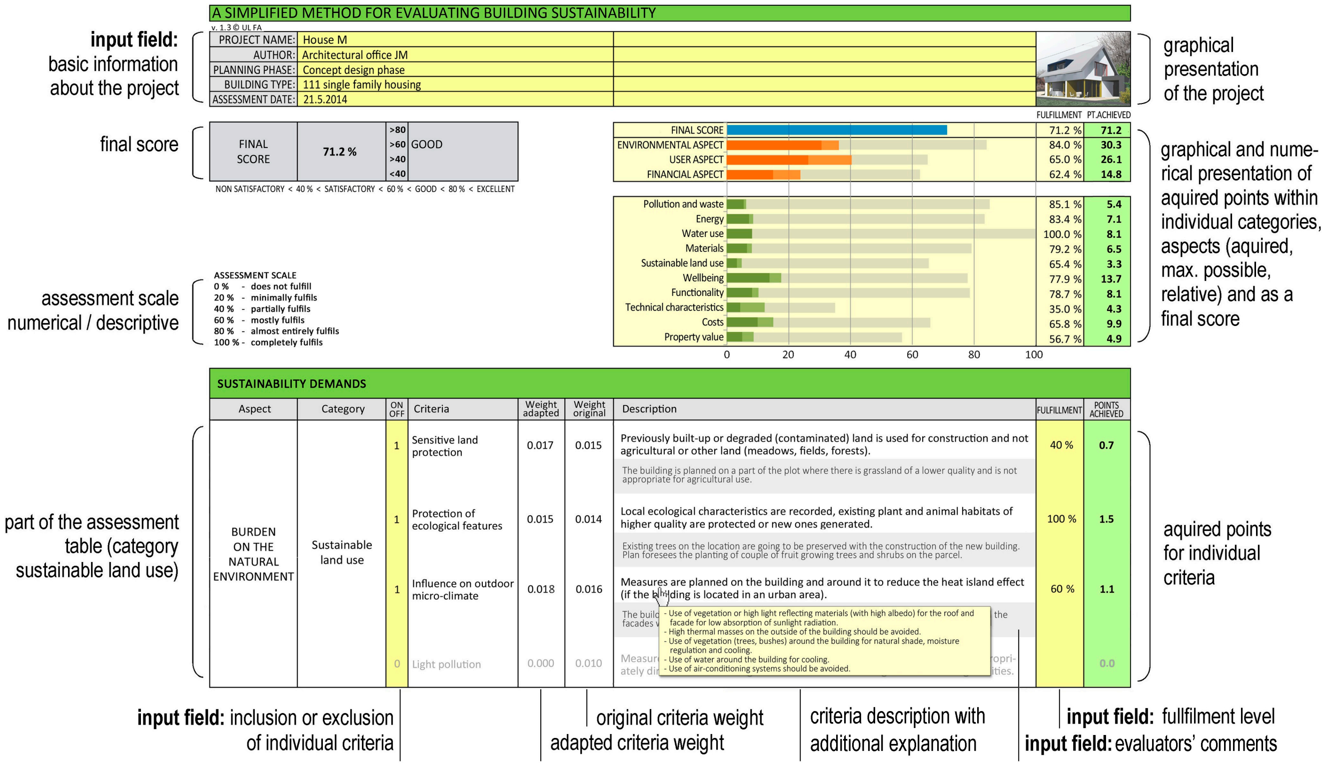
Table 5. *Cont.*

Aspect	Local Weight	Category	Local weight	Criteria	Global Weight	Global Weight	Global Weight
Quality of built environment–User aspect	0.3960	Well-being	0.2724	Thermal comfort	0.0443	0.1627	0.4108
			0.1912	Visual comfort	0.0311		
			0.1078	Acoustic comfort	0.0175		
			0.2496	Ventilation	0.0406		
			0.1006	User control	0.0164		
			0.0784	Safety and security	0.0128		
	0.3268	Functionality	0.3305	Accessibility for the disabled	0.0444	0.1342	
			0.3792	Internal layout adaptability	0.0509		
			0.2903	Ease of Maintenance	0.0390		
	0.2772	Technical characteristics	0.3732	Fire security	0.0425	0.1139	
			0.2519	Noise protection	0.0287		
			0.3749	Seismic safety	0.0427		
Economic efficiency–Financial aspect	0.5679	Costs	0.2200	Construction costs	0.0306	0.1392	0.2452
			0.4624	Operational costs	0.0644		
			0.3176	Maintenance and renovation costs	0.0442		
	0.4321	Property value	0.2466	Marketability	0.0261	0.1060	
			0.1366	Art on the site	0.0145		
			0.2388	Outdoor plan	0.0253		
			0.3781	Location	0.0401		

6. A Simplified Method for Evaluating Building Sustainability (SMEBS)

We developed the SMEBS on the basis of the model for building sustainability assessment and the acquired weights for parameters from the AHP. It is intended as a tool to aid architects in the project planning phases. It is prepared as an Excel spreadsheet and allows an early and quick evaluation of the extent to which the demands of sustainable building are fulfilled (Figure 4). It is intended primarily for the project planner and investor to have an overview of the fulfilment of sustainability demands already in the early planning stages. On the basis of the acquired results it is possible to optimize the project and improve it while it is still in the early planning stage when this is most effective. The user of the tool (the architect) assesses the project with the 33 criteria, which are given a priority weighting based on the judgment made by experts in the field of sustainable building. Alongside the basic description, we prepared the detailed explanation of demands for all the criteria. They are based on the demands of criteria in existing BSAM (Section 2), which were extracted, summarized and adjusted for a simplified evaluation of the building with this tool. The detailed explanations of criteria form the basis for determining to what extent individual criteria are fulfilled. The criteria are assessed on a six-tier scale depending on how many demands they meet: (project: 0%-does not fulfil; 20%-minimally fulfils; 40%-partly fulfils; 60% mostly fulfils; 80%-almost entirely fulfils and 100%-completely fulfils the criteria demands). Certain criteria are measured quantitatively on the basis of a quick calculation with the help of certain program tools that are freely available. The calculated results are then given a fulfilment level rating which is determined in the detailed explanation of the criteria. To check visual comfort, for example, the average daylight coefficient in the inside of the building is to be calculated using a simple program tool like Velux Daylight Visualizer [49] or other similar programs. Energy demand for heating, which is a good indicator of building energy use in operation in this region, is also calculated with a freely available simple program like Isover Multi-Comfort House Designer [50]. The acquired results are assessed on a scale that relates to the levels of the national Energy Performance Certificate for buildings, which must be attained by all new buildings [51,52]. For the criteria which are assessed qualitatively, the score is determined based on the user's own estimation of the fulfilment of the demands, which are described in greater detail in the additional explanation. Simplified evaluation for most of the criteria can be met quite early in the design process. The choice of main construction material is directly linked with the environmental footprint and also with construction costs. Energy efficiency of the building (in Slovenia predominantly influenced by energy demand for heating) can also be determined quite early based on the location, shape, orientation, building envelope, the use of the building and type of mechanical equipment. The comments on how the demands are fulfilled are to be written down in the tool next to each criteria. The scores and comments can be updated during the stages of the design process, so that the assessment is more precise with the development of the project. The user of the tool still takes full responsibility for the realization of criteria demands in the final phases of the project (e.g., selection of ecological materials, air-tightness of the building envelope, structure without thermal bridges, energy efficient heating systems, appropriate ventilation *etc.*). It is possible to exclude individual criteria if the user decides they are not relevant in the assessment of a particular building or if the information to evaluate it is not yet available at the current stage of design. In this case, the weighted portion of the excluded criteria is proportionally shared out amongst the remaining criteria. This open structure of the tool allows application to various different types of building in different contexts. The score attained for individual criteria, categories and aspects, and the final score are refreshed automatically. This allows a comprehensive overview of the score achieved and the effects of different criteria on it. The graphic depiction of points scored makes it even easier to see to what extent the demands of sustainable building are met and facilitates communication between the architect and the client. The final score is expressed in terms of how many demands are met with a ranking in one of four building sustainability levels (less than 35%-non satisfactory; between 35% and 55%-satisfactory; between 55% and 75%-good; more than 75%-excellent). These limits were determined after a couple of test evaluations on different projects with the architects. They were asked to evaluate their projects where the sustainability in construction was considered in the planning phases. The typical score was around 65%. The score above 75% was very difficult to acquire. The result of the evaluation serves as information to the architect and the project investor for optimizing the building in the design phase.

Figure 4. Part of the user interface of the developed SMEBS.



Adaptation to a Regional Context

When assessing a building with the help of various international methods it is necessary to be aware of the differences between them as each method has different priorities depending on the importance given to different criteria. Certain demands connected with some criteria can be less relevant outside the specific region. It therefore makes sense to use a building assessment method that is best adapted to a specific region. The manner of SMEBS development means that it is designed to be used locally.

On the basis of a review of the current situation in the field of assessment we found that underneath the different assessment structures of various BSAM, they all deal with common issues. This shows itself also in attempts to grasp and harmonize the included demands in various international research projects and in the ongoing international standardization of this field. Taking international assessment methods as a starting point therefore ensures that the sustainability issues will be included. We have prepared relevant content that we believe is important for sustainable building in Slovenia. The respondents who defined the priority weighting of parameters are known in Slovenia as leading experts in the field of sustainable construction so their opinion is respected in this domain. Chandratilake and Dias [42] find that the judgments of the experts on criteria importance are not coincidental. On the basis of comparisons of BSAM priority weightings given to specific parameters in different countries and their connections with certain national statistics, they have found a good mutual correlation. The results are an expression of an individual's comprehension of specific characteristics of an environment or context, which Chandratilake and Dias call embodied-subjectivity. In this way they prove that the local context had an influence on the experts when giving priority weighting for parameters in BSAM. Ali and Al Nsairat [38] also argue that when giving priority weights to individual parameters it is important to bear in mind the local characteristics of the region where the method will be employed. The experts who participated in defining weights using the AHP method all work in Slovenia, so their judgments can be considered to be a realistic reflection of the priorities in the regional context. The selection of criteria and determination of the weights by local experts ensures that the tool is adapted to the specific local environment. On the basis of the methodology that was used, it is possible to repeat the process and develop a SMEBS for use in other environments.

7. Conclusions

Future climate change will, according to predictions, amplify the impacts on natural and human systems with more frequent extreme weather [53,54]. As an answer to these risks, the concept of future-proofing is gaining increased attention. The building designed today should be able to accommodate various uncertainties in the future so that it will not become prematurely obsolete. Building sustainability with the integration of three sustainability pillars and lifecycle thinking is following this logic [55].

In this article, we have presented a new method for evaluating building sustainability that is adapted for use in a specific environment. The main novelty of the presented method is its simplicity and low expense. The method was developed on the basis of a study of commonly used foreign BSAM and international standards in the field of building sustainability assessment. In order to acquire the priority weights of individual parameters in the assessment model, experts used the AHP to give their judgments in pairwise comparisons. On this basis, a SMEBS was developed that is adapted for use especially in the early stages of project planning. The tool can provide a good overview and a reference score for the architect and investor on how well the building design meets the sustainability goals. Following the demands in the criteria would also result in a design that is more future-proofed against possible impacts of climate change or other changes in society. The use of the tool in the early planning phases means that optimization in design can be more easily implemented. It can be employed without the need for external assessors and the score is quickly obtained.

Acknowledgments

This research has been supported by the Slovenian Research Agency (ARRS) through its young researcher financing scheme. This article forms part of a doctoral study at the Faculty of Architecture of the University of Ljubljana. The authors would like to thank the Slovenian Research Agency for its financial support–Jernej Markelj and Martina Zbašnik-Senegačnik for the financial support within the programme group P5-0068, Manja Kitek Kuzman for the program group P4-0015-0481.

Author Contributions

Jernej Markelj and Martina Zbašnik-Senegačnik conceived this research; Manja Kitek Kuzman and Petra Grošelj provided expertise regarding the use of AHP methodology in the research and contributed to the overall quality of the paper; Petra Grošelj wrote part of the Section 4; Jernej Markelj performed the research survey, analyzed the data and wrote the paper; Martina Zbašnik-Senegačnik supervised the research. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References and Notes

1. Bragança, L.; Mateus, R.; Koukkari, H. Building Sustainability Assessment. *Sustainability* **2010**, *2*, 2010–2023.
2. Attia, S.; Gratia, E.; de Herde, A.; Hensen, J.L.M. Simulation-based decision support tool for early stages of zero-energy building design. *Energ. Build.* **2012**, *49*, 2–15.
3. Lee, W.L. A comprehensive review of metrics of building environmental assessment schemes. *Energ. Build.* **2013**, *62*, 403–413.
4. Hopfe, C.J.; Augenbroe, G.L.M.; Hensenc, J.L.M. Multi-criteria decision making under uncertainty in building performance assessment. *Build. Environ.* **2013**, *69*, 81–90.
5. Ekici, B.B.; Aksoy, U.T. Prediction of building energy needs in early stage of design by using ANFIS. *Expert Syst. Appl.* **2011**, *38*, 5352–5358.
6. Santos, P.; Martins, R.; Gervásio, H.; da Silva, L.S. Assessment of building operational energy at early stages of design–A monthly quasi-steady-state approach. *Energ. Build.* **2014**, *79*, 58–73.
7. Baek, C.; Park, S.-H.; Suzuki, M.; Lee, S.-H. Life cycle carbon dioxide assessment tool for buildings in the schematic design phase. *Energ. Build.* **2013**, *61*, 275–287.
8. Malmqvist, T.; Glaumann, M.; Scarpellini, S.; Zabalza, I.; Aranda, A.; Llera, E.; Díaz, S. Life cycle assessment in buildings: The ENSLIC simplified method and guidelines. *Energy* **2011**, *36*, 1900–1907.
9. Gallas, M.-A.; Halin, G. DaylightGen: From Daylight Intentions to Architectural Solutions. *eCAADe* **2013**, *31*, 107–116.
10. Bogenstätter, U. Prediction and optimization of life-cycle costs in early design. *Build. Res. Inf.* **2000**, *28*, 376–386.
11. Arpacioğlu, Ü.; Ersoy, H.Y. Daylight and Energy Oriented Architecture Design Support Model. *Gazi Univ. J. Sci.* **2013**, *26*, 331–346.
12. Azhar, S.; Carlton, W.A.; Olsen, D.; Ahmad, I. Building information modelling for sustainable design and LEED rating analysis. *Automat. Constr.* **2011**, *20*, 217–224.
13. Nielsen, T.R. Simple tool to evaluate energy demand and indoor environment in the early stages of building design. *Sol. Energy* **2005**, *78*, 73–83.
14. Petersen, S.; Svendsen, S. Method and simulation program informed decisions in the early stages of building design. *Energ. Build.* **2010**, *42*, 1113–1119.
15. Yao, J. A Multi-Objective (Energy, Economic and Environmental Performance) Life Cycle Analysis for Better Building Design. *Sustainability* **2014**, *6*, 602–614.
16. Essig, N.; Eberl, S.; Beck, T. OPEN HOUSE–An European methodology for assessing the sustainability of buildings. Available online: http://www.sciforum.net/conference/wsf/paper/676/download/pdf (accessed on 13 March 2014).

17. BREEAM New Construction. Technical Manual SD5073, 2011. Available online: http://www.breeam.org/breeamGeneralPrint/breeam_non_dom_manual_3_0.pdf (accessed on 22 November 2013).
18. LEED v4 BD+C: New Construction, 2013. Available online: http://www.usgbc.org/credits/new-construction/v4 (accessed on 22 November 2013).
19. DGNB System für Gebäude, 2014. Available online: http://www.dgnb-system.de/de/system/kriterien (accessed on 15 April 2014).
20. CASBEE for New Construction (2010 edition)-Technical Manual. Available online: http://www.ibec.or.jp/CASBEE/english/download/CASBEE-NC_2010manual.pdf (accessed on 22 November 2013).
21. HQE. Assessment Scheme for the Environmental Performance of Buildings–"Non-residential buildings"–Version 07 June 2012. Available online: http://www.certivea.fr/home (accessed on 13 September 2013).
22. SBTool 2012. Available online: http://www.iisbe.org/sbtool-2012 (accessed on 22 November 2013).
23. Krídlová Burdová, E.; Vilčeková, S. Building Environmental Assessment of Construction and Building Materials. *J. Front. Constr. Eng.* **2012**, *1*, 1–7.
24. TQB Bewertung. Available online: http://www.oegnb.net/de/tqb.htm (accessed on 7 January 2014).
25. OPEN HOUSE. D1.5 Baseline model and assessment methodology, 2011. Available online: http://www.openhouse-fp7.eu/assets/files/D1.5_Baseline_model_and_assessment_methodology.pdf (accessed on 7 January 2014).
26. ENERBUILD-ENERgy Efficiency and Renewable Energies in the BUILDing Sector, Annex 1: Description of the Tool in German, Italian and French, 2012. Available online: http://www.enerbuild.eu (accessed on 23 November 2013).
27. Sustainability of Construction Works–Assessment of buildings, EN 15643-2. -3, -4, CEN–European Committee for Standardization, 2010.
28. Sustainability in building construction–Sustainability indicators: Framework for the development of indicators and a core set of indicators for buildings, ISO 21929-1, ISO–International Organization for Standardization, 2011.
29. Kleist, T.; Dorßt, T. Der DGNB Auditierungsprozess, Consense 2010–Internationaler Kongress für nachhaltiges Bauen, 2010, Available online: http://www.dgnb-international.com/fileadmin/consense/Vortraege_2010/Workshops_100622/ThomasKleist_DerDGNBAuditierungsprozess_Consense2010.pdf (accessed on 13 March 2014).
30. Birgisdottir, H.; Hansen, K. Test of BREEAM, DGNB, HQE and LEED on two Danish office buildings. In Proceedings of the World Sustainable Building Conference, Helsinki, Finland, 18–21 October 2011.
31. Lupišek, A. Multi-Criteria Assessment of Buildings in Context of Sustainable Buildings. Ph.D. Thesis, Czech Technical University, Prague, Czech Republic, 2011.
32. Seinre, E.; Kurnitski, J.; Voll, H. Building sustainability objective assessment in Estonian context and a comparative evaluation with LEED and BREEAM. *Build. Environ.* **2014**, *82*, 110–120.
33. Markelj, J.; Kitek Kuzman, M.; Zbašnik-Senegačnik, M. A review of building sustainability assessment methods. *Archit. Res.* **2013**, *1*, 22–31.

34. Berardi, U. Sustainability Assessment in the Construction Sector: Rating Systems and Rated Buildings. *Sustain. Dev.* **2012**, *20*, 411–424.
35. Singh, R.K.; Murty, H.R.; Gupta, S.K.; Dikshit, A.K. An overview of sustainability assessment methodologies. *Ecol. Indic.* **2009**, *9*, 189–212.
36. Chang, K.-F.; Chiang, C.-M.; Chou, P.-C. Adapting aspects of GBTool 2005—Searching for suitability in Taiwan. *Build. Environ.* **2007**, *42*, 310–316.
37. AlWaer, H.; Sibley, M.; Lewis, J. Different Stakeholder Perceptions of Sustainability Assessment. *Archit. Sci. Rev.* **2008**, *51*, 48–59.
38. Ali, H.H.; Al Nsairat, S.F. Developing a green building assessment tool for developing countries—Case of Jordan. *Build. Environ.* **2009**, *44*, 1053–1064.
39. Bhatt, R.; Macwan, J. Global Weights of Parameters for Sustainable Buildings from Consultants' Perspectives in Indian Context. *J. Archit. Eng.* **2012**, *18*, 233–242.
40. Wong, J.K.W.; Li, H. Application of the analytic hierarchy process (AHP) in multi-criteria analysis of the selection of intelligent building systems. *Build. Environ.* **2008**, *43*, 108–125.
41. Pons, O.; Aguado, A. Integrated value model for sustainable assessment applied to technologies used to build schools in Catalonia, Spain. *Build. Environ.* **2012**, *53*, 49–58.
42. Chandratilake, S.R.; Dias, W.P.S. Sustainability rating systems for buildings: Comparisons and correlations. *Energy* **2013**, *59*, 22–28.
43. Saaty, T.; Vargas, L. *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process*, 2nd ed.; Springer: New York, NY, USA, 1980.
44. Grošelj, P. Group methods in analytic hierarchy process and their application to the management of protected area Pohorje. Ph.D. Thesis, University of Ljubljana, Biotechnical Faculty, Ljubljana, Slovenia, 2013.
45. Aczel, J.; Saaty, T. Procedures for synthesizing ratio judgments. *J. Math. Psychol.* **1983**, *27*, 93–102.
46. Goepel, K.D. Implementing the Analytic Hierarchy Process as a Standard Method for Multi-Criteria Decision Making In Corporate Enterprises–A New AHP Excel Template with Multiple Inputs. In Proceedings of the International Symposium on the Analytic Hierarchy Process 2013, Kuala Lumpur, Malaysia, 23–26 June 2013.
47. EC 2010. Nature 2000 Area Calculation. Available online: http://ec.europa.eu/environment/nature/natura2000/db_gis/index_en.htm (accessed on 14 October 2014).
48. Hlad, B.; Skoberne, P. Pregled stanja biotske raznovrstnosti in krajinske pestrosti v Sloveniji (In Slovene), MOP ARSO, Ljubljana, Slovenia. Available online: http://www.arso.gov.si/narava/poro%C4%8Dila%20in%20publikacije/ (Stanje biotske raznovrstnosti) (accessed on 14 October 2014).
49. Velux Daylight Visualizer, 2011. Available online: http://viz.velux.com (accessed on 10 May 2014).
50. Multi-Comfort House Designer, 2013. Available online: http://www.isover-construction.com (accessed on 10 May 2014).
51. Directive 2010/31/EU of 19 May 2010 on the energy performance of buildings (recast). Available online: http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32010L0031 (accessed on 25 August 2014).

52. Pravilnik o metodologiji izdelave in izdaji energetskih izkaznic stavb (in Slovene). *Ur. l. RS 77/2009*. Available online: http://www.uradni-list.si/1/objava.jsp?urlid=200977&stevilka=3362 (accessed on 25 August 2014).
53. IPCC. Climate change 2014. Synthesis Report. 2014. Available online: http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_SPM.pdf (accessed on 15 November 2014).
54. Georgiadou, M.C.; Hacking, T.; Guthrie, P. A conceptual framework for future-proofing the energy performance of buildings. *Energ. Pol.* **2012**, *47*, 145–155.
55. Mu, W.; Yu, F.; Xie, Y.; Liu, J.; Li, C.; Zhao, N. The Copula Function-Based Probability Characteristics Analysis on Seasonal Drought & Flood Combination Events on the North China Plain. *Atmosphere* **2014**, *5*, 847–869.