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Quantification of the Contribution of High-Weight Demountable Construction to the Sustainability. Case Study: Sayab

Luis De Garrido[1, 2, 3]

1. PhD Architect, PhD Computer Engineer, PhD Fine Arts, PhD Cognitive Neuroscience, PhD History of Art, PhD st Building Engineering, Universitat Politècnica de València, Spain

2. PhD st Medicine. PhD student Aerospatial Engineering, Universidad Politécnica de Madrid, Spain

3. AAA Research Center, 46022 Valencia, Spain

Abstract: This study quantifies for the first time the contribution of high-weight *demountable construction* to the sustainable level of a building using 11 of the most representative and internationally used GBRSs (*Green Building Rating Systems*). The scores of a prefabricated, high-weight demountable building (*Sayab*) were compared with those of a non-demountable building (a baseline), in both cases using 11 of the most important GBRSs. All GBRSs have found that high-weight demountable construction provides a higher level of sustainability. However, the resulting scores varied widely (from an increase of 1.4% to an increase of 22.72%), and only three GBRSs clearly valued its obvious sustainable advantages (CEDES: 22.72%, DNGB: 14.79%, SBTools: 12.4%) while the rest valued it very little, and four of them barely valued it. The results of this case study are generalizable, since the different existing GBRSs do not have the capacity to detect small changes in high-weight *demountable construction systems*. However similar studies should be carried out to confirm the results obtained and accurately quantify the contribution of demountable construction to the sustainable level of buildings.

Key words: Prefabricated systems, sustainable evaluation, high-weight demountable construction, Green Building Rating System.

1. Introduction

This paper quantifies for the first time the contribution of high-weight *demountable construction* to the level of sustainability of buildings.

High-weight *demountable construction*, usually based on reinforced concrete panels, has great environmental and economic benefits, since its components can be easily assembled and disassembled and can be removed, repaired and reused as many times as desired. In this way, their durability can be extended to the maximum, while their environmental impact over time can be reduced to the minimum, by minimal maintenance. Some studies have analyzed the general advantages of demountable buildings based on reinforced concrete panels, especially with regard to the optimization of resources, reduction of waste and emissions, reduction of energy consumption, etc. [1-9]. Previous studies also analyzed specific construction systems but using only a few sustainable indicators [10-17].

However, very few studies of the overall contribution of high-weight *demountable construction* to the sustainability of buildings are available in the literature [18, 19].

To quantify the overall level of sustainability of buildings, multivariate assessment tools, called GBRSs (*Green Building Rating Systems*) have been implemented in recent years. Sustainability is a concept that integrates several components (energy, resources, emissions, waste, etc.), so GBRS has several different indicators to evaluate these components together, and provide a

Corresponding author: Luis De Garrido, Prof. E-mail: info@luisdegarrido.com.

final score. These GBRSs have been widely used to determine the sustainable level of buildings, although there are very few studies that use any of these GBRSs to quantify the overall sustainable benefits of high-weight *demountable construction* [20, 21].

This study aims to do just that. To this end, a high-weight demountable building (*Sayab*) was evaluated alongside 11 of the most representative existing GBRSs. A non-demountable hypothetical version of the same building (*ND-Sayab*) was also evaluated as a reference baseline. By comparing both results the contribution of high-weight *demountable construction* to the buildings' sustainability was quantified.

The chosen building is representative of all high-weight *demountable construction systems*, but similar case-studies must be conducted to confirm the results obtained. However, based on their in-depth knowledge, GBRSs are unable to quantify small differences that may exist between various high-weight demountable construction systems, so the results obtained are highly generalizable.

2. Context and Objectives

The objective of this paper is to quantify the contribution of high-weight *demountable construction* to a building's sustainability.

A building built in Colombia (*Sayab*) was chosen for the study. A non-demountable version of the same building (*ND-Sayab*) was also evaluated as a reference baseline. By comparing both results the contribution of high-weight *demountable construction* to the buildings' sustainability could be quantified.

Sayab can be located anywhere where each of the chosen GBRSs is commonly used. The goal is to determine what score it would obtain when evaluated with each of them.

It should be noted that the common objection is that each GBRS has been designed for a specific environmental context and with specific socioeconomic interests, and that is why they are so different from one another. Therefore, with this study, we wish to draw attention to this issue for several reasons:

1. Each GBRS has been designed in a specific environment, but it is often used in different places. For example, LEED was designed in the USA, and within the USA, there is a huge disparity in climatic, environmental and socio-economic contexts. Does LEED work for all? If so, will it also work for similar environments found in Europe or Asia?

2. In some places, such as the UK, France, Germany, Italy, Poland, etc., several GBRSs are routinely used. Does this mean that any of them is valid?

3. After an in-depth examination of the categories, indicators, and assessment systems, it is clear that GBRSs are unable to detect small differences, so buildings with substantial differences would obtain the same score even if they have certain different characteristics. For example, the overall score would not change if a demountable house made with steel frames, containers, or wood-derived components is assessed. Therefore, the results obtained in this evaluation can be extrapolated to similar single-family houses. In fact, the authors evaluated quite different demountable buildings, and the scores were quite similar.

Therefore, by comparing the results obtained by the different GBRSs, in addition to quantifying the contribution of high-weight *demountable construction*, we also seek to reflect on the structure, merit, legitimacy, and usefulness of the different GBRSs used.

3. Comparative Evaluation Methodology and Description of the Two Buildings to Be Evaluated

To accurately quantify the contribution of high-weight *demountable construction* in the sustainable score of a building, a modular and demountable building (*Sayab*) was compared with a *baseline*: its non-demountable hypothetical version *(ND-R4Sayab)*. The evaluation will be carried out through 11 leading GBRSs, and to simplify the study, only the indicators whose scores varied from one building to another are shown in the comparison. The remaining indicators are not taken into account because they would give the same score to one building as another. Therefore, only indicators related to demountability (those whose scores vary depending on whether a building is demountable or not) have been included in the evaluation tables.

3.1 Choice of the 11 Leading GBRSs

Five guidelines were followed to select the main GBRSs for the sustainable evaluation.

- Their geographical and territorial representation;
- Number of buildings evaluated;
- Number of citations in the Scimago database;
- Number of citations in Google;
- Complete manuals and user guides are available.

Based on these guidelines, a complete list of GBRSs was compiled, and the top performers were selected. Please note that only those with an operating manual were selected. As a result, a total of 11 GBRSs were selected, which is certainly a representative number: ASGB [22], BEAM [23], BREEAM [24-27], CEDES [28, 29], DNGB [30], GBI [31], GG [32], GS [33], IGBC [34], LEED [35], and SBTool [36] (whole words of GBRS names in references). From each GBRS, the most recent and appropriate version for evaluating house buildings has been chosen.

The evaluation system for each of these 11 GBRSs is summarized below (Table 1), along with a comparison showing the different categories for each GBRS, as well as the maximum score that can be obtained in each category (Fig. 1). This gives an idea of the strengths and weaknesses of each GBRS used.

Figure 1 shows a mutual comparison based on the 14 common categories to the eleven GBRSs chosen which were identified (even if they do not have the same name). In this way, all the indicators of each GBRS can belong to one of these categories, without any ambiguity and without any missing or extra indictors. The categories were organized into 4 groups: 1. *Essential*: Categories directly involved in measuring the ecological level of a building; 2. *Complementary*: Additional categories needed to measure properly its level of sustainability; 3. *Added*: Categories that are not necessary, and whose indicators are already indirectly contained in Essential or Complementary categories and could serve only to emphasize some sustainable aspects of the building, but it offsets the importance of some indicators; 4. *Superfluous*: Categories not related to sustainability.

Table 1 Summary of the method used to evaluate by the 11 GBRSs.

GBRS	Evaluation strategy
ASGB	Prerequisites of the standard must be met. The score of each index must not add up to less than 40 points. When the total score of a green building reaches 50, 60 or 80 points, the green building rating is one star, two stars or three stars respectively. This is calculated using the following formula: $\sum Q = W1\ Q1 + W2\ Q2 + W3\ Q3 + W4\ Q4 + W5\ Q5 + W6\ Q6 + W7\ Q7 + Q8$. First, the Qi score (i = 1, 2, 3, 4, 5, 6, 7) is obtained according to the grade of the item that can be scored under various indicators. Second, Q8 is the Promotion and Innovation score. Each Qi is multiplied by its Wi weight, and the Bonus Elements score is added to final evaluation score, obtaining 1, 2, or 3 stars.
BEAM	It is made up of 7 categories and 22 subcategories that are scored to obtain a sum that, according to its value, obtains as a result: Certificate, Bronze, Silver, Gold, Platinum, Diamond.
BREEAM	The assessment method is about ten categories that allow a maximum of 110 points. Each category has different weight regarding to total, and they are divided in subcategories, and indicators. Once the score for each category is obtained, a percentage weighting factor is applied in each case, proportionally granting the total number of 110 credits. According to the final score, the final can be: Exceptional, Excellent, Very Good, Good, Correct, or Unrated.
CEDES	It incorporates eight categories and a system of indicators hierarchically structured into four levels. Each indicator has a specific, well-structured weight and can be assigned a value from 0 to 5. The final score ranges from 1 to 10.
DNGB	The evaluation is based on 29 criteria, subdivided into six categories. Points are awarded to each category obtaining a partial result. Then a weighting factor is applied to them, obtaining a final result by category that, when added together, grants the certification: Bronze, Silver, Gold, Platinum.

Table 1 to be continued

GBI	It has 3 stages: Stage 1: Application and registration, Stage 2: Evaluation of the design, Stage 3: Completion evaluation and verification. To obtain the certification, its categories are scored and then added to determine a final result: Certified, Silver, Gold, Platinum.
GG	The maximum score that can be obtained is 1,000 points, divided into six categories. They are divided in subcategories, and indicators too. Some of the categories offer different assessment paths, which makes the method adaptable to some project particularities. Depending on the percentage of points obtained, 1 to 4 globes can be awarded.
GS	The assessment tool awards points for the achievement of certain specific credits in each category. Once their score is calculated, an environmental weighting factor is applied, and the partial results are added. Finally, the points related to the incorporated innovations are added. The final result allows obtaining: One, two, three, four, five, six stars.
IGBC	It is composed of 6 categories, which together have 37 criteria and 10 mandatory requirements. Each criterion is assigned a score. To achieve certification, the project must meet all the mandatory prerequisites and add a minimum score of 50 to 100 credits, obtaining as a result: Certificate, Silver, Gold, Platinum.
LEED	It incorporates 9 categories, which together have 41 criteria. Each criterion is assigned a score and 16 mandatory requirements. To achieve certification, the project must meet all the mandatory prerequisites and add a minimum score of 50 to 110 credits, obtaining as a result: Certificate, Silver, Gold, Platinum.
SBTools	It is an adaptive valuing framework for rating buildings using scores and credits that are weighted depending on the type of building. It is organized into four levels: (1) detected problems, (2) performance categories, (3) performance criteria, and (4) performance sub-criteria. According to the result, the corresponding qualification is obtained

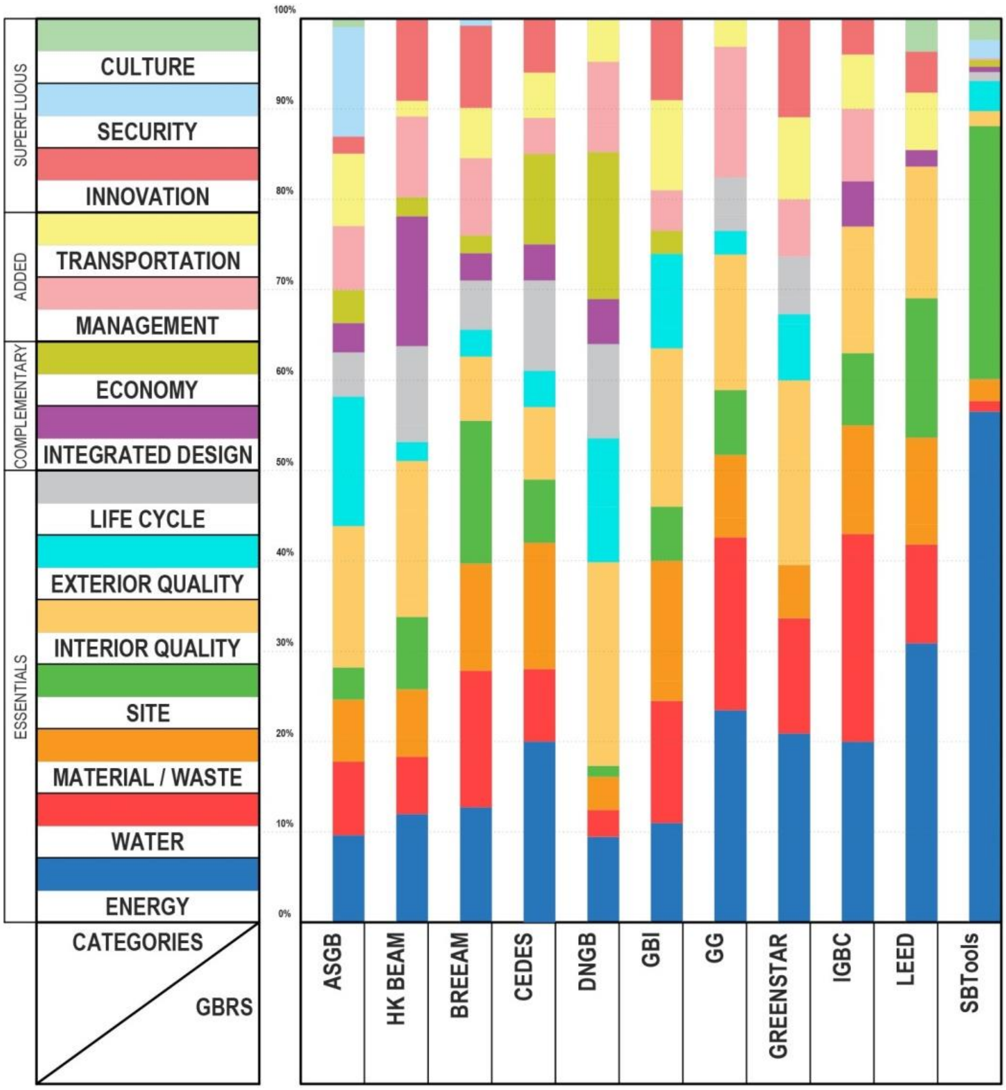


Fig. 1 Mutual comparison and maximum score of the different categories of each of the 11 GBRSs.

3.2 Description of the Demountable Building. Sayab

3.2.1 General Information

Sayab is a complex of 4 residential buildings intended for the middle social stratum (social stratum 4) built in Cali, Colombia (Figs, 2, 3). Each building contains around 100 dwellings with an average surface area of about 60 m^2 [37-40]. Here one of the 4 blocks is analyzed.

Sayab was designed to have a high ecological and sustainable level, and in fact it has been internationally recognized in several publications and received awards and was built using several strategies to optimize resources to the maximum while generating the minimum of waste and emissions in all stages of its construction. The building has a refined bioclimatic design so that the houses do not need air conditioning, ventilation or heating devices. As a consequence, *Sayab* houses have minimal energy consumption (barely 30% of what is usual for this type of houses in the area) [37-39] (Figs. 4, 5).

Sayab hardly needed maintenance due to the robustness and durability of the materials used, and due to the fact that there are few electromechanical devices (due to its special design). *Sayab* was also built with healthy materials, which do not produce emissions, to maximize the residents' well-being and health. It should be said that the economic cost of the houses is similar to the average market price of other houses with the same characteristics, and in the same area. However, its most notable feature is that it was built of industrialized, modular, prefabricated and removable components, including its structure.

The houses' economic cost is similar to the average market price of other houses with the same characteristics in the same area, although it was built of industrialized, modular, prefabricated and removable components.

3.2.2 Demountable Design

The *Sayab* building structure (foundations, load-bearing walls and slabs) was built of prefabricated reinforced concrete panels ("formaletas"), assembled bymetal connectors so that the different components do not have differential displacements, although the robustness and rigidity of the whole is achieved by proper assembly between them (Figs. 6, 7, 8) [37-40]. The final removable structure is capable of resisting all external stresses, including the strong seismic demands

Fig. 2 ***Sayab. First Building.***

Fig. 3 ***Sayab*** **floor plan layout.**

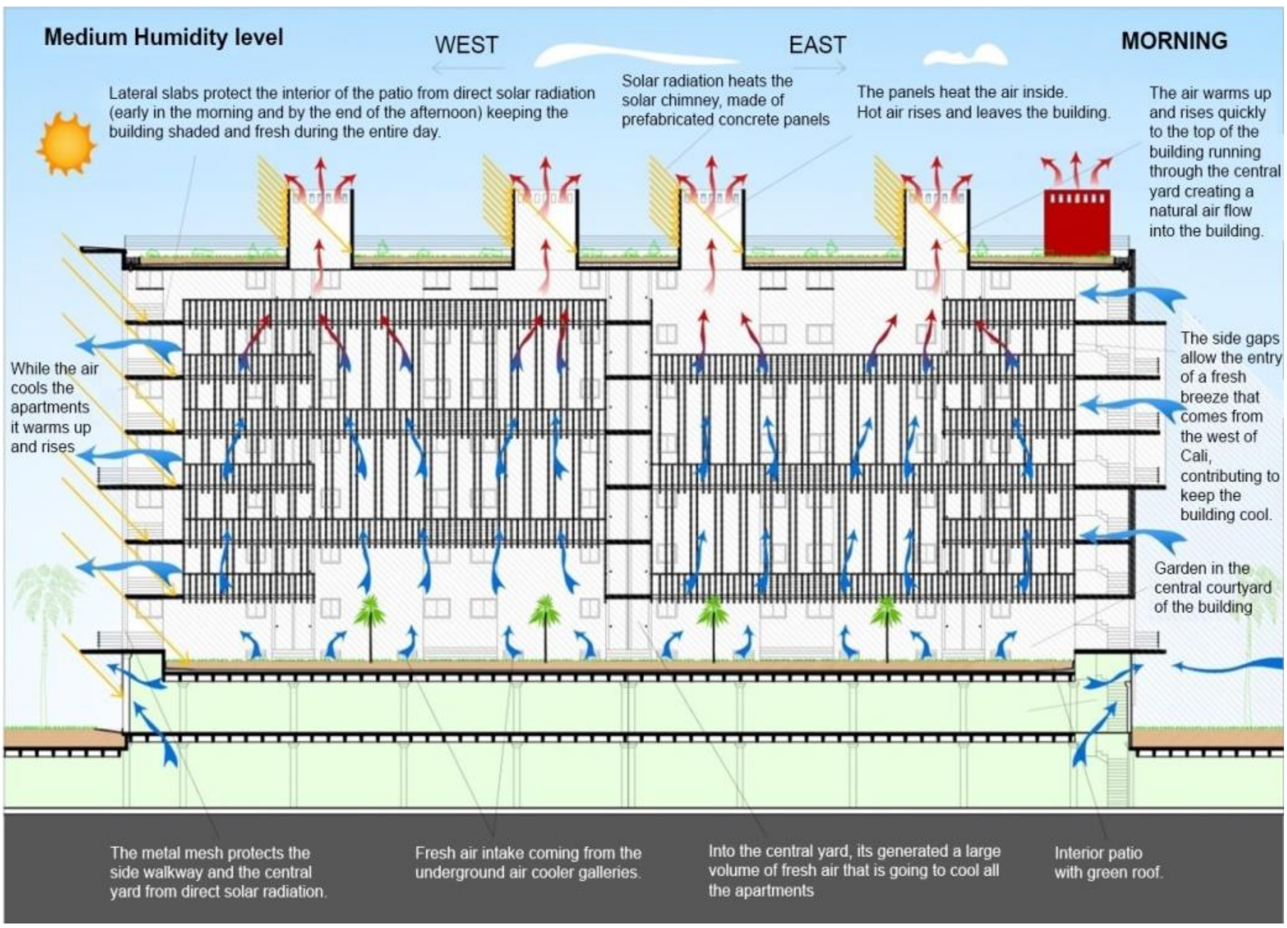


Fig. 4 **E-W cross section of** ***Sayab*****, showing bioclimatic functioning.**

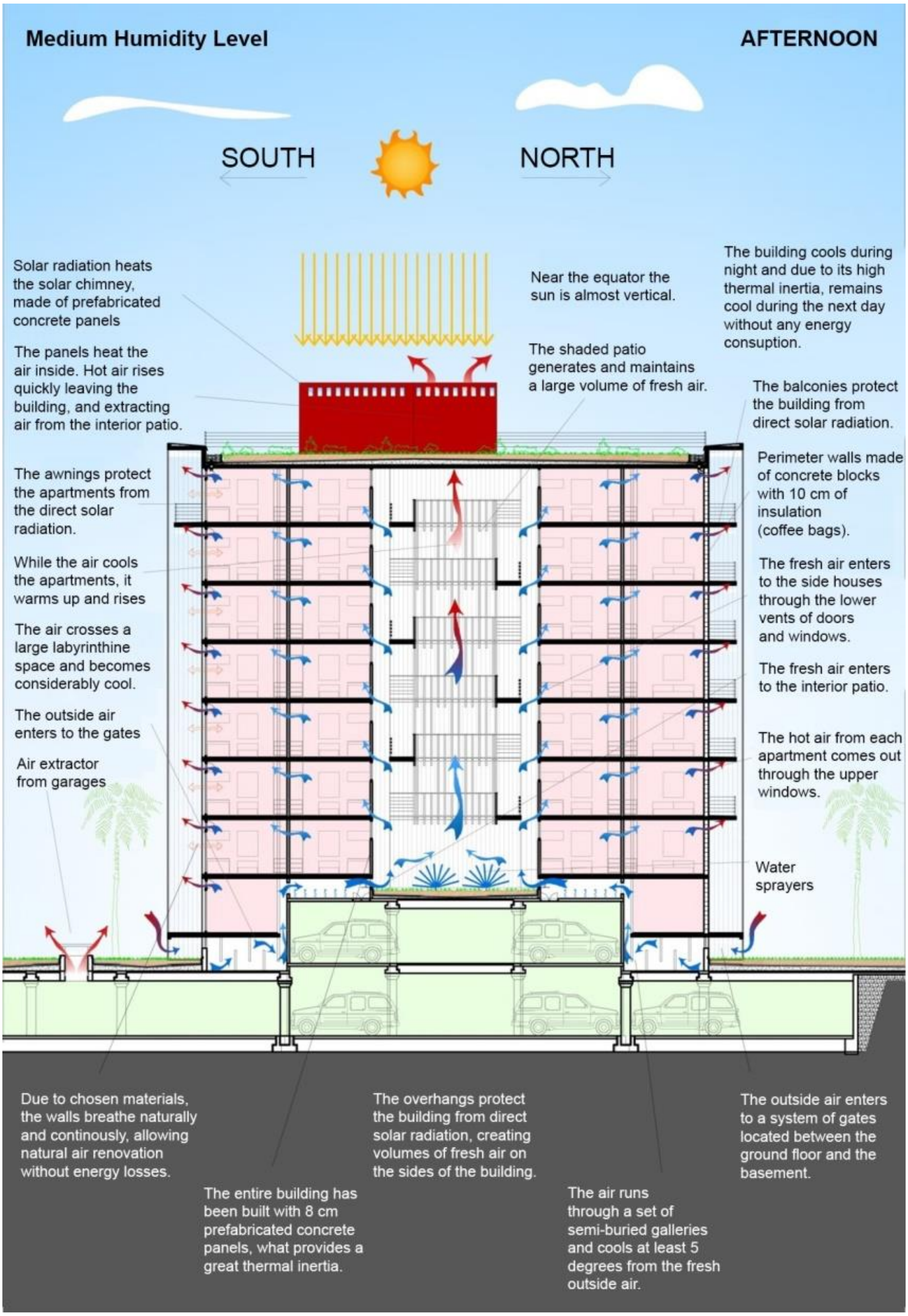


Fig. 5 N-S cross section of *Sayab*, showing bioclimatic functioning.

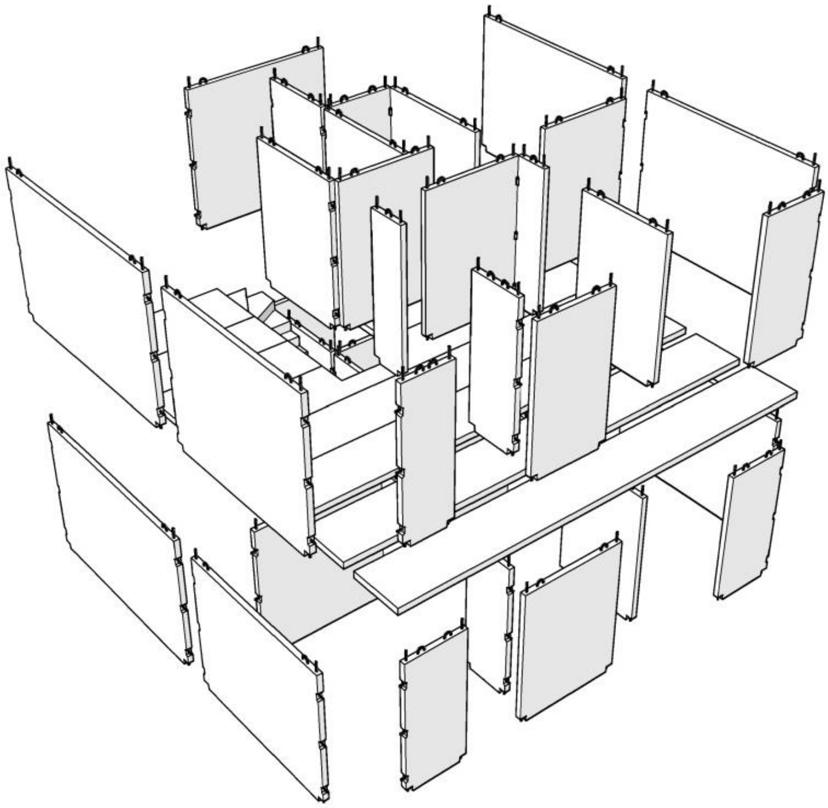


Fig. 6 ***Sayab*'s demountable structure based on prefabricated reinforced concrete panels.**

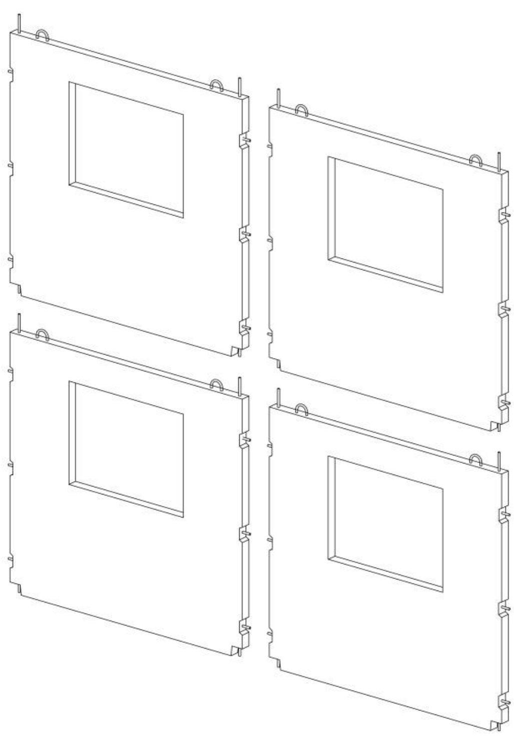


Fig. 7 **Demountable prefabricated reinforced concrete *Sayab* panels.**

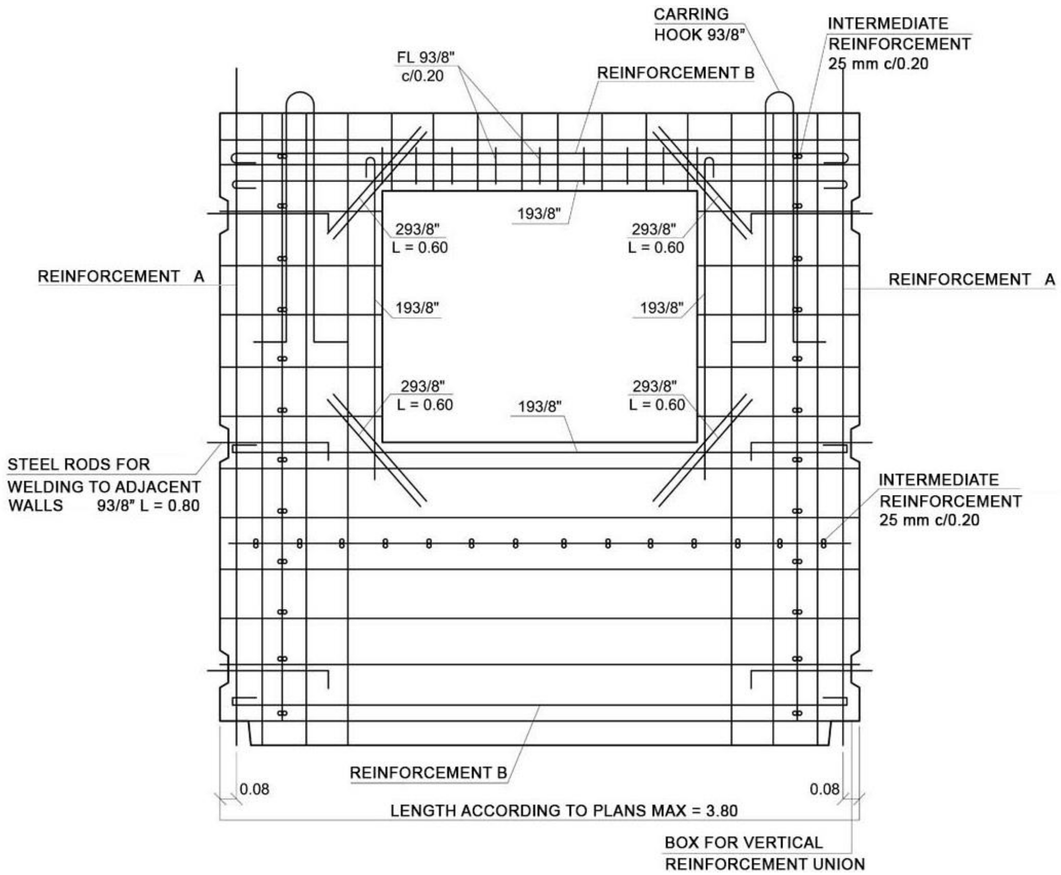


Fig. 8 Reinforcement of prefabricated concrete *Sayab* panels.

of the area (seismic activity is significant in Cali) (Figs. 9, 10). All the structural panels can be easily removed from the building for convenient repair and/or replacement. The architectural envelopes are also made from concrete blocks and wood-cement panels, which can also be easily disassembled. The exterior metal elements (doors and windows) and all decorative elements are also demountable. Even the installations and equipment of the building have been made based on demountable components that can also be easily removed, repaired and reused (Figs. 9, 10, 11, 12, 13).

As a result, all components of the building can be extracted, repaired and reused indefinitely, providing the building with durability that can be infinite (Figs. 9, 10, 11). Repair of components can be done easily, and if necessary they can be replaced with new components. As a result, by maximizing the durability of the building and minimizing the need for maintenance, the environmental impact per unit of time tends to zero. It should be added that *Sayab* components can be repaired and reused as many times as possible, but, at the point where some of these components are very deteriorated, and their repair becomes very expensive, they could be used in another type of construction less aesthetically demanding (for example a retaining wall). In this way, the durability of the components is further increased, and their environmental impact is further reduced.

Although *Sayab* meets high ecological and sustainable standards [37-40], in this work we only quantified the contribution of its *demountable construction* in its sustainable level, using the most leading GBRS. As has been analyzed in previous studies [11-15, 19, 21, 37-39], the environmental and economic advantages of demountable buildings are many, including the following:

- Adaptability to new uses, and easy reconfiguration of the building;

- Easy repair of all components;
- Low energy consumption;
- Maximum optimization of resources;
- Minimum need for maintenance;
- Quick construction;
- Zero generation of emissions and waste.

Fig. 9 Assembly process of demountable prefabricated reinforced concrete panels in *Sayab*.

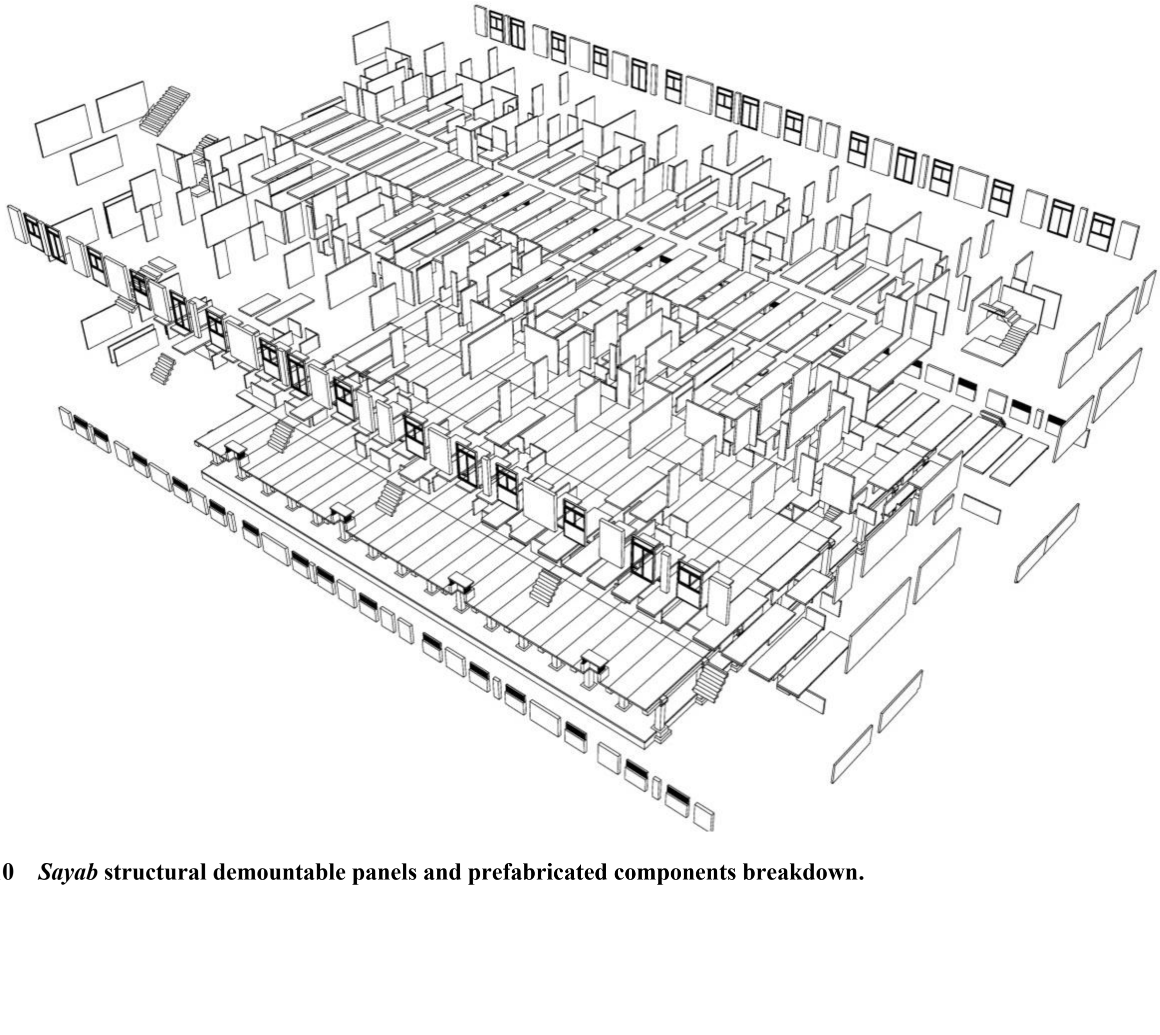


Fig. 10 *Sayab* structural demountable panels and prefabricated components breakdown.

Fig. 11 Interior view of *Sayab* structure, based on demountable prefabricated reinforced concrete panels.

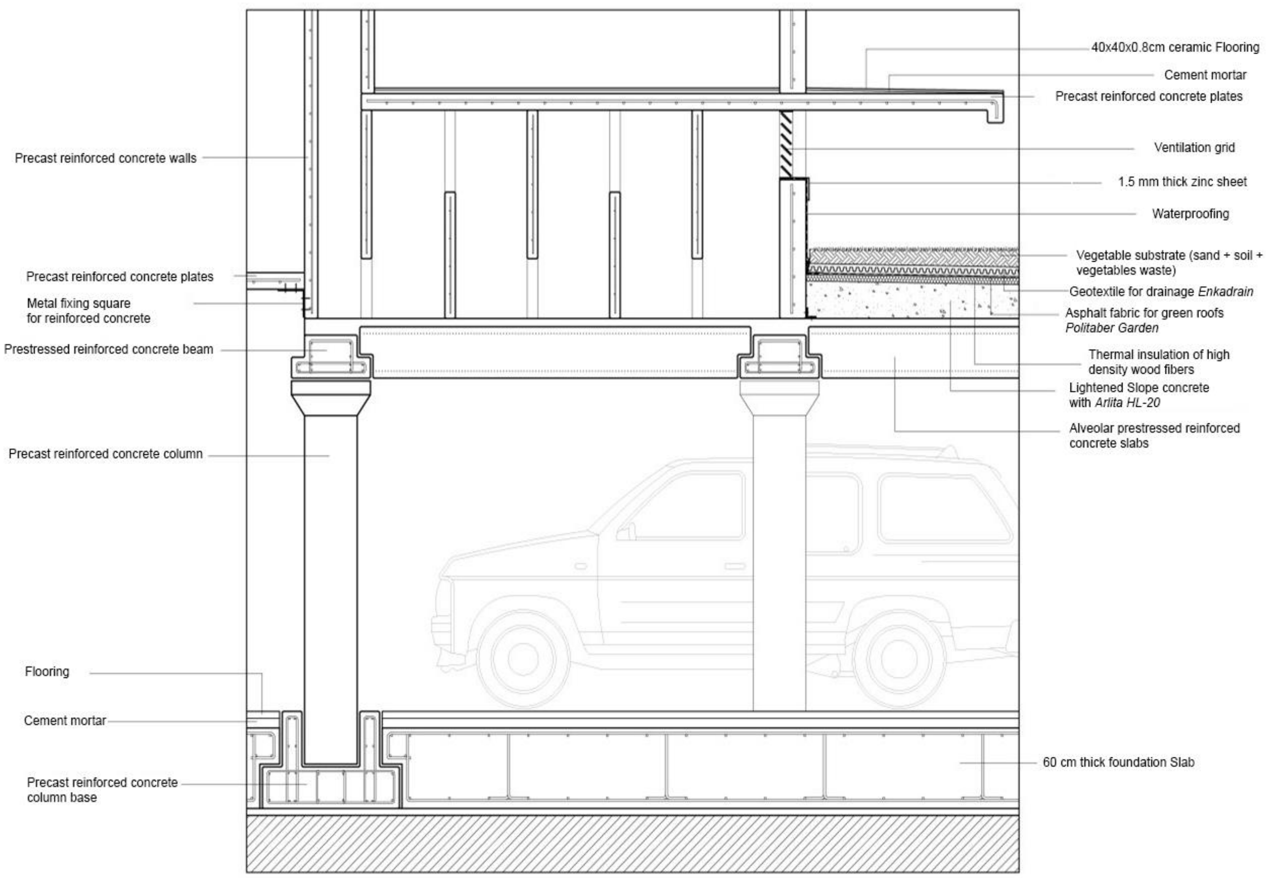


Fig. 12 Construction detail of the base structure of the *Sayab* building.

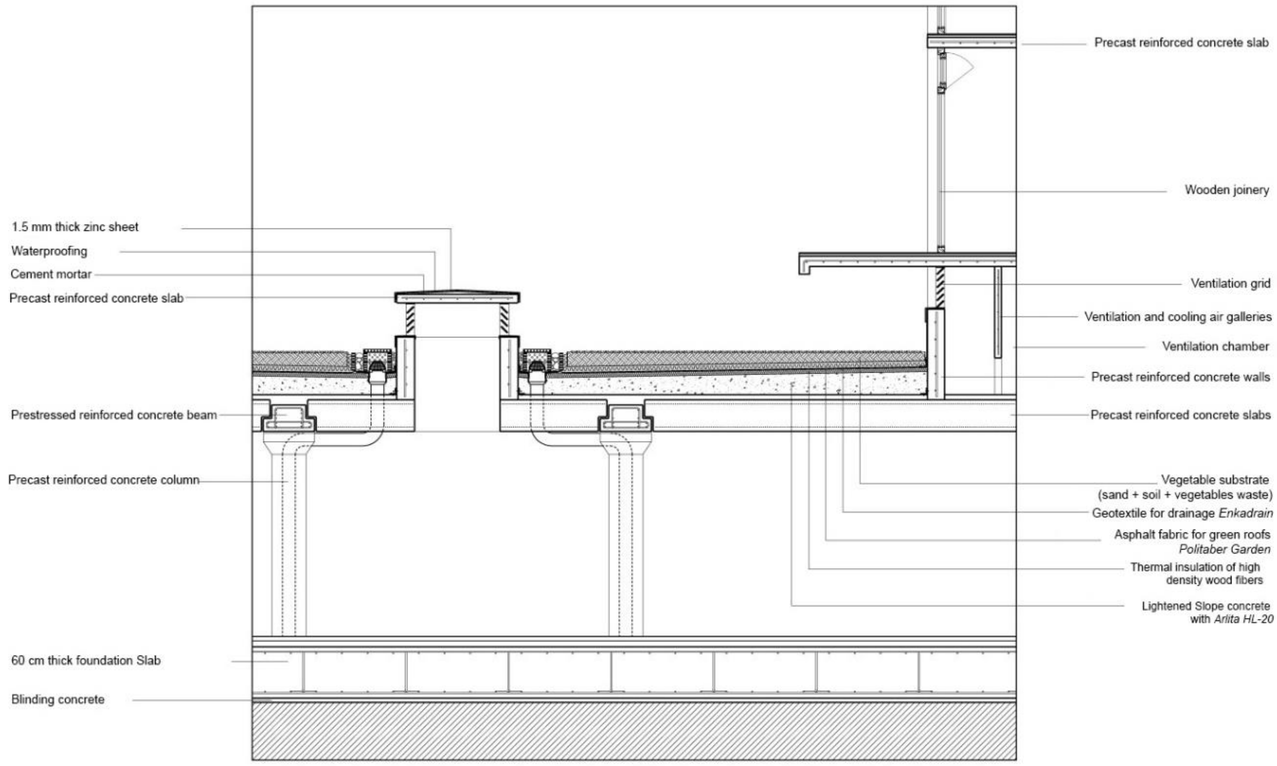


Fig. 13 Construction detail of the base structure of the *Sayab* building.

It is therefore assumed that the different GBRSs must appropriately value these advantages and assign a considerable score to disassembly. Otherwise it would be deduced that the GBRSs that do not adequately assess it would be deficient, and should be modified.

3.3 Description of the Non-demountable Building. ND-Sayab

In order to measure the differential score of the individual GBRSs for *demountable construction*, *Sayab* was compared to a reference baseline: a hypothetical non-demountable, but otherwise identical, version of *Sayab*, known as the *ND-Sayab*.

The specific characteristics of *ND-Sayab* do not matter.

3.4 Comparative Evaluation Methodology

To evaluate the contribution of high-weight *demountable construction* to the general level of sustainability, *Sayab* was compared with *ND-Sayab* using eleven of the most leading GBRSs, considering only the indicators with different scores in each case, creating a comparative table for each GBRS. The set of indicators whose score varies when comparing a demountable with a non-demountable building is referred to as a "demountable group".

The evaluation tables show the scores obtained by both buildings:

- The score given to each indicator (strictly following the guidelines of each GBRS manual);
- The maximum possible score for each indicator;
- The weight of the indicator within the category to which it belongs;
- The weight of the category;
- The conversion factor of the scoring scale of each method, to a scale of 0-100 (Since some GBRSs score from 0 to 75, others from 0 to 100, others from 0 to 110, others from 0 to 1,000, the conversion factors used are therefore: 100/75, 100/100, 100/110, 100/1,000).

A very simple process has been followed to make each table (Fig. 14). By multiplying the percentage score of an indicator (score/maximum score), by its weight within the category, by the weight of the category, and by the conversion coefficient, a value is obtained (from 0 to 100), which is the contribution of each indicator to the total score, so that adding the score of all the indicators of the "demountable-group" gives the total score that each group gives to both Sayab and ND-Sayab. Finally, by subtracting both scores, the contribution of demountable construction is obtained in the final score provided by each of the GBRSs used.

It should be noted that each GBRS has a different internal structure and a different scoring system. Some GBRSs do not have categories but only indicators, and the determination of the specific weight of each system is different and has to be calculated on a common weighting basis of 0 to 100. However, essentially all the tables show the same: the final score of each indicator on a scale from 0 to 100 and the total score of all of them for both buildings.

To describe the evaluation process and the contribution of each indicator in the final evaluation of the building, let us take an example from ASGB (Table 2).

The ASGB indicator "BA (building adaptability)" has a maximum score of 18 points. This indicator has a weight of 18/100 within the "SD (security and Durability)" category, and in turn this category has a weight of 10 out of 110 (ASGB has a total evaluation range of 0 to 100+10).

Sayab was given the maximum score (18), that is ((12 / 18) = 0.66). By multiplying this value (0.66) by the weight of the BA indicator within the category, a value of (0.66 * (18 / 100)) is obtained, that is 0.12. Multiplying this value by the weight of the SD category in the total score gives (0.12 * (10 / 100)) = 0.012, based on a score of (0-110). Converting this percentage to a common base of (0-100), the final score is (0.012 * (100 / 110)) = 0.0109, i.e. 1.09%.

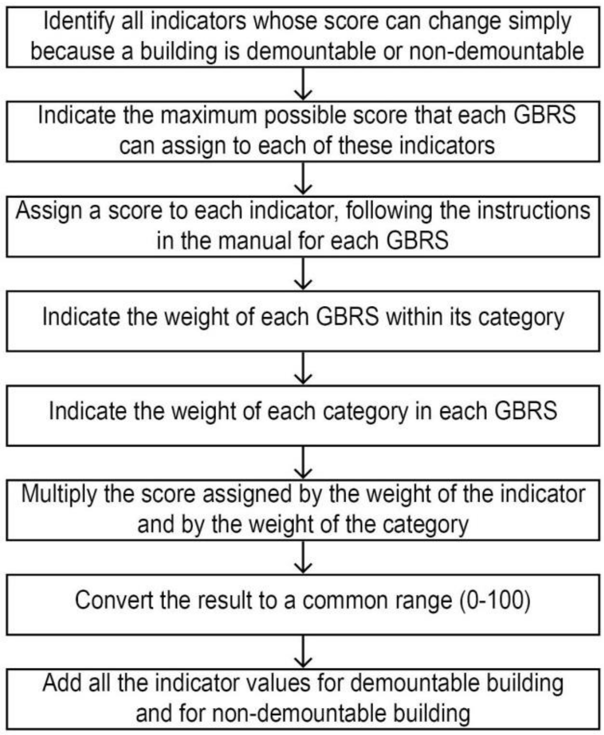


Fig. 14 Process to obtain the quantification of the contribution of demountability to the sustainable level of buildings using different GBRSs.

Table 2 ASGB indicators involved in demountable construction. Score differences between *Sayab* and *ND-Sayab*.

Demountable group		*Sayab*						*ND- Sayab*					
Indicators	Category	Score	Max. score	Indicator weight	Category weight	Result (0-110)	Result (0-100)	Score	Max. score	Indicator weight	Category weight	Result (0-110)	Result (0-100)
BA (*1)	SD (*6)	12	18	18/100	10%	1.20	1.09%	6	18	18/100	10%	0.60	0.55%
LULC (*2)	SD	10	10	10/100	10%	1.00	0.91%	6	10	10/100	10%	0.60	0.55%
IIDP (*3)	RC (*7)	8	8	8/200	20%	0.80	0.73%	4	8	8/200	20%	0.40	0.36%
URRWM (*4)	RC	12	12	12/200	20%	1.20	1.09%	6	12	12/200	20%	0.60	0.55%
SSIC (*5)	II (*8)	10	10	10/190	10%	0.53	0.48%	5	10	10/190	10%	0.27	0.24%
Partial score							4.30%						2.24%
Difference		2.06%											

ASGB provides a maximum score of 100 points, and can provide an additional 10 points, therefore, the total score ranges from 0 to 110. (*1) Building adaptability, (*2) Longer useful life of components, (*3) Industrialized interior design parts, (*4) Use of recyclable, reusable and waste materials, (*5) Structural system and industrialized components, (*6) Security and durability, (*7) Resource conservation, (*8) Improvement and innovation.

Table 3 BEAM indicators involved in demountable construction. Score differences between *Sayab* and *ND-Sayab*.

Demountable group		*Sayab*						*ND- Sayab*					
Indicators	Category	Score	Max. score	Indicato r weight	Category weight	Result (0-110)	Result (0-100)	Score	Max. score	Indicator weight	Category weight	Result (0-110)	Result (0-100)
MSD (*1)	MW (*4)	0/2	2	2/35	9%	0.00	0.00	0/2	2	2/35	9%	0.00	0.00%
PREF (*2)	MW	4/4	4	4/35	9%	1.03	0.93%	1/4	4	4/35	9%	0.26	0.23%
AD (*3)	MW	2/2	2	2/35	9%	0.51	0.47%	0/2	2	2/35	9%	0.00	0.005
Partial score							1.40%						0.23%
Difference		1.17%											

BEAM provides a maximum score of 100 points, and can provide an additional 10 points, therefore, the total score ranges from 0 to 110. (*1) Modular and standardized design, (*2) Prefabrication, (*3) Adaptability and deconstruction, (*4) Materials and waste.

ND-Sayab was given a score of 6 out of a maximum of 18, that is, ((6 / 18) = 0.33). Multiplying this value (0.33) by the weight of the BA indicator within the category gives a value of (0.66 * (18 / 100)), that is, 0.06. Multiplying this value by the weight of the SD category in the total score gives (0.06 * (10 / 100)) = 0.006, percentage based on a score of (0-110). Converting this percentage to a common base of (0-100), the final score is (0.006 * (100 / 110)) = 0.0055, i.e. 0.55%.

Repeating the process for the 5 demountability indicators in ASGB, *Sayab* has a score of 4.30%, compared to 2.24% for *ND-Sayab*. That is, according to ASGB a demountable building like *Sayab* has an increase in the level of sustainability of 2.06% (4.30 - 2.24) (Table 2).

4. Results

4.1 ASGB Evaluation

ASGB has 5 indicators involved in *demountable construction*, and therefore, their score varies in the evaluation of *Sayab*, and *ND-Sayab*. The score difference for both cases is only 2.06% and this is because ASGB does not consider many important aspects such as: economic cost, resources needed, level of exploitation of resources, energy consumption in building construction and in demolishing/disassembling (Table 2).

4.2 BEAM Evaluation

BEAM has only 3 indicators involved in *demountable construction* and therefore their score varies in the evaluation of *Sayab*, and *ND-Sayab*. The score difference for both cases is only 1.17% and this is because BEAM does not consider many important aspects such as: economic cost, resources needed, level of exploitation of resources, energy consumption in building construction and in demolishing/disassembling (Table 3).

4.3 BREEAM Evaluation

BREEAM has only 4 indicators involved in *demountable construction* and therefore their score varies in the evaluation of *Sayab*, and *ND-Sayab*. The score difference for both cases is only 5.38% and this is because BREEAM does not consider many important aspects such as: economic cost, energy consumption in building construction and in demolishing (Table 4).

4.4 CEDES Evaluation

CEDES is the best GBRS and has 7 indicators involved in *demountable construction* and therefore their score varies in the evaluation of *Sayab*, and *ND-Sayab*. The score difference is 22.72% (Table 5).

4.5 DNGB Evaluation

DNGB has 6 indicators involved in *demountable construction* and therefore their score varies in the evaluation of *Sayab*, and *ND-Sayab*. The score difference for both cases is 14.79% and this is because DNGB does not consider: resources needed and level of exploitation of resources (Table 6).

Table 4 BREEAM indicators involved in demountable construction. Score differences between *Sayab* and *ND-Sayab*.

Removable group				*Sayab*						*ND- Sayab*			
Indicators	Category	Score	Max. score	Indicator weight	Category weight	Result (0-110)	Result (0-100)	Score	Max. score	Indicator weight	Category weight	Result (0-110)	Result (0-100)
MAN 02	MAN (*1)	4	4	19.05%	11%	2.10	1.91%	1	4	19.05%	11%	0.52	0.47%
MAT05	MAT (*2)	1	1	7.14%	15%	1.07	0.97%	0	1	7.14%	15%	0	0%
WST01	WST (*3)	4	5	45.45%	6%	2.18	1.98%	0	5	45.45%	6%	0	0%
WST06	WST	2	2	18.18%	6%	1.09	0.99%	0	2	18.18%	6%	0	0%
Partial score							5.85%						0.47%
Difference		5.38%											

BREEAM provides a maximum score of 100 points, and can provide an additional 10 points, therefore, the total score ranges from 0 to 110. (*1) Management, (*2) Material, (*3) Waste.

Table 5 CEDES indicators involved in demountable construction. Score differences between *Sayab* and *ND-Sayab*.

Demountable group				*Sayab*						*ND- Sayab*			
Indicators	Category	Score	Max. score	Indicator weight	Category weight	Result	Result (0-100)	Score	Max. score	Indicator weight	Category weight	Result	Result (0-100)
1.2.1	RO (*1)	4	5	0.072	18%	-	1.04%	2	5	0.072	18%	-	0.52%
1.2.4	RO	4	5	0.306	18%	-	4.41%	1	5	0.306	18%	-	1.10%
1.2.6	RO	5	5	0.225	18%	-	4.05%	1	5	0.225	18%	-	0.81%
2.4	ECIC (*2)	5	5	0.115	34%	-	3.91%	3	5	0.115	34%	-	2.35%
2.7	ECID (*3)	4	5	0.024	34%	-	0.65%	1	5	0.024	34%	-	0.16%
4	WE (*4)	5	5	1	12%	-	12%	1	5	1	12%	-	2.4%
6	EC (*5)	4	5	1	10%	-	8%	2	5	1	10%	-	4%
Partial score							34.06%						11.34%
Difference		22.72%											

(*1) Resources optimization, (*2) Energy consumption in building construction, (*3) Energy consumption in demolishing/disassembling, (*4) Reduction of waste and emissions, (*5) Economic cost.

Table 6 DNGB indicators involved in demountable construction. Score differences between *Sayab* and *ND-Sayab*.

Demountable group				*Sayab*						*ND- Sayab*			
Indicators	Category	Score	Max. score	Indicator weight	Category weight	Result	Result (0-100)	Score	Max. score	Indicator weight	Category weight	Result	Result (0-100)
ENV1.1	ENV (*1)	122.5	130	10/24	25%	-	9.82%	60	130	10/24	25%	-	4.81%
ENV1.2	ENV	120	135	5/24	25%	-	4.63%	115	135	5/24	25%	-	4.44%
ECO1.1	ECO (*2)	110	130	4/10	25%	-	8.46%	87.5	130	4/10	25%	-	6.73%
TEC1.6	TEC (*3)	110	125	3/9	25%	-	7.33%	60	125	3/9	25%	-	2.40%
PRO1.6	PRO (*4)	280	280	2/10	25%	-	5.00%	180	280	2/10	25%	-	3.21%
PRO2.1	PRO	110	110	2/10	25%	-	5.00%	85	110	2/10	25%	-	3.86%
Partial score							40.24%						25.45%
Difference		14.79%											

(*1) Environmental quality, (*2) Economic quality, (*3) Technical quality, (*4) Process quality.

Table 7 GBI indicators involved in demountable construction. Score differences between *Sayab* and *ND-Sayab*.

Demountable group			*Sayab*					*ND-Sayab*					
Indicators	Category	Score	Max. score	Indicator weight	Category weight	Result	Result (0-100)	Score	Max. score	Indicator weight	Category weight	Result	Result (0-100)
SM7	SSPM (*1)	2	2	-	-	-	2%	0	2	-	-	-	0%
MR1	MRSC (*2)	2	2	-	-	-	2%	1	2	-	-	-	1%
MR2	MRSC	2	2	-	-	-	2%	0	2	-	-	-	0%
MR6	MRSC	2	2	-	-	-	2%	0	2	-	-	-	0%
Partial score							8%						1%
Difference		7%											

(*1) Sustainable site plan management, (*2) Material resources.

Table 8 GG indicators involved in demountable construction. Score differences between *Sayab* and *ND-Sayab*.

Demountable group			*Sayab*					*ND- Sayab*					
Indicators	Category	Score	Max. score	Indicator weight	Category weight	Result (0-1,000)	Result (0-100)	Score	Max. score	Indicator weight	Category weight	Result (0-1,000)	Result (0-100)
1.3 LCCA	PM (*1)	12	12	-	-	12	1.20%	0	12	-	-	0	0%
5.2 PLC	MAT (*2)	39	39	-	-	39	3.90%	10	39	-	-	10	1%
5.5.1 S&E	MAT	0	22	-	-	0	0.00%	0	22	-	-	0	0%
5.5.2 MROS	MAT	0	8	-	-	0	0.00%	0	8	-	-	0	0%
5.7.1 OSFC	MAT	4	4	-	-	4	0.40%	2	4	-	-	2	0.2%
5.7.2 DFD	MAT	6	6	-	-	6	0.60%	0	6	-	-	0	0%
Partial score							6.10%						1.2%
Difference		4.90%											

(*1) Project management, (*2) Materials.

Table 9 GS indicators involved in demountable construction. Score differences between *Sayab* and *ND-Sayab*.

Demountable group		*Sayab*						*ND- Sayab*					
Indicators	Category	Score	Max. score	Indicator weight	Category weight	Result (0-110)	Result (0-100)	Score	Max. score	Indicator weight	Category weight	Result (0-110)	Result (0-100)
5	MGMT (*1)	2	2	-	-	2	1.818%	1	2	-	-	1	0.909%
19	MAT (*2)	7	7	-	-	4	6.364%	3	7	-	-	3	2.727%
22	MAT	1	1	-	-	3	0.909%	0	1	-	-	0	0.000%
Partial score							9.09%						3.64%
Difference		5.46%											

GS provides a maximum score of 100 points, and can provide an additional 10 points (innovation), therefore, the total score ranges from 0 to 110. (*1) Management, (*2) Materials.

4.6 GBI Evaluation

GBI has 4 indicators involved in *demountable construction*, and therefore, their score varies in the evaluation of *Sayab*, and *ND-Sayab*. The score difference for both cases is 7% and this is because GBI does not consider many important topics such as: economic cost, resources needed, level of exploitation of resources, energy consumption in building construction and in demolishing/disassembling (Table 7).

4.7 GG Evaluation

GG has 6 indicators involved in *demountable construction* and therefore their score varies in the evaluation of *Sayab*, and *ND-Sayab*. The score difference for both cases is 4.90% and this is because GG does not consider many important aspects such as: economic cost, and energy consumption in building construction (Table 8).

4.8 GS Evaluation

GS has only 3 indicators involved in *demountable construction* and therefore their score varies in the evaluation of *Sayab*, and *ND-Sayab*. The score difference for both cases is only 5.46% and this is because GS does not consider many important aspects such as: economic cost, resources needed, level of exploitation of resources (Table 9).

4.9 IGBC Evaluation

IGBC has only 2 indicators involved in *demountable construction* and therefore their score varies in the evaluation of *Sayab*, and *ND-Sayab*. The score difference for both cases is only 3% and this is because IGBC does not consider many important aspects such as: economic cost, resources needed, level of exploitation of resources, energy consumption in building construction (Table 10).

4.10 LEED Evaluation

LEED has only 2 indicators involved in *demountable construction* and therefore their score varies in the evaluation of *Sayab*, and *ND-Sayab*. The score difference for both cases is only 4.54% and this is because LEED does not consider many important topics such as: economic cost, resources needed, level of exploitation of resources, energy consumption in building construction and in demolishing/disassembling (Table 11).

4.11 SBTools Evaluation

SBTools has 13 indicators involved in *demountable construction* and therefore their score varies in the evaluation of *Sayab*, and *ND-Sayab*. The score difference for both cases is only 12.4% and this is because SBTool does not consider some topics such as: economic cost, resources needed, level of exploitation of resources (Table 12).

The results of the comparative evaluation by each GBRS have been the following: ASGB: 2.06%, BEAM: 1.17%, BREEAM: 5.38%, CEDES: 22.72%, DNGB: 14.79%, GBI: 7%, GG: 4.90%, GS: 5.46%, IGBC: 3%, LEED: 4.54% and SBTools: 12.4% (Tables 13, 14).

Table 10 IGBC indicators involved in demountable construction. Score differences between *Sayab* and *ND-Sayab*.

Demountable group		*Sayab*						*ND- Sayab*					
Indicators	Category	Score	Max. score	Indicator weight	Category weight	Result	Result (0-100)	Score	Max. score	Indicator weight	Category weight	Result	Result (0-100)
C2	MR (*1)	1	1	-	-	-	1%	0	1	-	-	-	0%
C7	MR	2	2	-	-	-	2%	0	2	-	-	-	0%
Partial score							3%						0%
Difference		3%											

(*1) Material resources.

Table 11 LEED indicators involved in demountable construction. Score differences between *Sayab* and *ND-Sayab*.

Demountable group		*Sayab*						*ND- Sayab*					
Indicators	Category	Score	Max. score	Indicator weight	Category weight	Result (0-110)	Result (0-100)	Score	Max. score	Indicator weight	Category weight	Result (0-110)	Result (0-100)
BLC IR (*1)	MR (*3)	3	5	-	-	3	2.72%	0	5	-	-	0	0%
CDWM (*2)	MR	2	2	-	-	2	1.82%	0	2	-	-	0	0%
Partial score							4.54%						0%
Difference		4.54%											

LEED provides a maximum score of 100 points, and can provide an additional 10 points, therefore, the total score ranges from 0 to 110. Indicators of the manual for collective housing. (*1) Building life cycle impact reduction, (*2) Construction and demolition waste management, (*3) Materials and resources.

Table 12 Indicators of SBTool involved in demountable construction. Score differences between *Sayab* and *ND-Sayab*.

Demountable group		*Sayab*						*ND- Sayab*					
Indicators	Category	Score	Max. score	Indicator weight	Category weight	Result	Result (0-100)	Score	Max. score	Indicator weight	Category weight	Result	Result (0-100)
B 1.1	ERC (*1)	3	5	6,48%	-	-	3.89%	0	5	6,48%	-	-	0.00%
B 1.2	ERC	3	5	3.24%	-	-	1.95%	0	5	3.24%	-	-	0.0%
B 3.3	ERC	3	5	0.20%	-	-	0.12%	0	5	0.20%	-	-	0.0%
B 3.5	ERC	5	5	0.20%	-	-	0.20%	3	5	0.20%	-	-	0.12%
B 3.6	ERC	3	5	0.20%	-	-	0.12%	0	5	0.20%	-	-	0.0%
C 1.1	EL (*2)	3	5	4.86%	-	-	2.92%	0	5	4.86%	-	-	0.0%
C 1.2	EL	3	5	4.86%	-	-	2.92%	0	5	4.86%	-	-	0.0%
E 4.1	SQ (*3)	5	5	0.05%	-	-	0.05%	3	5	0.05%	-	-	0.03%
E 4.2	SQ	5	5	0.41%	-	-	0.41%	3	5	0.41%	-	-	0.25%
E 4.3	SQ	5	5	0.05%	-	-	0.05%	3	5	0.05%	-	-	0.03%
G 1.1	CEA (*4)	5	5	0.10%	-	-	0.10%	0	5	0.10%	-	-	0.0%
G 1.2	CEA	3	5	0.10%	-	-	0.06%	0	5	0.10%	-	-	0.0%
G 1.3	CEA	5	5	0.10%	-	-	0.10%	3	5	0.10%	-	-	0.06%
Partial score							12.89%						0.49%
Difference		12.4%											

(*1) Energy and resource consumption, (*2) Environmental loadings, (*3) Service quality, (*4) Cost and economic aspects.

Table 13 Score differences between *Sayab* and *ND-Sayab* for the 11 GBRSs.

GBRS	ASGB	BEAM	BREEAM	CEDES	DNGB	GBI	GG	GS	IGBC	LEED	SBTool
Score *Sayab*	4.30	1.40	5.85	34.06	40.24	8.00	6.10	9.09	3.00	4.54	12.89
Score *ND-Sayab*	2.24	0.23	0.47	11.34	25.45	1.00	1.20	3.64	0.00	0.00	0.49
Score difference	2.06	1.17	5.38	22.72	14.79	7.00	4.90	5.46	3.00	4.54	12.40

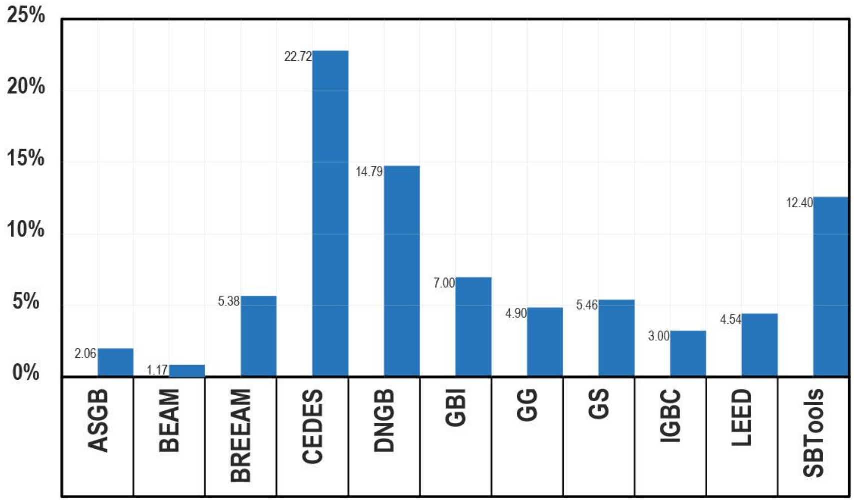
Sayab can be dismantled and reassembled as many times as desired. In addition, all its components are easily demountable, repairable and reusable, so the durability of the building can be maximized and with minimal maintenance required the environmental impact per unit of time can be minimized. Likewise, its construction reduced energy consumption to a minimum, resources were optimized to the maximum and the generation of emissions and waste was greatly reduced. It could thus be expected that all the GBRSs would adequately value these environmental advantages by giving to *Sayab* a high score, although this was not the case.

Only three of the GBRSs used adequately assessed the environmental advantages of a *demountable construction* based on prefabricated concrete components (CEDES: 22.72%, DNGB: 14.79% and SBTools: 12.40%). The other GBR considered it of little value and three gave it a very low score (BEAM (1.17%), ASGB (2.06%) and IGBC (3.00%). However, the most surprising aspect of the results is the disparity in the scores obtained.

Taking into account the average scores of the 11 GBRSs, the contribution of low-weight demountability to the level of sustainability of buildings is 7.58% ((2.06 + 1.17 + 5.38 + 22.72 + 14.79 + 7.00 + 4.90 + 5.46 + 3.00 + 4.54 + 12.40) / 11 = 7.58).

However, if only CEDES, DNGB and SBTools are taken into account, the contribution of demountability to the level of sustainability of buildings is 16.63% ((22.72 + 14.79 + 12.40) / 3 = 16.63).

Table 14 Contribution of *demountable construction* to a building's sustainability level, using 11 GBRSs.



5. Discussion

In this work, the contribution of high-weight *demountable construction* to the sustainability of buildings was quantified. To this end, a building, *Sayab*, was analyzed as a representative of high-weight *demountable construction systems*, using 11 GBRSs.

The results show that low-weight *demountable and modular construction* increases a building's level of sustainability.

The study was conducted using a single case study, but the results of this case study are generalizable, since the different GBRSs used do not have the capacity to detect small changes in high-weight *demountable construction systems*. Furthermore, the study has important implications for practitioners, policy makers, and standard-setting bodies because, for the first time, an important reference can be found. If a high-weight, demountable construction is used, the increase in the building's sustainability is 16.63% according to the most appropriate GBRS.

However, it is surprising that the results obtained varied considerably. Only three GBRSs adequately assessed the sustainability of a demountable modular home, while the others considered it unimportant, and three of them gave it an extremely low score.

It is unacceptable that the level of sustainability depends on the GBRSs chosen, which suggests that the GBRSs analyzed are not suitable for adequately assessing a building's level of sustainability. However, further comparative studies should be conducted to determine whether other GBRSs are more suitable for assessing sustainability.

It should be noted that an increasing number of studies are appearing that question the validity of the current GBRSs. Some works doubt their validity due to the fact that they are very different from each other, and therefore provide different results when evaluating the same building. This is because there is no international consensus on the concept of sustainability and there is no common framework to achieve and evaluate it [41]. Other studies indicate that the current GBRSs cannot evaluate sustainability correctly since they do not consider architectural design in their scoring system [38-40, 42-44], while still others are even more critical and conclude that when analyzing many buildings designed according to some of these GBRSs, substantial energy savings or optimization of resources were compared to conventional buildings [42, 43, 45-47]. As if that were not enough, there are increasingly more works that harshly criticize the usefulness of some of the best-known GBRSs, such as LEED [48]. The current GBRSs should therefore be substantially modified or replaced by more suitable ones.

It is often argued that the different GBRSs are very different from each other due to the vast environmental and socioeconomic differences between countries. However, within a single country (China, USA, Italy, Brazil, Germany, France, etc.) there are big differences between its different regions, and there is a tendency to impose a single GBRS. On the other hand, many GBRSs have been designed to be international, and in fact, they are used in many places. Finally, there are countries where several GBRSs are often used, which are very different from each other (UK, France, Spain, Portugal, Brazil, etc.).

The real reason for the enormous differences between current GBRSs is that they have been conceived with different conceptions of sustainability, including specific economic interests [49].

Therefore, an international consensus on the concept of sustainability is needed, and based on this, a global conceptual taxonomic framework must be created under which new, more appropriate GBRSs can be created. Obviously, these GBRSs would have small differences, depending on the socio-economic and environmental context of their applicability. In fact, there are already proposals for new, more valid and legitimate GBRSs that can serve as a reference framework for developing new GBRSs at the international level [29].

However, until such a consensus is reached, existing GBRSs should be improved. To this end, two important suggestions are made. The first is that much less emphasis should be placed on the devices and much more on the design. Second, the weights of the different indicators should be adjusted to make them more balanced. In this regard, a table has been prepared with the opportunities and areas of growth for each of the 11 GBRSs used (Table 15).

Table 15 Categories, scores, opportunities and areas of growth of the 11 GBRSs.

GBRS	Categories and scoring system	Opportunities	Areas of growth
ASGB	Safety and durability, health and comfort, living comfort, resource conservation, livable environment, improvement and innovation. (1 star, 2 stars, 3 stars)	Very balanced categories and indicators. Values the innovation to carry out sustainable strategies. Categories well grouped	Too much importance to prerequisites. Official guides and tools are written only in Chinese. Does not give importance to waste/emissions
BEAM	Integrated design and construction management, sustainable site, materials and waste, energy use, water use, health and wellbeing, innovations and additions. (Diamond, Platinum, Gold, Silver, Bronze, Certified)	Values decrease in resource consumption through industrialization. The category's weights are very balanced	Too much relative importance of interior quality. The assessment must be renewed every 5 years. The assessment environment is too close
BREEAM	Management, Health and well-being, energy, transport, water, materials, waste, soil and ecology, pollution and innovation. (Unrated, Correct, Good, Very Good, Excellent, or Exceptional)	Importance of resource optimization. Values passive design	Does not give importance to natural energy. Passive design doesn't have much weight
CEDES	Optimization of resources, reduction in energy consumption, use of natural energy sources, reduction of waste and emissions, increased health and quality of life of building occupants, economic cost, social adequacy, complementary sustainable aspects. (final score: 1 to 10)	Hierarchical system of categories and indicators, avoiding oversized and undersized indicators. Design properly assessed	The weights of the categories and indicators must be adapted to each socio-economic and environmental environment
DNGB	Ecological quality, economic quality, sociocultural and functional quality, technical quality, process quality, site quality. (Bronze, Silver, Gold, Platinum)	It values life cycle, resource optimization and bioclimatic design and component recovery	Little value to energy, water consumption and waste. Too many bonus points and difficulty in scoring
GBI	Energy efficiency, indoor environment quality, planning and sustainable management of the site, materials and resources, water efficiency, innovation. (Platinum, Gold, Silver, Certified)	The buildings continue to be evaluated in their use. Easy to use	Does not value design and disassembly. Little value to economy. High value to site
GG	Project management, site, energy, water efficiency, materials, and indoor environment. (One to four green globes)	It includes design for deconstruction, modular and prefab construction	Does not give importance to natural energy sources

Table 15 to be continued

GS	Management, indoor environmental quality, energy, transportation, water, materials, land use and ecology, emissions and innovation. (1 star, 2 stars, 3 stars, 4 stars, 5 stars, 6 stars)	It values bioclimatic design, construction and monitoring	It does not value the use of natural energy sources
HQE	General aspects, quality of life, respect for the environment, economic performance. (Approved, Good, Very Good, Excellent, Exceptional)	Takes into account the local context. It refers to the disassembly of the building	Too much importance to equipment performance. Does not give much importance to bioclimatic design
LEED	Integrative process, location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation, regional priority. (Platinum, Gold, Silver, Certified)	It has a relatively simple operation	It does not give importance to bioclimatic design. In many categories points can be added using technology
SBTools	Site development and infrastructure, energy and resource consumption, indoor environmental loads, environmental quality, service quality, social, cultural and perceptual aspects, costs and economic aspects. (-1 , 0, 1, 3, 5)	Adaptable to all regions with their cost variation. International	Little importance to indoor air quality. Gives much importance to energy consumption and site

6. Conclusions

This work has quantified for the first time the contribution of high-weight *demountable construction systems* to the sustainable level of buildings. For this, a demountable and a non-demountable buildings were assessed by 11 GBRSs and the results obtained were compared. The chosen GBRSs were: ASGB, BEAM, BREEAM, CEDES, DNGB, GBI, GG, GS, IGBC, LEED and SBTools. The building analyzed, *Sayab*, is completely demountable, and its components can be easily assembled and disassembled, so they can be easily removed from the building, repaired and reused as many times as necessary to extend its durability to the maximum and reduce its environmental impact per unit of time to the minimum.

Taking into account the considerable environmental benefits of demountable construction (maximum durability, minimum environmental impact per unit of time, reduced emissions and waste, optimized resources, low energy consumption, elimination of programmed obsolescence, etc.), one would expect all GBRSs to rate them appropriately, providing a high score. However, that has not been the case.

Although the eleven GBRSs used gave a higher level of sustainability to the demountable building, eight gave it very low scores, despite its obvious environmental benefits, and only three GBRSs have provided a more adequate score. Aditionally, the scores of the eleven GBRSs varied widely, which is unacceptable, since the same building obtained different scores depending on the GBRSs used.

The study's first conclusion is that, based on the results obtained, the GBRSs that best assess high-weight *demountable construction* are CEDES, DNGB and SBTools. Therefore, and if only these three GBRSs are taken into account, the contribution of demountability to the level of sustainability of buildings is 16.63%. The results of this case study are very generalizable, since the different GBRSs can hardly differentiate one demountable construction system from another.

The second conclusion is that most current GBRSs cannot correctly assess sustainability and should be modified.

Of course, more studies must be conducted, and different GBRSs must be used. But with this study, professionals who wish to build completely demountable buildings now have a reference for the sustainable level they can add to their buildings.

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National Association for Sustainable Architecture [51], in Spain. In this Master, the 16 GBRSs analyzed are studied in depth.

References

[1] Chewe Ngapeya, G., and Waldmann, D. 2021. "Design Model for Dry-Stacked and Demountable Masonry Blocks." *ORBIlu Support.* http://hdl.handle.net/10993/46894.

[2] Croonen, L. 2020. "A Sustainable and Reusable Concrete Facade System." Master's thesis, TU Delft Architecture and the Built Environment. http://resolver.tudelft.nl/uuid:ff156480-0d96-4530-90d5-a6234d6f6b68.

[3] Fayyad, T., and Abdalqader, A. 2020. "Demountable Reinforced Concrete Structures: A Review and Future Directions." *Civil Engineering Research in Ireland 2020* 5: 5. https://event.ceri2020.exordo.com/.

[4] Figueira, D., Ashour, A., Yıldırım, G., Aldemir, A., and Şahmaran, M. 2021. "Demountable Connections of Reinforced Concrete Structures: Review and Future Developments." *Structures* 34: 3028-39. https://doi.org/10.1016/j.istruc.2021.09.053.

[5] Jamil , M., Zain, M., and Sadafi, N. 2014. "Structural and Functional Analysis of an Industrial, Flexible, and Demountable Wall Panel System." *International Journal of Engineering* 27 (2): 247-60. doi:10.5829/idosi.ije.2014.27.02b.09.

[6] Moradi, M., Valipour, H., Foster, S., and Bradford, M. 2016. "Deconstructable Steel-Fibre Reinforced Concrete Deck Slabs with a Transverse Confining System." *Materials & Design* 89: 1007-19. https://doi.org/10.1016/j.matdes.2015.10.059.

[7] Morice, P., and Base, G. 2015. "The Design and Use of a Demountable Mechanical Strain Gauge for Concrete Structures." *Magazine of Concrete Research* 5 (13): 37-42. https://doi.org/10.1680/macr.1953.5.13.37.

[8] Odenbreit, C., and Kozma, A. 2020. "Demountable and Reusable Construction System for Steel-Concrete Composite Structures." In *Life-Cycle Civil Engineering: Innovation, Theory and Practice*, pp. 521-528, edited by A. Chen, X. Ruan, and D. Frangopol. doi:10.1201/9780429343292-66.

[9] Pavlović, M., and Veljković, M. 2017. "Prefabricated Demountable Concrete and FRP Decks in Composite Structures." *Ce/papers* 1: 1889-98. https://doi.org/10.1002/cepa.233.

[10] Akanbi, L., Oyedele, L., Omoteso, K., Bilal, M., Akinade, O., Ajayi, A., Dávila Delgado, J. M., and Owolabi, H. 2019. "Disassembly and Deconstruction Analytics System (D-DAS) for Construction in a Circular Economy." *Journal of Cleaner Production* 223: 386-96. https://doi.org/10.1016/j.jclepro.2019.03.172.

[11] Boedianto, P., and Walraven, J. 2000. "Optimizing the Environmental Impact of Demountable Building." In *International Symposium on Intergrated Life-Cycle Design of Materials and Structures*, pp. 135-141, edited by A. Sarja.

[12] Cruz Rios, F., Chong, W., and Grau, D. 2015. "Design for Disassembly and Deconstruction—Challenges and Opportunities." *Procedia Engineering* 118: 1296-304. https://doi.org/10.1016/j.proeng.2015.08.485.

[13] Negrin, F., and Plitt, T. 2019. "Designer Demountable." *Sanctuary: Modern Green Homes* 48: 16-21. https://www.jstor.org/stable/26906361.

[14] Ortlepp, S., Masou, R., and Ortlepp, R. 2015. "Demountable Construction for Sustainable Buildings." *High Performance Fiber Reinforced Cement Composites (HPFRCC)*. Vol. 7. Stuttgart.

[15] Ortlepp, S., Masou, R., and Ortlepp, R. 2017. "Green Construction Methods of Buildings Capable for Disassembly to Support Circular Economy." In *Challenges for Technology Innovation: An Agenda for the Future*, edited by F. da Silva, H. Bártolo, P. Bártolo, R. Almendra, F. Roseta, H. Almeida, and A. Lemos. London: Taylor & Francis Group. https://doi.org/10.1201/9781315198101.

[16] Reinhardt, H. 2018. "Demountable Concrete Structures—An Energy and Material Saving Building Concept." *International Journal of Sustainable Materials and Structural Systems* 1 (1): 18-28. doi:10.1504/IJSMSS.2012.050452.

[17] Salama, W. 2018. "Design for Disassembly as an Alternative Sustainable Construction Approach to Life-Cycle-Design of Concrete Buildings." Doctoral thesis, Gottfried Wilhelm Leibniz University. https://doi.org/10.15488/5121.

[18] Pai, V., and Elzarka, H. 2021. "Whole Building Life Cycle Assessment for Buildings: A Case Study on How to Achieve the LEED Credit." *Journal of Cleaner Production* 297: 126501. https://doi.org/10.1016/j.jclepro.2021.126501.

[19] De Garrido, L 2025. "Aportación de los sistemas estructurales desmontables de hormigón prefabricado en el nivel de sostenibilidad de un edificio." International Congress EDIFICATE, 13-14 November 2025. Burgos University. Building Engineering Faculty.

[20] De Garrido, L. 2025. "Quantifying the Joint Contribution of Demountable Construction and Bioclimatic Design to a Building's Sustainability. Case Study: Beardon Eco-House." *Journal of Sustainable Development* 18 (6): 133-59. https://doi.org/10.5539/jsd.v18n6p133.

[21] De Garrido, L., and Picco, N. 2025. "Ventajas sostenibles y eficiencia energética de la construcción modular y

bioclimática." International Congress iENER, 3-4 July 2025. Universidad Politécnica de Madrid. Mining and Energy Engineering Faculty.

[22] ASGB. 2019. "Assessment Standard for Green building." Accessed 1 November 2024. https://www.eia543.com/documents/14%E5%BB%BA%E7%AD%91%E8%AE%BE%E8%AE%A1%26%E5%AE%A4%E5%86%85%E7%A9%BA%E6%B0%94%E6%B1%A1%E6%9F%93%E7%A0%94%E7%A9%B6/%E7%BB%BF%E8%89%B2%E5%BB%BA%E7%AD%91%E8%AF%84%E4%BB%B7%E6%A0%87%E5%87%86%EF%BC%88GB%20T%2050378-2019%EF%BC%89.pdf.

[23] BEAM. 2024. "Building Environmental Assessment Method HK-BEAM Plus. 4/04 New Buildings—Technical Manual." Accessed 1 November 2024. https://www.ibeam.hk/public/knowledgeDatabase/?tab=downloadArea https://www.beamsociety.org.hk/files/_4-04%20New%20Buildings%20(Full%20Version).pdf. https://www.beamsociety.org.hk/en/BEAM-Plus/BEAM-Plus-New-Buildings.

[24] BREEAM. 2018. "BREEAM UK New Construction 2018 3.0—Technical Manual." https://breeam.es/manuales-tecnicos.

[25] BREEAM. 2019. "Building Research Establishment Group. BREEAM Worldwide. 2019." https://www.breeam.com/worldwide.

[26] BREEAM. 2019. "Building Research Establishment Environmental Assessment Method ES." http://www.breeam.es/.

[27] BREEAM. 2017. "BREEAM International: Watford, UK, 2017." Accessed 1 November 2024. https://hbreavis.com/wp-content/uploads/2017/06/BREEAM-International-New-Construction-2016.

[28] CEDES. 2024. "CEDES Technical Manual GBRS Designed by National Association for Sustainable Architecture in Spain." Accessed 1 November 2024. https://www.anas-sostenible.com/.

[29] De Garrido, L 2025. "CEDES: A Complete, Legitimate and Seamless Green Building Rating System." *Journal of Sustainable Development* 18 (6): 42-76. https://doi.org/10.5539/jsd.v18n6p42.

[30] DGNB. 2023. "Deutsche Gesellschaft für Nachhaltiges Bauen DNGB System 2023—Technical Manual." Accessed 1 November 2024. https://www.dgnb.de/en/certification/buildings/new-construction/version-2023.

[31] GBI. 2014. "Green Building Index 2014 V. 3.1—Technical Manual." https://www.greenbuildingindex.org/gbi-tools/. https://www.greenbuildingindex.org/Files/Resources/GBI%20Tools/RNC%20Reference%20Guide%20V3.1.pdf (residential buildings). Accessed 1 November 2024. https://www.greenbuildingindex.org/Files/Resources/GBI%20Tools/RNC%20Reference%20Guide%20Amendment%20Notes%203.1.pdf.

[32] GG. 2022. "Green Globes Green Globes New Construction 2021—Technical Reference Manual Version 1.0—September 2022." Accessed 1 November 2024. https://thegbi.org/wpcontent/uploads/2022/11/Green_Globes_NC_2021_ES__BEQ_Technical_Reference_Manual.pdf.

[33] GS. 2022. "Green Star Green Star Design & As Built V1.2—Technical Manual." https://s3.ap-southeast-2.amazonaws.com/hdp.au.prod.app.nthbchyoursay.files/1415/6214/8137/2018_701322__Green_Star_Design_and_As_Built_Submission_Guidelinev1.2_GBCA_1.PDF. Accessed 1 November 2024. https://www.gbca.org.au/shop/green-star-rating-tools/#.

[34] IGBC. 2019. "Indian Green Building Council IGBC Green New Buildings Rating Systems V3.0—Technical Manual." Accessed 1 November 2024. https://igbc.in/igbc-green-homes.php.

[35] LEED. 2019. "Leadership in Energy and Environmental Design LEED v4.1 Residential BD+C Multifamily Homes—Technical Manual." https://www.usgbc.org/tools/leed-certification/homes_CLASIFICACION.pdf. Accessed 1 November 2024. http://www.spaingbc.org/web/leedv4-1-bd+c.php.

[36] SBTool. 2022. "SBtools for Performance Assessment 2022." Accessed 1 November 2024. https://www.iisbe.org/sbmethod.

[37] Sayab. 2024. https://luisdegarrido.com/es/proyectos-realizados/sayab/.

[38] De Garrido, L. 2012. *A New Paradigm in Architecture*. Barcelona: Monsa. ISBN:978-84-152-2375-7.

[39] De Garrido, L. 2017. *Manual of Advanced Ecological Architecture*. Florida: Editorial Nobuko Design. ISBN:978-98-74160126.

[40] De Garrido, L. 2023. *Luis De Garrido. Dream Green Architecture. International Houses.* Florida: Nobuko Design. ISBN:978-987-29499-1-4.

[41] Andújar, J. M., Gómez, S., and Sánchez, A. 2020. "Green Building Rating Systems and the New Framework Level(s): A Critical Review of Sustainability Certification within Europe." *Energies* 13 (1): 66. https://doi.org/10.3390/en13010066.

[42] Chen, X., Yang, H., and Lu, L. 2015. "A Comprehensive Review on Passive Design Approaches in Green Building Rating Tools." *Renewable and Sustainable Energy Reviews, Elsevier* 50 (C): 1425-36. https://doi.org/10.1016/j.rser.2015.06.003.

[43] Katiyar, M., Sahu, A. K., Agarwal, S. K., and Tiwari, P. K. 2021. "Role of Spatial Design in Green Buildings—A Critical Review of Green Building Rating Systems." *IOP Conference Series: Materials Science and Engineering 1116* 1: 12-166. https://doi.org/10.1088/1757-

899x/1116/1/012166.

[44] Lee, W. 2013. “A Comprehensive Review of Metrics of Building Environmental Assessment Schemes.” *Energy and Buildings* 62: 403-13. https://doi.org/10.1016/j.enbuild.2013.03.014.

[45] Scofield, J. H. 2009. “Do LEED-Certified Buildings Save Energy? Not Really…” *Energy and Buildings* 41: 1386-90. https://doi.org/10.1016/j.enbuild.2009.08.006.

[46] Scofield, J. H., and Cornell, J. 2019. “A Critical Look at Energy Savings, Emissions Reductions, and Health Co-benefits of the Green Building Movement”. *Journal of Exposure Science & Environmental Epidemiology* 29: 584-93. https://www.nature.com/articles/s41370-018-0078-1.pdf.

[47] Conniff, R. 2017. “Why Don’t Green Buildings Live Up to Hype on Energy Efficiency?” *Yale Environment 360*. New Haven, CT. https://e360.yale.edu/features/why-dont-green-buildings-live-up-to-hype-on-energy-efficiency.

[48] Scofield, J. H., and Doane, J. (2018). “Energy Performance of LEED-Certified Buildings from 2015 Chicago Benchmarking Data.” *Energy and Buildings* 174: 402-13. https://doi.org/10.1016/j.enbuild.2018.06.019.

[49] De Garrido, L., and Paya-Laforzeta, I. 2025. “Análisis comparativo de los principales sistemas de evaluación sostenible de edificios.” International Congress EDIFICATE, 13-14 November 2025. Burgos University. Building Engineering Faculty.

[50] MAS. 2024. “Advanced Master in Sustainable, Bioclimatic and Self-Sufficient Architecture (M.A.S.).” Accessed 1 November 2024. www.masterarquitectura.info.

[51] ANAS. 2024. “Asociación Nacional para la Arquitectura Sostenible, España.” Accessed 1 November 2024. www.anas-sostenible.com.