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Methodology for environmental assessment in Antarctic buildings

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1. Introduction

Antarctica, known as the most remote, coldest, windiest, driest, highest, most desert and least inhabited land, presents some of the worst conditions of habitability on the planet, and stands out for its environmental vulnerability and scientific importance (Alvarez, 2014).

It is known that the Antarctic continent is the site of scientific research, whose results have global implications (Dodds et al., 2017). Researches in the areas of the marine environment, environmental and climate changes and forecasts, and soil investigations that may lead to significant pharmacological discoveries (Dodds et al., 2017) are examples of the above mentioned. It is worth remembering that the inhospitable conditions, environmental fragility, and isolation will further encourage the research in the area of construction. These studies generally rely on the continued human presence on the site and require that the environment remains without interference that could endanger the fragile Antarctic ecosystem (Alvarez, 2014). Thus, it is extremely important to achieve a balance between the interests that attract humans to Antarctica and the impacts that may be caused by the human presence there (Bargagli, 2005).

Currently, there are few areas on the planet that have not yet been altered by humans - called inviolate areas - which, in addition to being rare, are valuable to the scientific world (Hughes et al., 2011).

Therefore, in accordance with the scientific importance and the desire to preserve the continent, 29 countries signed the Protocol on Environmental Protection to the Antarctic Treaty. This document is used as a reference and leads the participant countries to conduct Environmental Impact Assessments (EIA) for all Antarctic activities and to prioritize environmental discussions, treating, among other aspects, the prohibition of mineral resource activities, and declaring the Antarctica as a scientific territory with strict environmental protection legislation (Secretariat of the Antarctic Treaty. SAT, 2016a, 2016b).

Besides the Protocol, the Antarctic Treaty Consultative Meeting's (ATCM) have also established guidelines and resolutions to effectively assess the environmental impacts. In these documents, in particular on the Resolution 1 named “Guidelines for Environmental Impact Assessment in Antarctica”, the ATCM suggested a method to analyze impacts by identifying environmental aspects: nature, extent, intensity, duration, significance and effect of the impact (Secretariat of the Antarctic Treaty. SAT, 2016a, 2016b). Noting that most of the environmental assessments conducted in accordance with the Protocol, annexes or resolutions, assess only the mandatory issues or the main impact factors and sources.

Considering that Antarctica is an area of environmental protection, all impacts at any level on the environment must be foreseen, and those documents should present strategies to avoid them. Despite being legally protected by the Protocol, among other legislations, the growing number of buildings and individuals interested in the continent (i.e. tourists and researchers) increases the threats to the ecological integrity and vulnerability of protected areas (Shaw et al., 2014). The content of the Environment Protocol mentions a guarantee of the implementation of constructions with adequate solutions to minimize environmental impacts. As yet, there are no effective guidelines for the development of sustainable projects for new scientific stations, containing generic recommendations, and little or no input in the design process (Montarroyos et al., 2015). Thus, each nation has been free to set its own assessment criteria and priorities.

Antarctica is an inhabited area of interest and environmental protection, there are no regulatory instruments directed for sustainable practices in the construction guidelines for the planning and execution in low environmental impact. The combination of strict environmental protection and high scientific value of the Antarctic territory imply more effectiveness in the project planning and execution of constructions. In many countries, the assessment tools are considered active instruments for the production of sustainable buildings. The tools can measure levels of sustainability promoting improvements in the building performance and in the user's life quality, and reducing costs and environmental impacts (Ali and Al Nsairat, 2009). Given the specific conditions of each region in which a building is located, most tools have been structured for specific locations and cannot be reproduced in other settings (Alyami and Rezgui, 2012). The tools comprise numerous indicators that are adapted to the characteristics of the assessed location, and their combination with their corresponding weights is one of the adopted strategies for conducting site-specific assessments.

Recognizing that the use of assessment tools by a number of countries has contributed to more sustainable buildings (Kibert, 2012), and that there are no specific assessment tools for the Antarctic context, indicators for the assessment of environmental issues can assist in the

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planning and construction of buildings aimed at eliminating or mitigating the negative effects of human occupation on the continent.

In Antarctica, the factors that interfere with the design process of infrastructures include: area covered by ice; water in a solid state; extremely low temperatures; low precipitation rate; low level of absolute humidity; long periods of absence of sunlight; strong winds; energy originating from fossil fuels; flora and fauna sensitive to human interventions; high radiation rate; absence of local materials, trained workers and equipment; geographic distance from other continents; reliance on logistics systems; environmental susceptibility to waste disposal; climatic variations; absence of monetary system; and sensitivity to emissions of harmful substances (Montarroyos et al., 2015).

In accordance with the atypical characteristics of the place, these factors can contribute to set relevant sustainability indicators and their weights for developing projects. Knowing that this site requires the application of concepts that differ from those traditionally adopted in urban areas underlines the need for a more effective implementation.

Note that the sustainability indicators appropriate to highly populated urban centers do not apply to areas of environmental interest. Certain aspects of great importance to the “Land of Superlatives” may be negligible in urban areas; the reverse situation may also occur.

The development of assessment tools specifically focused on the Antarctic context may allow the improvement of existing buildings, stimulate the precautionary principle in natural resource management, as well as induce preventive measures related to the production and destination of waste, the protection of soil, water, atmosphere and species affected by human occupation.

Moreover, the proposal of an assessment methodology, considering specific indicators and weights for Antarctica, can contribute to abide by the current international protocols. Furthermore, these indicators serve as an instrument for the development of design guidelines for the construction of environmentally-responsible buildings. Hence, the presented research aims at proposing an environmental assessment methodology for planning and project phases of Antarctic scientific stations.

2. Methodology

According to Andrade and Bragança (2016), for the development or adaptation of a sustainability assessment method of the built environment, the process starts from the recognition of the specific characteristics of the place or region, and such information is generally used in all stages, from the selection of the indicators until the definition of the weights of each one.

It is worth mentioning that the assessment tools are composed of categories, criteria, and indicators that seek to align with the issues inherent to the global concept of sustainability, respecting the local characteristics (Mateus and Bragança, 2011). However, there is no consensus in the meaning of the nomenclatures used in the several assessment methods and tools (Wallhagen et al., 2013). So, for the present work, the meanings are adopted according to the ones presented in Table 1.

To achieve the aimed results, authors organized this study according to the following steps: 1) Establishment of environmental indicators for construction of new scientific stations; 2) Verification of the relevance of each indicator; 3) Weighting from the Environment Protocol viewpoint; and 4) Definition of weights.

Table 1
Nomenclature and definitions.

Nomenclature	Definition	Example
Category	Set or combination of indicators	Water
Criteria	Performance required for the achievement of a goal	Water use in building systems
Indicator	Variables that condense the relevant information for evaluations. It allows quantifying and evaluating compliance with the associated criteria.	Use of water-saving equipment and/or use of rainwater storage systems

2.1. Step 1 – Defining environmental indicators

The initial research had as objective the bibliographical review for the contextualization of the Antarctic environment. The review includes the Protocol, resolutions, EIAs, ATCM documents, article, thesis and dissertations, from 1991 until 2018, related to Antarctica environment, sustainable buildings and environmental impacts of the construction activities in Antarctica. The review contributed to the definition of adjusted indicators to the continent for the construction of scientific stations, through the survey of environmental restrictions, in addition to the limiting factors and potential of Antarctica and, afterwards, the insertion of data in the analytical structure Pressure-State-Response (PSR). The PSR structure is characterized by a dynamic analysis in which the cause, the effect, and the possible mitigating or compensatory measures can be identified for a given situation. It can be adapted and, given the flexibility that it presents, this analytical structure has undergone changes, such as the Driving force-State-Response (DSR) and the Driving force-Pressure-State-Impact-Response (DPSIR), to be used for many other purposes (Organization for Economic Cooperation and Development. OECD, 2003).

Therefore, for the use of the PSR in this research, it was necessary to make an adjustment on the incompatibility of the structure with the specificities inherent in Antarctica. The adequacy of the analytical structure was accomplished through the adaptation of the Pressure and of the State usual conditions, as they do not represent the reality of a preservation area, in which its fragility does not allow environmental pressures or changes in the environment state throughout the construction activities, use and disassemble of buildings. Thus, the analytical framework was adapted and the analysis elements considered were State-Pressure-Response or SPR.

The SPR analytical framework represents a cycle that describes the pressures caused by the construction activities and possible solutions. The process of analysis of the response elements of the analytical framework also contributes to enriching the data, as it enables new solutions and techniques to be proposed; thus, this framework exhibits potential temporary adequacy.

The State generates one or more responses that could also function as an indicator for the design guidelines for Antarctic buildings, as exemplified in Table 2. The answers generated the indicators named as List 1.

In parallel to List 1 of SPR indicators, a review of selected sustainability indicators from the Sustainable Building Tool (SBTool) was carried out. SBTool was chosen as the main source of indicators because it is worldwide recognized as the first assessment method and global tool specially developed to be adapted in other regions (Andrade and Bragança, 2016).

SBTool covers a wide range of issues and more than 100 criteria. The system allows third parties to modify as desired and change weighting parameters according to specific context factors. For that matter, the basis of the SBTool weighting system presents pre-set values related to extend, duration and intensity of the potential effect. An authorized user can change those values up or down to 10% to adapt the tool for local context (Larsson and Bragança, 2012).

In this methodology, SBTool was used to provide Antarctica-specific indicators. Considering the broadness of the SBTool framework for the identification of the indicators compatible to the Antarctic context, the selection of indicators was made taking into account the prerequisites of adaptability and vulnerability as follows:

1) Adaptability, ability of an indicator to change according to Antarctica's reality; and 2) Sensitivity to changes, given the importance of building adaptability over the years in environmentally vulnerable

Table 2
SPR analytical structure adapted from PSR.

Typology	Original definition (directly related to environmental issues)	Study-adjusted definition (directly related to the built environment)	Example
S - State	Characterized by physical, biological, or chemical states of the environment resulting from environmental pressures	Characterized by the state of the environment, environmental conditions, and the physical, chemical, biological, or geographic events that limit the construction of buildings in Antarctica	Wind speed
P - Pressure	Describes the environmental pressures caused by human actions	Describes the possible pressure that the state of the Antarctic environment can cause on buildings and users and the possible pressure that buildings can cause on the environment	Accumulation of snow on the building facade that blocks the flow of the prevailing wind
R - Response	Responses to proposed design decisions that help to eliminate or mitigate the effect that can be caused by construction	Responses to proposed design decisions that help to eliminate the pressure caused by buildings	Design of aerodynamic shapes that enable the free flow of wind and prevent the accumulation of snow and ice

Reference (Montarroyos et al., 2015)

and sensitive areas (Protocol's scope of duration and intensity).

This selection allowed the indicators used in urban areas to be adapted to the Antarctic reality, resulting in the indicators of List 2.

After the creation of Lists 1 and 2, a separate analysis of each predefined list was performed to identify similarities and differences. The indicators were organized based on the three basic dimensions of sustainability – environmental, social, and economic –, and categorized into topics and subtopics according to the SBTool framework. The arrangement of these two lists allowed the definition and formulation of the indicators adapted to Antarctic context.

2.2. Step 2 – Relevance verification

Considering the need to evaluate if the indicators proposed would be understood and useful to architects and engineers when planning and constructing sustainable buildings in Antarctica, a survey was sent to Antarctica's researchers (9 architects, 4 engineers and 1 Logistics manager) to check the relevance of each indicator for future definition of weights.

It is important to note that the number of top-level professionals linked to the development of projects for buildings in Antarctica available to participate in this research is small, however, all of them answered the survey.

The selection of the respondents was made considering those who effectively work or have worked in Antarctica and that, somehow, have had contact with activities related to research in Antarctic research stations.

Respondents should rate the level of importance or Indicator Score (IS) for each indicator using a scale of 0 to 3: 0 - irrelevant; 1- not very relevant; 2 - relevant; and 3 -very relevant. In case of not understanding the meaning of the indicator, an alternative answer of "not understood" was proposed, as well as an open field for description of contributions and suggestions. In addition, the answers from the respondents that indicated "not understood" were excluded.

For the individual weighting, indicators of greater and minor relevance were assessed through the weighted average and the higher frequency of the scores. For a general analysis, the relevance values assigned by researchers were inserted in an organizational structure. It was possible to distinguish, by categories and criteria, indicators with higher percentages of "great relevance", "minor relevance" and/or "not clear". Furthermore, in order to get the weighted averages of each item, such data were represented in this research as values of the Relevance of the Indicator (RI) and Relevance of the Category (RC).

Having the data, the index RI was obtained through the sum of the Indicators Score divided by the Number of Researchers (NR) who understood each indicator, as shown in Eq. (1).

$$\mathrm{RI} = \frac{\Sigma IS}{QNR} \tag{1}$$

The Relevance of the Category (RC) is the ratio of the averages produced by indicators that make up the categories divided by the number of indicators in each category, as shown in Eq. (2).

$$RC = \frac{\Sigma RI}{QNI} \tag{2}$$

RI = Relevance of the Indicator.

QNI = number of indicators in each category.

Thus, in this preliminary step, the evaluation scores given by 14 respondents served as the basis for the exclusion of irrelevant indicators and the calculation of the coefficients of the Relevance of the Indicator (RI) and the Relevance of the Category (RC).

2.3. Step 3 – Weight from the protocol on environmental protection viewpoint

The first concerns about the negative impacts of human activities on the Antarctic environment and ecosystems were expressed by the Antarctic Treaty in 1961. However, only in the Protocol on Environmental Protection, agreed by the participating nations in 1991, an attempt to control and manage the activities on the continent was made, with special emphasis on possible environmental impacts. In the protocol, the ATCM agreed to provide guidelines, among other documents, to assist the parties in assessing environmental impacts in Antarctica (Secretariat of the Antarctic Treaty. SAT, 2016a, 2016b).

As a result, this step 3 has included the assessment and identification of the environmental impacts of the construction activities according to the Protocol on Environmental Protection to the Antarctic Treaty. The Protocol requires that the human activities in the Antarctic Treaty area should be organized and carried out in such a way as to avoid the following: negative effects on climate or climate patterns; significant negative effects on air or water quality; significant changes in the atmospheric, terrestrial, glacial and marine environments; harmful changes to the distribution, quantity or reproductive capacity of species or populations of animal and plant species; the additional risks for endangered or threatened species or populations of animal and plant species; and the degradation or serious risk of degradation of areas with special biological, scientific, historical, aesthetic or natural significance (Secretariat of the Antarctic Treaty. SAT, 1991).

Besides the Environment Protocol, the Resolution 1 also states that during the planning and conduct of Antarctic activities the nature, extent, duration, intensity and the possible areas of impacts of these activities on the ecosystem are made explicit, informing the influence of each activity on the climate, air quality, soil, water and local species. In addition, these documents require effort to predict the effect and significance of the impact (Secretariat of the Antarctic Treaty. SAT, 2016a, 2016b).

In agreement with the content of the Protocol and Resolution 1, to adapt the framework to local context, SBTool also establishes pre-set values based on nature, extend, duration and intensity. Considering future adaptation of SBTool to Antarctica, the proposed methodology focus on the requirements by evaluating the influence of each activity on the environment and predicting all effects and significance of the

Table 3
Direct and Indirect Impact Area.

Values	Classification	Explanation	Example of impact
1,0	Direct impact	The non-attendance of an indicator may cause interference in environmental values	The non-existence of liquid waste treatment systems can cause water pollution
0,5	Indirect impact	The non-attendance of an indicator may cause secondary reactions in relation to the initial interference.	The water pollution can cause decrease in marine population

indicators evaluated in the previous step. In order to quantify the data, as well as provide weights to the indicators, the variables Impact Area (IA) and Impact Degree (ID) were used.

The Impact Areas (IA) represent the effect of the impact on the environment (climate, air, ground, water and ecosystem). The IA is subdivided into two categories: direct impact and indirect impact. It is understood as area of direct impact the area where the relation of cause and effect is direct, that is to say, it is the territorial portion directly affected by the action that caused the interference in the environment. The indirect impact area is the one that is affected by a secondary reaction in relation to the initial action causing the impact (Glasson et al., 2012). For the weighting process, one point was assigned for each Direct Impact Area and half a point for each Indirect Impact Area (Table 3).

It should be noted that the primary system of SBTool assigns one point for each directly affected area, thus obtaining a scale of one to five (Larsson, 2015). For this research, it was decided to maintain the same system of SBTool, adding the values of indirect impacts in order to consider the additional effects on the established areas. To do so, half the value of the direct impacts was assigned to the indirect impacts. Each indicator obtained a scale between 0 (does not interfere in any area) to 5 (directly interferes in all the impact areas).

The Impact Degree (ID) establishes a classification of the indicator as to the significance of the impact. According to the Environment Protocol and Resolution 1, this can be defined as: i) less than a minor or transitory impact; ii) minor or transitory impact; or iii) more than a minor or transitory impact. For the quantification of the Level of Impact, values from 1 to 2 were assigned to the Impact Degree, as shown in Table 4.

Thus, to obtain the Level of Impact (LI) of an indicator in the Antarctic environment, the Impact Area (IA) and the Impact Degree (ID) were multiplied.

The multiplication followed the same principle of the SBTool weighting system where, in order to obtain the weights of each indicator, the values related to intensity, duration and extension are multiplied (Larsson, 2015).

In this work, the values of the Impact Area and the Impact Degree were defined so that the product or resulting Level of Impact was represented in a scale of 1 to 10. Therefore, according to the above explained, a score equal to 1 for the Level of Impact means that neglecting an indicator may present minor or transitory impact on just one area of impact. A score equal to 10 for the Level of Impact means that neglecting such indicator can cause more than a minor or transitory impact in all the 5 areas established by the Protocol (climate, air quality, soil, water and local species), which can cause harmful alterations to the natural Antarctic environment.

2.4. Step 4 – Weight definition

In accordance with Lee and Burnett (2006) and Bissoli et al. (2016), the establishment of weights and weighting systems for sustainability assessment tools is carried out through structured surveys or detailed analysis of public policies such as Agenda 21.

Based on this information, the levels of relevance of each item of the tools are verified and weights are considered compatible with the significance of each question. The relevance levels of each item are verified, e.g. SBTool, and weights consistent with the significance of each issue are established. The weighting systems are usually supported by the information obtained during the formulation process of the method. To quantify the relevance of each item mathematical expressions, equations, and algorithms are used.

To define the weights in this work, the values of the Level of Impact (LI), as well as the relevant coefficients obtained in the previous step, were inserted in Eq. (3), based on the principles established by Shamseldin (2016).

$$WI = \frac{LI}{RI} x\ RC \tag{3}$$

Where:

WI = Weights of indicators.
LI = Level of Impact.
RI = Relevance of the Indicator.
RC = Relevance of the Category.

The results obtained for the weights of the indicators were analyzed and compared with the importance given to the environmental issues discussed in the reports of the scientific stations built in Antarctica. These reports, available on the official website of the Secretariat of the Antarctic Treaty, aim at disseminating the available information about construction activities in Antarctica and establish a collaborative platform for the environmental protection knowledge development (Secretariat of the Antarctic Treaty. SAT, 2016a, 2016b).

The content of those reports contributed to analyze the compatibility between the results obtained and the main concerns about the environmental impacts caused by buildings, from the point of view of different Nations.

3. Results

The methodological steps previously defined allowed to obtain indicators and the definition of their respective weights adjusted to the

Table 4
Grading of the Impact Degree (ID).

Values	Classification	Explanation
1	Less than a minor or transitory impact	Impact of shorter duration, in which its execution or repetition does not entail changes in the natural configuration and no mitigating measures, repairs or evaluations are necessary.
1,5	Minor or transitory impact	Impact of short duration that does not change the natural configuration of the environment. In this case, there may be mitigating measures, but there are no requirements for recovery and/or evaluation measures.
2	More than a minor or transitory impact	Impact of short or long duration that changes the natural configuration of the environment and/or violates international agreements. Consequently, there is a requirement for recovery, assessment and/or repair measures.

Reference Secretariat of the Antarctic Treaty. SAT (2016a, b).

Antarctic reality. To this end, the results are organized and presented in following steps: 1) definition of the list of environmental indicators; 2) verification of indicators; 3) weights from the Environment Protocol viewpoint; and 4) definition of proposed weights and comparison.

3.1. Definition of the list of environmental indicators

An assessment procedure is based on indicators and benchmarks, hence derived from a process in which the main factors are identified and weighed (Bragança et al., 2010). In other words, for the definition of criteria and indicators, local issues that influence the process of construction and the possible impacts that these constructions may have on the environment are raised.

In the context of Antarctica, the main constraints that influence the construction process of buildings are: solid state water; very low temperatures; low precipitation index; low absolute humidity content; long periods of absence of sunlight or solar radiation; strong winds; energy from fossil fuels; fauna and flora vulnerable to human intrusion; absence of local raw materials; difficulty of skilled labor; absence or deficiency of support equipment for buildings and maintenance; geographical distance from other continents; dependence on logistics systems; environmentally protected site; environmental vulnerability to waste disposal; rapid weather variations; and vulnerability to emissions of harmful substances. In addition, aspects that emerge as difficult to measure and that do not cause pollution or generate waste, but have an aggregate environmental value, such as the landscape and the soundscape should also be considered.

In possession of the factors that impact on the construction process of buildings in Antarctica, their insertion in the SPR framework resulted in a list of answers and guidelines, which have contributed to the formulation of indicators in accordance with the specificity of the Antarctic environment (List 1). Arranging them according to categories, the indicators related to environmental impacts inherent to the materials presented a significant number. Considering that the indicators are the responses to the pressures caused by environmental restrictions, the organizational framework allows to conclude that pressure caused by materials are the issues of higher pressure in the process of construction of buildings.

The analytical framework SPR represents a cycle of understanding of the pressures caused by constraints in the construction and the reflection about possible solutions. By analyzing the local issues of greater influence in the buildings, it came out that the aspects related to logistical difficulties and the aggressiveness of the Antarctica environment resulted in a larger number of indicators.

In parallel with the SPR framework, the List 2 established the selection of indicators present in the SBTool assessment tool relevant to the design and construction in Antarctica. The prerequisites of adaptability and vulnerability to changes led to the identification of 37 indicators that could contribute as environmental guidelines for buildings in Antarctica. The grouping of two lists, with the exclusion of similar indicators, resulted in a set of 57 environmental indicators (Table 5).

The observed divergence between the indicators coming out from the SPR framework and the indicators established in the assessment tools is in line with the theoretical assumption that justifies the development of this research. Environment assessment methods are essentially targeted at buildings inserted in an urban context, with less stringent environmental restrictions, in addition to infrastructure, resources and systems available.

Therefore, due to the completely distinct situation, it was expected that the indicators related to environmental vulnerability in Antarctica would not be fully represented by SBTool, requiring a specific methodology for the environmental assessment of buildings on the continent.

An analysis of the categories listed in Table 5 shows that the category "Relationships between building and surroundings" in Antarctica include indicators especially related to the susceptibility of the site, with measures which are, mostly, to avoid interference in soil and biodiversity as well as encouraging the deployment of building in areas of less ecological value, or non-virgins.

Table 5
Number of environmental indicators resulting from the combination of List 1 and List 2.

Dimension	Category	Number of indicators		
		List 1	List 2	Final List
Environmental	Interactions between the building and its surroundings	8	3	9
	Water	6	3	6
	Energy	5	5	7
	Materials	12	15	21
	Waste	6	6	7
	Environmental Loads	2	7	7
Total		40	37	57

As for the categories "Water" and "Energy", although in Antarctica, of course there are no public water supply systems or energy – water is obtained from water bodies or thaw and energy from generators or batteries – there is the same concern in Antarctica and in traditional urban areas in relation to the optimization and efficiency of systems with strategies to minimize the impacts of water and energy consumption.

In the "Materials" category, most of the indicators intended to minimize the effect of the environmental restrictions on Antarctic buildings. Thus, the demand for more sustainable materials influences not only the environment but also the durability and performance of the building.

The indicators of "Waste" and "Environmental Loads" provide specific strategies for Antarctica, where the deposition of waste and emissions of pollutants can assume great proportions, undermining the environmental balance and the scientific research that have been carried out on the continent.

The final ratio of proposed indicators has undergone the validation process for verification of relevance and feasibility through consultations and interviews with professionals linked to construction activities in Antarctica.

3.2. Verification of indicators

The development of an assessment tool necessarily takes into consideration the assessment and verification of the proposals by experts and professionals whose field of expertise is the effects and impacts of construction in the area where it is built. These professionals, in addition to being responsible for identifying the degree of significance of each item (Fekry et al., 2014), contribute to the development of instruments for the evaluation of a building, verification of indicators and may also add specific knowledge, desirable for obtaining better results.

The participation of the experts contributed to the achievement and corroboration of the final list with 57 environmental indicators. It is worth mentioning that one of the main results was the definition of the relevant indexes of categories Relevance of Categories (RC) and the Relevance of Indicators (RI).

According to the results of the collaboration from the experts about the RC values (Fig. 1), the category "Waste" obtained greater relevance indexes (average of 2.78) followed by the categories "Energy", "Relationships between building and surroundings" and "Environmental Loads" (averages of 2.74, 2.69 and 2.66, respectively), while the lowest rates were registered in the categories Materials (2.46) and Water (2.45).

Regarding the results of the RI (Fig. 2), within the category "Waste", the following indicators stand out: 45 "Generation of non-organic solid waste in step of use/operation" and 50 "Security for storage of hazardous wastes". Still, another environmental indicator that had high RI was the number 8, "Measures to isolate areas with pollution potential",

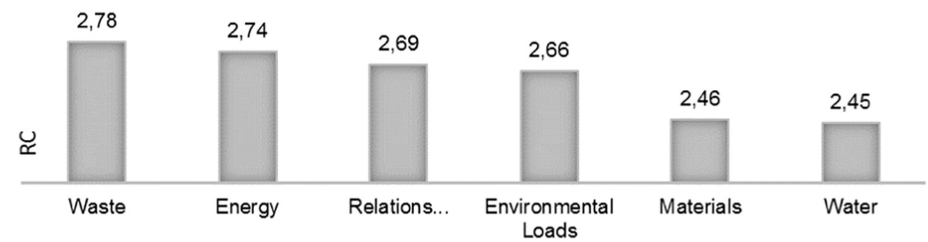

Fig. 1. Relevance of the Category values (RC).

also directly related to the contamination of the Antarctic environment. The highest score for "Energy" category was for the indicator 20 "Energy efficiency determined by envelopment" (Fig. 2).

With these results, it can be concluded that the researchers considered the construction waste the biggest factor of concern with respect to the sustainability of Antarctica.

Regarding the indicators with the highest rate of rejection by researchers, the following indicators stand out: number 10 "Presence of water in liquid form"; number 15 "Use of black water reuse systems"; number 32 "Use of reused material or recycled items from existing buildings"; and number 35 "Amount of drinking water consumed in production stage".

The rate of the indicator number 10 is due to the abundant presence of potable water on the continent and because most of the consulted experts have their experience with buildings along the coast, where the presence of water in liquid form is more abundant. The rejection rate of indicator 32 is due to the small number of buildings available for reuse of recycling, and the indicator 35 for the reason that there is no production of materials or systems in Antarctica.

On the subject of the indicator number 15, the Environment Protocol provides rules for disposal of waste in Antarctica (Annex III to the Protocol in article 5). In this matter, this rejection could be related to the duplication of a mandatory article.

3.3. Weight of categories from the environment protocol viewpoint

In Accordance with the Environment Protocol, this research included assessment procedures to measure the impacts of activities in Antarctica, by evaluating the interference intensity and the areas of direct or indirect impact. As a result, the value of Level of Impact (Fig. 3) demonstrated that the categories "Waste" (5.45) and "Energy" (5.28) showed the highest level of impact. The other categories with high level of impact were "Water" (4.79), "Relations between the building and the surroundings" (4.59), "Environmental Loads" (4.57) and "Materials" (3.98).

From all the indicators analyzed, the ones that have obtained the highest score were the indicator "Measures to restore or maintain the original functionality of the natural environment" and the indicator "Measures to isolate areas with pollution potential", which are indicators belonging to category "Relationships between the building and the surroundings".

It should be noted that the results of the presented method are in line with the international practices established by the Protocol, since the research was carried out based on the most recent reports of the new scientific stations provided by the Secretariat of the Antarctic Treaty, and showed that the major foreseen concerns in the planning of buildings in Antarctica are: atmospheric emissions; spillage of oil into water or soil; waste disposal; among other environmental impacts caused by human activity on the continent (see Table 6).

It is worth noting that the major concerns of the nations about the possible impacts of the construction of scientific stations are systematically in themes of waste and energy, in addition to the concerns about the preservation of the natural state of the Antarctic environment, which is completely in line with the highest scores of the impact level obtained for the categories and indicators analyzed in this work.

3.4. Definition of proposed weights and comparison of impacts

The weighting of the importance – or weight – of each indicator is a widely discussed issue in the processes of elaboration of assessment tools, either for the establishment of the hierarchical importance between categories or for indicators within the same category.

In this work, the weighting system was established based on the list of indicators adjusted to the Antarctica reality, taking into consideration the levels of relevance and the impact levels of indicators and categories. Eq. (3) was used for the quantification of the weight of each indicator, which takes into consideration the importance recognized by professionals, as well as the international recommendations concerning environmental protection of the continent.

The weighting calculation method establishes greater weight to the indicators that present higher Level of Impact (LI), which can be seen in Table 7 for the indicator "Presence of water in liquid form". It is worth observing that this indicator, at the validation step, presented one of the lowest rates of relevance for Antarctic researchers, however, it obtained the highest level of impact.

For water consumption in Antarctic buildings it is essential that the resource is available in liquid form, if there is no availability or presence of water in this state, the ice must go through the processes of collection, thawing, treatment and distribution, which usually involve the burning of fossil fuel. The lack of water in liquid form or thaw lakes

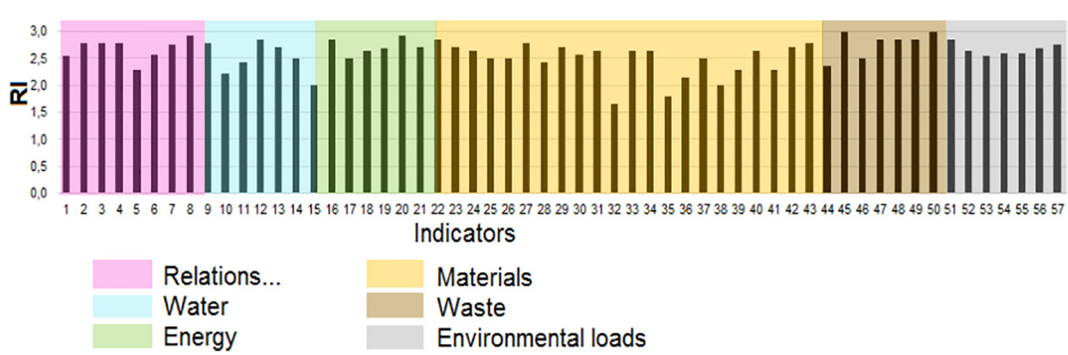

Fig. 2. Relevance of the Indicators (RI) values.

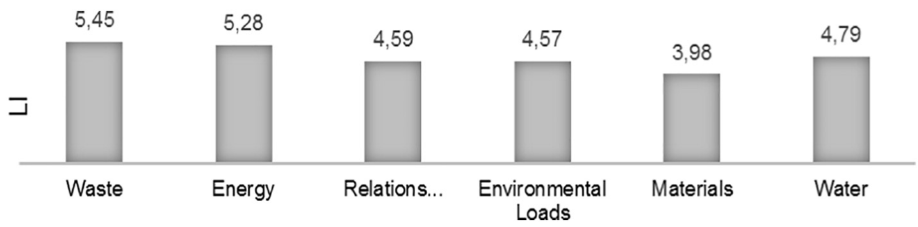

Fig. 3. Level of Impact (LI) of categories.

Table 6
Main environmental concerns of the new scientific stations in Antarctica.

Year	Scientific station	Country	Impact
2006	*New Belgian research station*	Belgian	• Atmospheric emissions • Fuel spills to snow or ice • Grey water discharge
2008	*New Chinese dome A station*	China	• Atmospheric pollutants from fuel consumption • Risks of fuel and oil spills from fuel • Discharge of hazardous and non-hazardous wastes • Wastewater • Noise from activities • Disturbance to the local ecosystem
2011	Jang Bogo	Korea	• Atmospheric emissions • Fuel spills • Discharge of hazardous and non-hazardous wastes • Wastewater • Disturbance to the local ecosystem
2013	Belarusian	Belarus	• Atmospheric emissions • Fuel spills • Discharge of hazardous and non-hazardous wastes

Reference National Academy of Sciences of Belarus (2015), Polar research Institute of China (2014), Korea Polar Research Institute (2011) and Belgian science policy (2006).

close to buildings may represent the need for greater investment in capture/thaw systems, energy cost and possible environmental impacts by the release of pollutants during the process. Therefore, it is possible that in the validation step of this indicator, there may have been some misunderstanding in the exact sense intended, being evaluated regardless of its impact on Antarctica. This example shows that the created mathematical expression allows the analysis of the impacts not considered or misunderstood by the Antarctic researchers.

The results obtained for the weights of the categories are the following: "Relationships between the building and the surroundings" 16%; "Water" 10%; "Energy" 14%; "Materials" 30%; "Waste" 18%; and "Environmental Loads" 12% (Fig. 4).

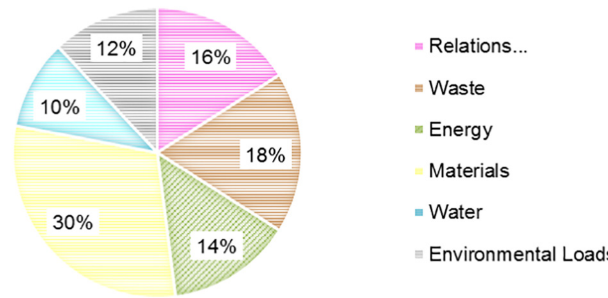

Fig. 4. Weights of categories.

Although the indicators in the "Materials" category have lower weight, this category presents a greater overall weight, guiding the designer to understand that the selection of materials in accordance with the specific conditions of the region has an important direct impact in the preservation of the environment, in addition to the integrity of the building.

In what concerns the results obtained for each indicator (Fig. 5), the indicators of the categories "Relationships between the building and the surroundings" and "Waste" achieved greater weight, while the indicators of category "Materials" achieved lower weights. As expected, the researchers showed that the greatest concern or the most important indicator in the Antarctic environment is related to the waste from the building, while the smaller importance was given to the choice of materials.

For individual analyses of those categories, the results are shown on Table 8. Table 8 presents the lowest and the highest indicator score. As expected for an area of environmental protection, the indicators "Measures to maintain or restore the original functionality of the natural environment" and "Measure to isolate areas with pollution potential" obtained the highest score.

Because of the rate of LI, the indicator from the "Materials" category "Use of vibration-resistant materials" obtained the lowest score. In this case, it is worth mentioning that the direct and indirect impact of the

Table 7
Weighting results of "Water" category.

	Indicator	RI	RC	Impact area (IA) a	b	c	d	e	ID	LI	WI
Water	Presence of liquid water	2,21	2,45		1	1	0,5	0,5	1,5	4,50	2,47
	Distance to bodies of water	2,43	2,45			1		1	1,5	3,00	1,5
	Existence of water-saving equipment	2,86	2,45				1		1,5	1,50	0,64
	Existence of systems for identification and prevention of leaks and waste	2,71	2,45			1	1	0,5	1,5	3,75	1,68
	Use of grey water reuse systems	2,50	2,45			1	1	0,5	1,5	3,75	1,82
	Use of black water reuse systems	2,00	2,45			1	1	0,5	1,5	3,75	2,27

Impact areas: a - Climate; b - Air; c - Ground; d - Water; e – Ecosystem.
RI - Relevance of the Indicator.
ID - Impact degree.
RC - Relevance of the Category.
LI - Level of Impact in a scale of 1 to 10.
IA - Impact Area.
WI - Weight of indicator expressed in percentage.

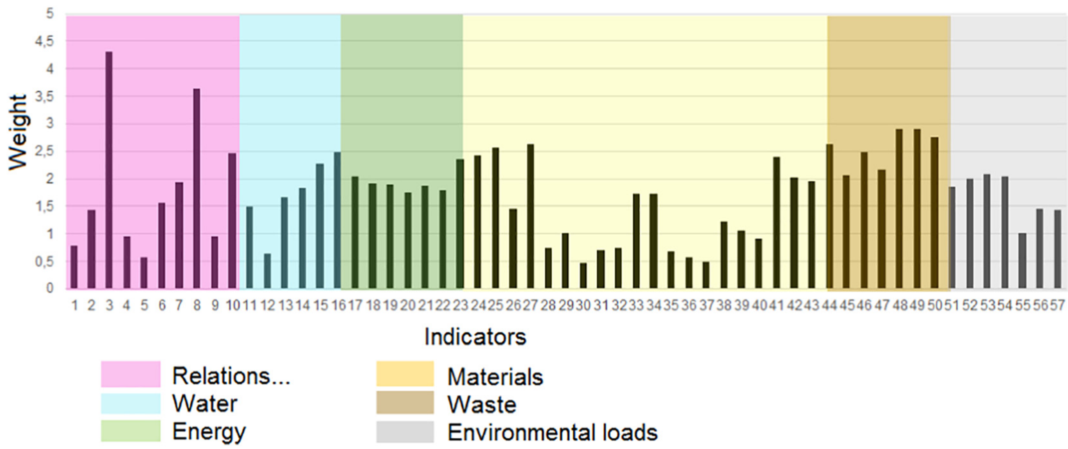

Fig. 5. Weigh of each indicator.

Table 8
Weighting results of "Relations between the building and the surroundings", "Materials" and "Waste" categories.

	Indicator	RI	RC	Impact area (IA) a	b	c	d	e	ID	LI	WI
Relations	Procedures for mitigating the sound pressure level of equipment	2,54	2,69					1	1,5	1,5	0,79
	Construction techniques without soil/ice interference	2,79	2,69			1		0,5	2	3,0	1,44
	Measures to maintain or restore the original functionality of the natural environment	2,79	2,69	0,5	1	1	1	1	2	9,0	4,31
	Level of human interference on local area	2,79	2,69			1			2	2,0	0,96
	Design in harmony with the landscape	2,29	2,69					1	1	1,0	0,58
	Aerodynamic shape	2,57	2,69			1		1	1,5	3,0	1,56
	Containment of biological materials in controlled room	2,75	2,69			1		1	2	4,0	1,94
	Measure to isolate areas with pollution potential	2,93	2,69	0,5	0,5	1	1	1	2	8,0	3,64
	Inference on fauna and/or flora	2,79	2,69					1	2	2,0	0,96
Materials	Use of materials with long life cycle and minimal maintenance requirements	2,71	2,46		1	1	1	0,5	1,5	5,3	2,36
	Measures to facilitate the replacement of parts, future demolition and/or the potential for reuse/recycling	2,64	2,46		1	1	1	0,5	1,5	5,3	2,42
	Use of flexible/adaptable building materials	2,50	2,46		1	1	1	0,5	1,5	5,3	2,56
	Use of protective packaging for transport that enable reuse/recycling	2,50	2,46			1	1	1	1	3,0	1,46
	Use of fire-resistant materials	2,79	2,46	1	1	0,5		0,5	2	6,0	2,63
	Protective measures against ultraviolet (UV) rays for materials for outdoor use	2,43	2,46			1			1,5	1,5	0,75
	Use of wind pressure-resistant materials and systems	2,71	2,46			1		0,5	1,5	2,3	1,01
	Use of vibration-resistant materials	2,57	2,46			1			1	1,0	0,48
	Protective measures against corrosion for materials for outdoor use	2,64	2,46			1			1,5	1,5	0,69
	Use of reused material or recycled items from existing buildings	1,64	2,46			1			1	1,0	0,74
	Use of modular, pre-fabricated, or fast-execution items	2,64	2,46		0,5	1	0,5	0,5	1,5	3,8	1,73
	Use of flexible/adaptable building systems	2,64	2,46		0,5	1	0,5	0,5	1,5	3,8	1,73
	Amount of drinking water consumed in production stage	1,79	2,46				1		1	1,0	0,68
	Amount of drinking water consumed in construction stage	2,14	2,46				1		1	1,0	0,57
	Amount of drinking water consumed in maintenance stage	2,50	2,46				1		1	1,0	0,49
	Amount of energy consumed in production stage	2,00	2,46	0,5	0,5	1			1	2,0	1,22
	Amount of energy consumed in construction stage	2,29	2,46	0,5	0,5	1			1	2,0	1,07
	Amount of energy consumed in maintenance stage	2,64	2,46	0,5	0,5	1			1	2,0	0,92
	Amount of toxic waste generated in production stage	2,29	2,46			1	1	1	1,5	4,5	2,4
	Amount of toxic waste generated in construction stage	2,71	2,46			1	1	1	1,5	4,5	2,02
	Amount of toxic waste generated in operation stage	2,79	2,46			1	1	1	1,5	4,5	1,97
Waste	Generation of solid, non-organic waste during construction	2,36	2,78			1	1	1	1,5	4,5	2,63
	Generation of non-organic solid waste in step of use/operation	3,00	2,78			1	1	1	1,5	4,5	2,07
	Generation of solid, non-organic waste during decommission or demolition	2,50	2,78			1	1	1	1,5	4,5	2,48
	Generation of liquid waste during use/operation	2,86	2,78			1	1	1	1,5	4,5	2,17
	Use of liquid waste treatment systems	2,86	2,78			1	1	1	2	6,0	2,89
	Implementation of facilities to store and sort solid waste	2,86	2,78			1	1	1	2	6,0	2,89
	Security for storage of hazardous wastes	3,00	2,78			1	1	1	2	6,0	2,76

Impact areas: a - Climate; b - Air; c - Ground; d - Water; e - Ecosystem.
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ID - Impact degree.
RC - Relevance of the Category.
LI - Level of Impact in a scale of 1 to 10.
IA - Impact Area.
WI - Weight of indicator expressed in percentage.

Table 9
Weighting results of “Energy” and “Environmental Loads” categories.

	Indicator	RI	RC	Impact area (IA)					ID	LI	WI
				a	b	c	d	e			
Energy	Renewable energy systems as a basis for energy buildings	2,86	2,74	0,5	1	1	0,5	0,5	1,5	5,3	2,49
	Estimated annual energy consumption per occupant in kWh/m^2 during summer	2,50	2,74	1	1	0,5			1,5	3,8	2,04
	Estimated annual energy consumption per occupant in kWh/m^2 during winter	2,64	2,74	1	1	0,5			1,5	3,8	1,93
	Estimation of energy expenditure by equipment	2,69	2,74	1	1	0,5			1,5	3,8	1,89
	Energy efficiency determined by the building envelope	2,92	2,74	1	1	0,5			1,5	3,8	1,74
	Energy efficiency determined by the heating system	2,71	2,74	1	1	0,5			1,5	3,8	1,88
	Existence of energy-saving equipment	2,86	2,74	1	1	0,5			1,5	3,8	1,78
Environmental loads	ODP emissions (kg CFC-11)	2,85	2,66	1	1				2	4,0	1,85
	CO2 emissions (Kg CO2)	2,64	2,66	1	1				2	4,0	2,00
	SO2 emissions (Kg SO2)	2,54	2,66	1	1				2	4,0	2,08
	POCP emissions (kg.C2H4)	2,58	2,66	1	1				2	4,0	2,04
	EP emissions (Kg PO4)	2,60	2,66				1		2	2,0	1,02
	Use of building systems, materials, and equipment that assurance low production of atmospheric emissions	2,69	2,66	1	1				1,5	3,0	1,47
	Actions to ensure that maintenance procedures generate minimal VOC	2,75	2,66	1	1				1,5	3,0	1,44

Impact areas: a - Climate; b - Air; c - Ground; d - Water; e – Ecosystem.
RI - Relevance of the Indicator.
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indicator is related to the user's security and sensation. Knowing that the 5 areas established by the Protocol do not include social issues, for future evaluation process of the impact area it is suggested to insert an additional impact area/issue: users.

Moreover, it should be noted that all the indicators of the category “Waste”, section of Appendix III of the Environment Protocol, obtained weights higher than 2,07. The indicators in this category aim the quantification, reduction and elimination of the waste produced, in order to minimize the potential environmental impacts in the whole area covered by the Antarctic Treaty.

Unlike the initial assessment phase, some weights of category “Energy” (Table 9) were lower when compared to the previous result, in which only the indicator “Renewable energy systems as a basis for energy buildings” obtained highest weight within the category, accounting for 2,49. In Antarctica, the main source of energy is fossil fuel brought from other continents (COMNAP, 2007). Besides the harmful usage of this energy source in a protected area and of environmental interest, it is worth emphasizing that the local exploitation of available energy– mainly wind and solar radiation, leaving fossil fuels only for emergencies – could be very helpful to reduce impacts, such as those caused by oil spills or emissions of pollutants.

However, it is worth noting that even considering the use of renewable energy in buildings, the impact caused by means of transport (terrestrial and marine) still remains, as well as the operation of any specific equipment. This highlights the concern with the continuity in the use of fossil fuels in the Antarctic region, justifying the high importance given to “Renewable energy systems as a basis for energy buildings”.

4. Conclusion

The results obtained show that the method used to obtain the weights of indicators and categories is valid and has made a great contribution to the achievement of the objectives of this research work. The specific context of Antarctica, as well as the information obtained in the Protocol on Environmental Protection to the Antarctic Treaty influenced directly the selection and definition of environmental indicators and can even be used as project guidelines for building design in the continent.

The result of this research work generated 57 environmental indicators and established their respective weights. It is important to note that the excessive number of indicators is due to the specificities of the environment in Antarctica and to the increasing world interest in how the human activities on the continent should be developed. Thus, it is understandable that the number of indicators for areas of interest for humankind and environmentally protected should be higher than the amount of indicators adopted in the assessment tools for urban areas. Further, the result of the comparison of weights provide a suitable communication to third parties, designers and decision makers that may be helpful to avoid impact of construction activities in Antarctica. Even though the research is focused on new scientific stations, the methodology suggested indicators and their weights that can be used as a reference for any building in Antarctica, regardless of the country of origin or its location on the continent.

As a contribution to science, in addition to the results obtained, the adopted methodology is flexible, suggesting the possibility of adaptation to other areas of future research or similar environmental situations assessing building sustainability.

The next steps of this research work will focus on a possible adaptation of the SBTool to Antarctica context, evaluation of weights (according to the nature, extend, duration and intensity) by the researches, the definition of methods and means for the assessment of the indicators and the definition of the respective benchmarks.

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