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# Vitrohouse. A Demountable House Built Entirely with Flat Glass. Technical, Bioclimatic, and Sustainable Analysis

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**Abstract:** This study shows a technical, bioclimatic, and sustainable analysis of the first demountable house built entirely from glass components, *Vitrohouse*. The technical analysis details the construction challenges overcome to create a demountable house using only flat glass for all components (foundations, slabs, supporting structure, beams, roof, envelope, furnishings, kitchen fixtures, appliances). Secondly, we analyze the thermal and bioclimatic behavior of this demountable all-glass house to evaluate its energy efficiency. We also assess the contribution of *Vitrohouse*'s bioclimatic design to its sustainability level, using 11 of the most internationally recognized GBRSs (*Green Building Rating Systems*), demonstrating that it achieves a higher degree of sustainability than a conventional, non-bioclimatic home of the same size. Thirdly, we analyze the contribution of *Vitrohouse*'s demountable nature, showing that it has a higher level of sustainability than a conventionally built house. Finally, the sustainable analysis of its demountability is quantified using 11 GBRSs. The results show that it is perfectly feasible to construct buildings solely from flat glass, achieving high energy efficiency and sustainability. Furthermore, the glass components can be easily disassembled and reused, or recycled to manufacture new components with minimal energy consumption.

**Key words:** Flat glass construction, house made with glass, bioclimatic design, sustainable assessment, demountable construction, Green Building Rating System.

## 1. Introduction

This study explores the potential of constructing buildings entirely from flat glass. To this end, we analyze the first house built solely with this material, *Vitrohouse*. Specifically, we examine the key construction challenges that were overcome, its bioclimatic behavior and its overall level of sustainability.

While there is vast literature on the use of flat glass in construction [1-7], no studies focus on buildings made exclusively from it. Similarly, the advantages of *bioclimatic design*—such reduced energy consumption, emissions, and waste, alongside improved quality of life and occupant health—are well documented [8-16]. However, most studies focus on a single comparative variable, such as energy consumption [8, 10, 15, 17-20], There are very few studies evaluating *bioclimatic design* with various GBRSs (*Green Building Rating Systems*) [21, 22], and the literature lacks references to bioclimatic buildings made entirely with glass, as they are often assumed to perform poorly (e.g., lower insulation, less solar protection, greater overall warming due to the greenhouse effect, etc.).

Likewise, demountable construction has been extensively studied [23-33], with many references highlighting its environmental and sustainability advantages [34-41], but there are very few studies

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evaluating *demountable construction* with various GBRSs [42, 43].

However, there are no references to demountable buildings made solely of glass, nor are there quantitative analyses of how demountability contributes to the sustainability of glass buildings.

To evaluate the overall level of sustainability of buildings, multivariate assessment tools, called GBRSs (*Green Building Rating Systems*) have been developed. GBRSs use multiple indicators, (energy, resources, emissions, waste, etc.), to provide a final score on sustainability. However, these tools have not previously been used to quantify the sustainable level of *demountable construction*.

Therefore, this study analyzed *Vitrohouse* from three perspectives: Section 2 describes the house and analyzes the innovative technical and construction solutions. Section 3 studies the bioclimatic strategies and quantifies the sustainability level achieved through bioclimatic design. Section 4 quantifies the level of sustainability achieved by its demountable design, which allows for the easy repair, reuse, and recycling of its components.

## 2. Technical Analysis of *Vitrohouse*

### *2.1 Vitrohouse. General Information*

*Vitrohouse* is a house with a surface area of 126 $m^2$, and consisting of a living-dining room, a kitchen, two bathrooms, two bedrooms, a central patio and two machine rooms (Figs. 1-5). *Vitrohouse* was built in 2005 and can be assembled and disassembled as many times as desired. In fact, since its construction it has been disassembled and reassembled twice [44, 45].

The most important feature of *Vitrohouse* is that it was built entirely with flat glass: foundations, walls, pillars, beams, enclosures, kitchen furniture, toilets, floors, roofs, plumbing, etc. *Vitrohouse* was built to demonstrate that fully demountable buildings can be constructed without mortar, adhesives, screws, rivets, etc., simply by fitting the pieces together with an elaborate design. Therefore, the most difficult material possible was chosen: glass. And it was demonstrated that a demountable glass building can be constructed, capable of withstanding all exterior stresses and any habitability requirements. Undoubtedly it was a technological challenge undertaken with the desire to

**Fig. 1 *Vitrohouse* was built using only removable components made of flat glass (project by Luis de Garrido).**

**Fig. 2** ***Vitrohouse*** **is an energy-self-sufficient home that integrates fresh air-capturing chimneys, solar thermal collectors, and photovoltaic solar collectors (project by Luis de Garrido).**

**Fig. 3** ***Vitrohouse*** **integrates green roofs, water roofs, and vertical gardens despite being built with glass.**

**Fig. 4 The central roof of *Vitrohouse* is composed of two layers of flat glass and integrates solar panels on its exterior, which in turn provide thermal insulation and solar protection to the interior.**

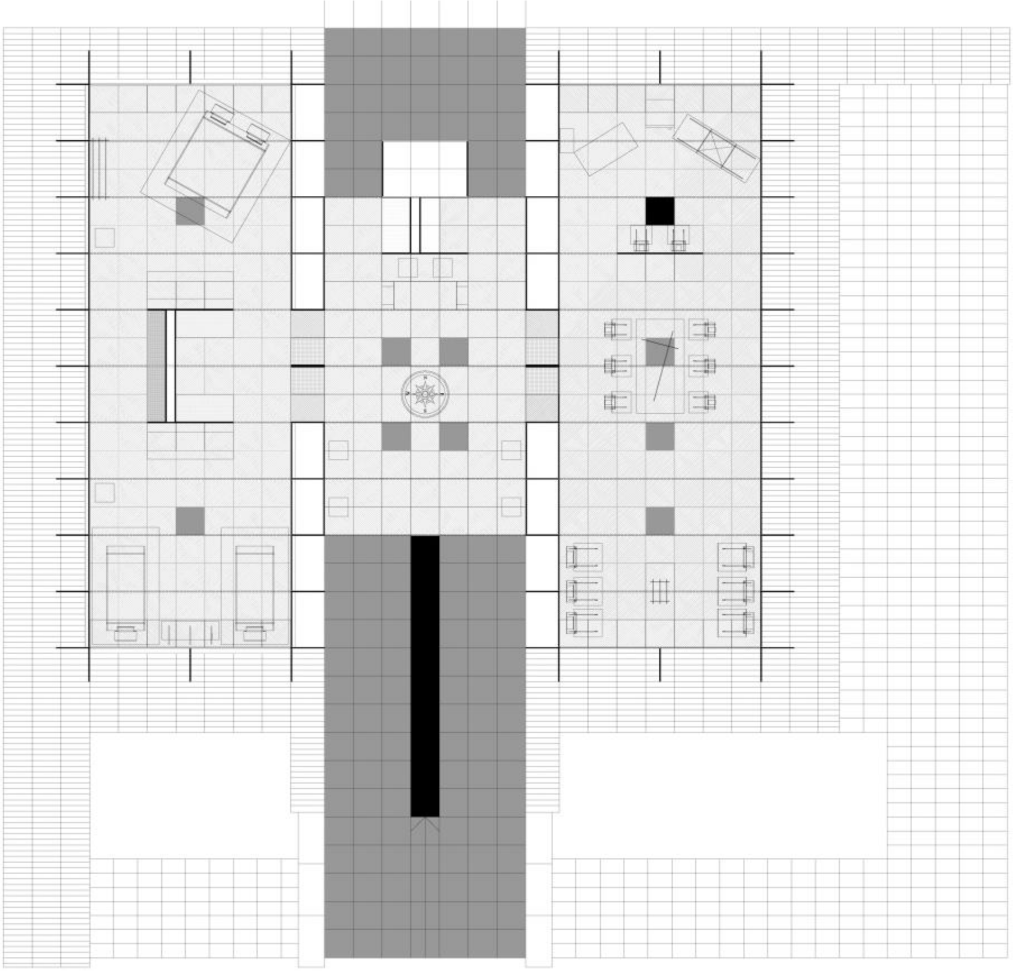


**Fig. 5 Vitrohouse ground floor layout.**

promote the industrialization and complete demountability of buildings.

Since glass is transparent, several strategies have been used to ensure the privacy of its occupants, to protect them from solar radiation, and to ensure proper thermal insulation.

To ensure privacy and solar protection, three strategies have been implemented:

1. Use of glass whose transparency can be adjusted using a small electric current;

2. Use of several layers of colored glass;

3. Adjustable blinds have been installed between the layers of flat glass.

To ensure thermal insulation, three layers of glass have been arranged in the envelope, creating two air chambers. The inner chamber is airtight, and the outer is ventilated.

*2.2 Demountable Design with Flat Glass Components*

*Vitrohouse* is built using flat glass components assembled without adhesives or screws, simply by fitting together (Figs. 6-10). The structure of *Vitrohouse* is composed of flat glass porticos. Each glass portico consists of two groups of three laminated flat glass pillars 25 mm thick (8+8+8) and 70 cm wide on each side, and a laminated flat glass beam, also 25 mm thick (8+8+8) and 70 cm wide. The beams are joined to each group of three pillars by a simple and ingenious metal profile (Fig. 11). This small profile holds the three flat glass pillars together at the top and also serves as a support for the flat glass beams. The laminated flat glass pillars are also supported at the bottom by the laminated glass panels that serve as their foundation. The laminated glass beams have small sheets of laminated flat glass on their upper parts (8+8+8), which in turn support horizontal panels of laminated flat glass (6+6+6) (Fig. 12). These panels slope along the perimeter of the house, forming a container to house the soil for the roof garden (Figs. 12, 13). As a result of


**Fig. 6** ***Vitrohouse* was built in Barcelona and has been dismantled and reassembled twice.**


**Fig. 7** ***Vitrohouse*'s architectural envelopes are highly varied and include a triple glass skin with two air chambers: a sealed inner chamber and a ventilated outer chamber. The outer chamber includes blinds that regulate sunlight from zero to 100%.**


**Fig. 8** **The left side of *Vitrohouse* incorporates glass whose opacity changes through small electric currents, regulating privacy and solar protection.**


**Fig. 9 The right side of *Vitrohouse* is completely transparent, and thermal insulation is achieved by injecting hot or cold air into the triple skin of the architectural envelope. The air is drawn in from inside the house as it is renovated.**

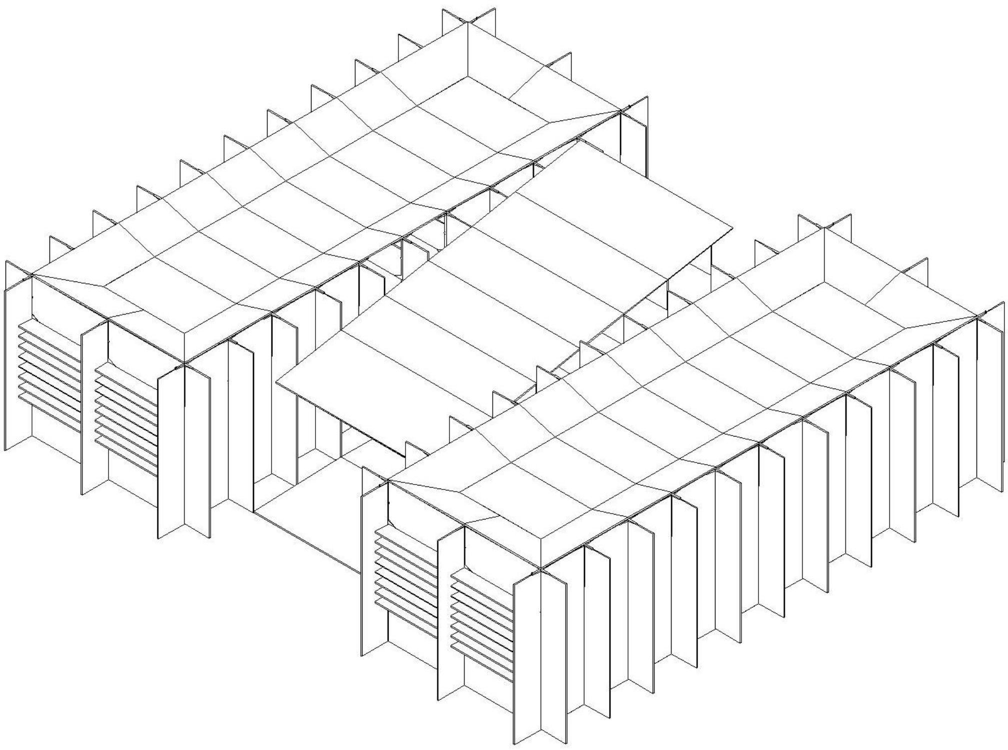


**Fig. 10 Exploded view of all *Vitrohouse*'s removable components. All have been joined together without adhesives, screws, or any other mechanical means.**

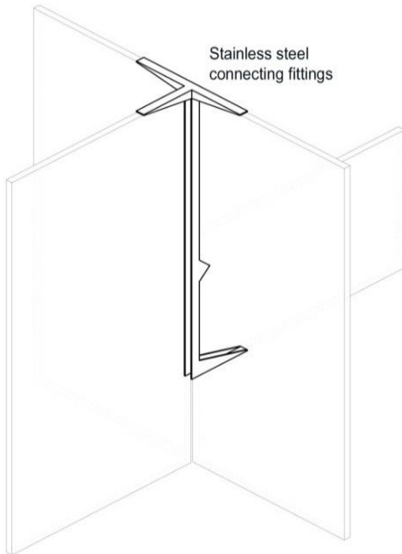



**Fig. 11 This special profile is the only *Vitrohouse* element not made of glass. It holds three flat glass pillars together with a flat glass beam without the use of glue, screws, or any other fastening method.**

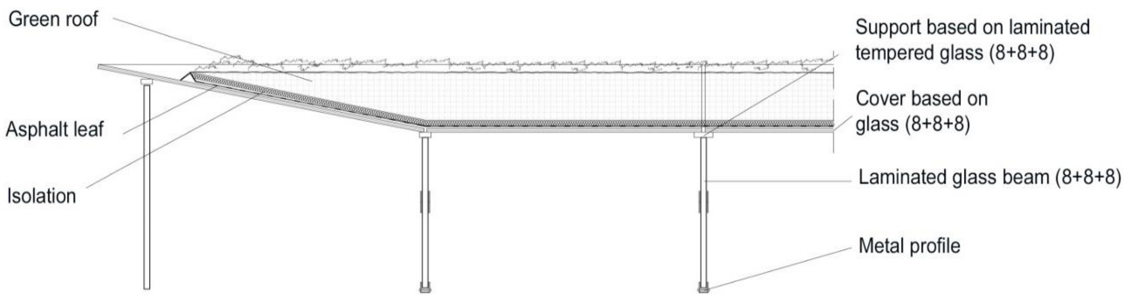



**Fig. 12 Detail of the *Vitrohouse* green roof.**

this articulated and assembled arrangement of laminated flat glass panels, all *Vitrohouse* components can be easily removed, repaired, and reused indefinitely. In this way the building can have a durability that tends to infinity and the least possible need for maintenance.

*Vitrohouse* is composed of flat laminated glass porticos assembled together, creating an articulated spatial grid capable of absorbing all types of external stresses and remaining stable everitime. The most complicated structural element to construct was the wind catcher, as it was constructed from laminated glass panels resting on their perimeter edges, one on top of the other, and in turn had to support the weight of the solar thermal collectors.

*2.3 Interior Design and Removable Glass Furniture*

The furniture and all the interior elements of the home are also made of flat glass. All the furniture has been designed solely from pieces of flat glass assembled together, without using any connecting elements. The furniture is sturdy and stable, yet can be easily disassembled (Figs. 14-18).

*2.4 Research and Testing on the Strength of Flat Glass*

There is no precedent for using flat glass as a structural element in foundations, pillars, beams, etc. Therefore, a large number of laboratory tests were conducted to determine the strength characteristics of flat glass. Multiple load tests were also performed to verify the resistance of the designed porticos to different combinations of external loads. A safety factor of 2.33 was also used (Fig. 19).

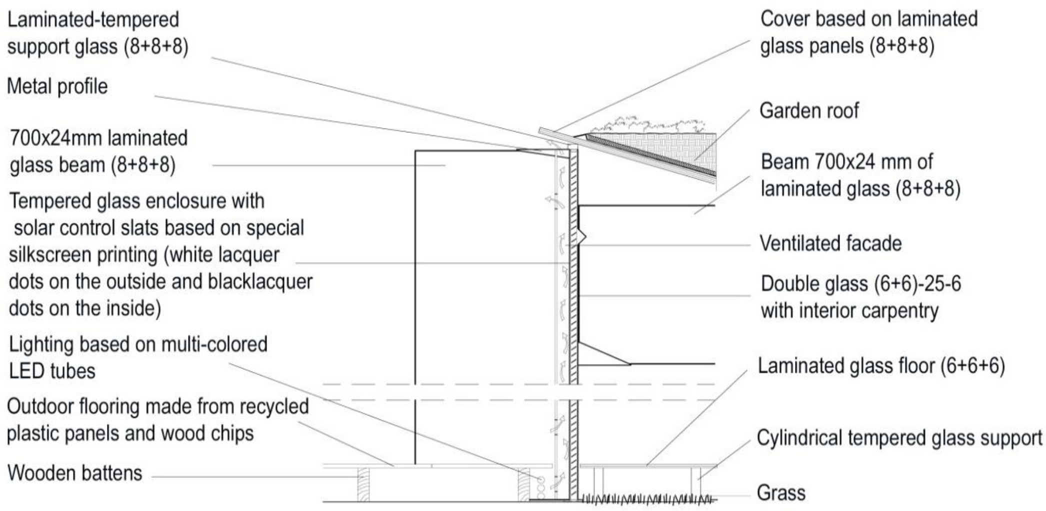



**Fig. 13 Detail of the junction of the architectural envelope with the green roof. The two insulating chambers can be seen: the ventilated outer chamber and the sealed inner chamber with adjustable sunshades.**

**Fig. 14 Wall-hung glass toilet. Faceted glass walls.**

**Fig. 15 Glass floors, walls and sinks.**

**Fig. 16 Glass overlay on natural grass. Flat glass beds and furniture.**

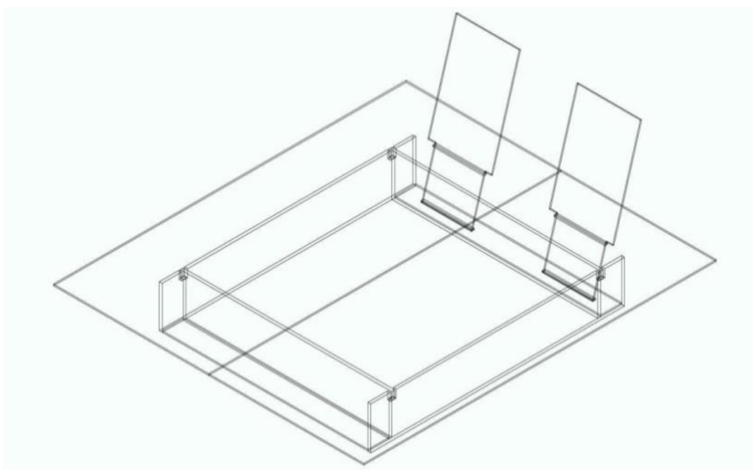


**Fig. 17 Glass bed made with only 8 pieces of flat glass assembled by pressure, without glue or screws.**

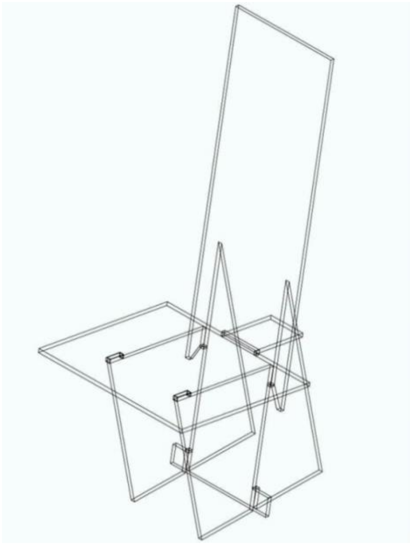


**Fig. 18 Glass chair made with only 4 pieces of flat glass assembled by pressure, without glue or screws.**

**Fig. 19 Load testing of one of the glass frames. The glass beam and pillars withstood point loads of 7,000 kg on several occasions. The maximum load the frame can withstand in the building is 3,000 kg, so the safety factor adopted is 2.33 (Luis de Garrido in front of the load test, confident in his calculations. The rest of the workers barricaded themselves behind protective barriers).**

*2.5 Vitrohouse's Sustainable Features*

*Vitrohouse* meets high ecological and sustainable standards [44, 45], including the following:

1. Resource optimization:

Optimization of industrialized manufacturing;

Ease of repair and reuse;

Easy disassembly;

Ease of recycling.

2. Energy consumption:

Bioclimatic design, despite being built with glass;

Energy self-sufficiency.

3. Waste and emissions generation:

Zero waste or emissions generation.

4. Price:

Market price;

Very fast construction.

5. Health and well-being:

No emissions, noise, vibrations, unpleasant odors, nothing that affects health and well-being;

Technical safety in construction.

6. Maintenance:

Minimal maintenance.

7. Adaptability to new uses and easy reconfiguration of the building.

However, the two most important features of *Vitrohouse* are its bioclimatic design and the fact that it is a demountable building, despite it was built only with flat glass. Therefore, the contribution of *Vitrohouse*'s bioclimatic design to its overall sustainable level is quantified below, and the contribution that detachability provides to *Vitrohouse*'s sustainable level is likewise quantified.

## 3. Bioclimatic Analysis of *Vitrohouse*

This section analyzes its overall thermodynamic and bioclimatic behavior and quantifies the contribution of bioclimatic design to *Vitrohouse*'s overall sustainability.

It might seem that a building made entirely of glass would become excessively hot in the summer and too cold in the winter, but this is not the case. *Vitrohouse*'s architectural envelope features a triple glass skin (with two air chambers), and in some places a quadruple glass skin (with three air chambers), which provide the necessary insulation and adequate solar protection. Furthermore, the highly insulated green roofs with high thermal inertia provide significant solar protection.

*3.1 Bioclimatic Design*

In this study, *bioclimatic design* is defined as the ability to maintain a comfortable and constant indoor temperature (19-25 °C) without the need for heating or air conditioning. Achieving this requires good professional skills, although in extreme climates, heating may occasionally be necessary. The energy savings of bioclimatic design are often measured as the "bioclimatic level".

*3.2 Description of the Bioclimatic House: Vitrohouse*

3.2.1 Heat Generation Due to Bioclimatic Design

The house heats itself in winter thanks to several special design features (Fig. 20), including:

- North-south orientation;
- Most windows on the south facade;
- High thermal inertia inside the enclosure;
- Adequate insulation on the exterior of the enclosure;
- Adequate greenhouse effect that generates the necessary thermal energy;
- Solar shading allows maximum solar radiation in winter;
- Main rooms facing south and service rooms facing north.

The windows located on the east, west and south side of the house (with a surface area of approximately 45 m²) generate an average of 13,500 W of heating in winter (as approximately 300 W/m² passes through the glass). The house's occupants and the energy losses from the refrigerator and other appliances provide an additional 1,500 W of heating. In other words, the house is capable of generating around 15,000 W of thermal power, enough to heat its main rooms (it is estimated that the entire house has a need of 14,210 W). *Vitrohouse* thus maintains an interior temperature of 22 °C in winter and does not need heating appliances.

3.2.2 Cold Generation Due to Bioclimatic Design

The house cools itself in summer thanks to several special design features (Fig. 21), including:

- North-south orientation;
- High thermal inertia inside the enclosure;
- Adequate insulation on the exterior of the enclosure;
- Cooling generation in underground galleries;
- Cooling generation through optimized interior nighttime ventilation;
- Solar shading minimizes solar radiation into the building in summer;
- Served spaces to the south and auxiliary service spaces to the north.

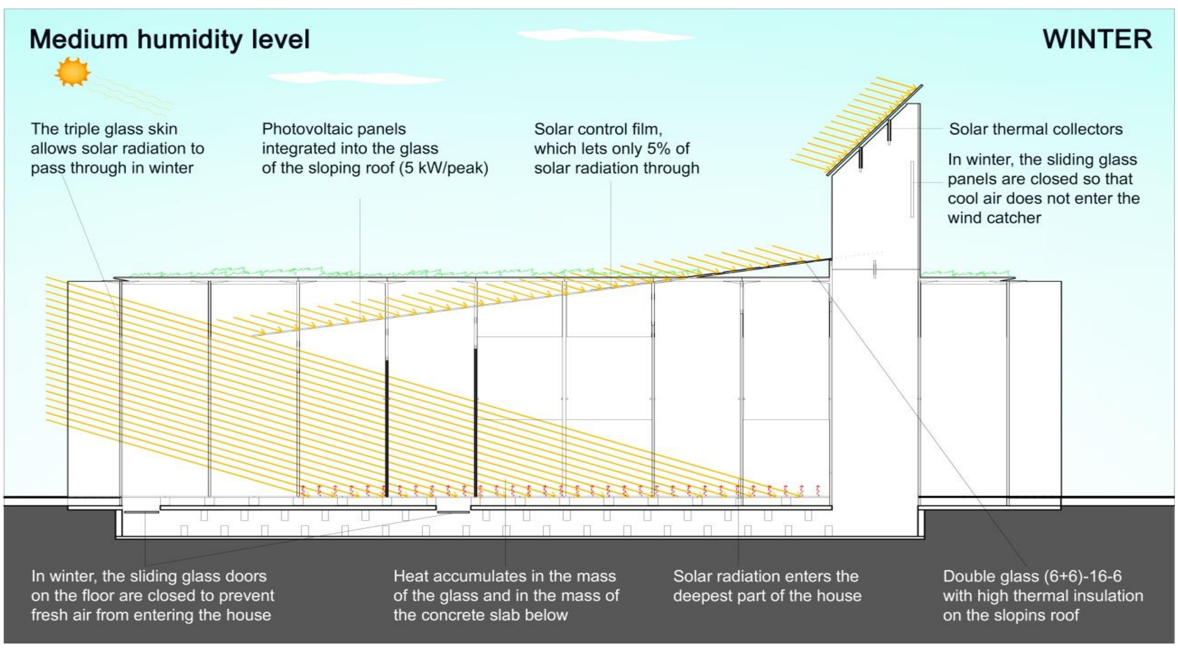



**Fig. 20 Bioclimatic behavior of *Vitrohouse* in winter.**

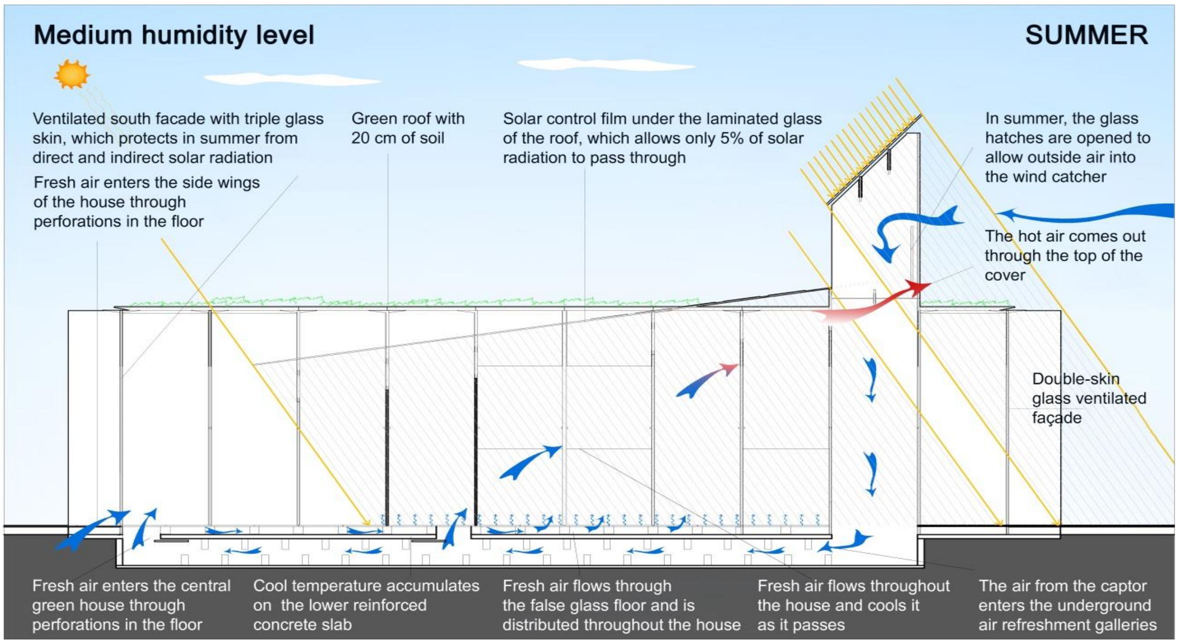



**Fig. 21 Bioclimatic behavior of *Vitrohouse* in summer.**

In addition, *Vitrohouse* has underfloor cooling powered by a small geothermal heat pump powered by photovoltaic panels. The photovoltaic panels have a power of 7,000 W, 3,000 W for the needs of the house and 4,000 W for the geothermal heat pump.

3.2.3 Energy Consumption of *Vitrohouse*

Thanks to the bioclimatic design, the housee does not require heating, air conditioning, or mechanical ventilation. Since the owners are committed to minimizing energy consumption, the house has very few appliances, with a total power of 3,406 W (Table 1) and an annual consumption of 43.37 kWh/m² (Table 2).

**Table 1 Total power of the appliances in *Vitrohouse.***

| | |
|---|---|
| Fridge | 75 W (average power) |
| Induction hob | 900 W |
| Microwave | 200 W |
| Washing machine | 800 W |
| TV | 150 W |
| PCs | 100 W |
| Lighting | 196 W |
| Water purification | 985 W |
| Total power: | 3,406 W |

**Table 2 Total energy consumption per m$^2$ of *Vitrohouse.***

| Surface 126 m$^2$ | Power | Active time | Energy per year | Energy year/m2 |
|---|---|---|---|---|
| | W (watts) | (hours) | (kwh/year) | (kwh/m$^2$/year) |
| Fridge (average power) | 75 | 24 h. * 365 | 657 | 5.21 |
| Induction hob | 900 | 2 h. * 365 | 657 | 5.21 |
| Microwave | 200 | 1 h. * 365 | 73 | 0.57 |
| Washing machine | 800 | 1 h. * 365 | 292 | 2.31 |
| TV | 150 | 8 h. * 365 | 438 | 3.47 |
| PC's | 100 | 8 h. * 365 | 292 | 2.07 |
| Lighting | 196 | 8 h. * 365 | 572.3 | 4.54 |
| Water purification | 985 | 1 h. * 365 | 359.5 | 2.85 |
| Cooling devices | 2,000 | 6 h. * 180 | 2,160 | 17.14 |
| Total energy consumed per m$^2$: 43.37 kwh/m$^2$/year | | | | |

### *3.3 Description of the No-bioclimatic House: Vitrohouse-No-Bio*

To measure the differential score that each GBRS (*Green Building Rating System*) gives to *bioclimatic design*, the *Vitrohouse* sustainability score was compared to that given to a reference baseline: a no-bioclimatic house with the same characteristics, known as *Vitrohouse-no-bio*. It was assumed that the *Vitrohouse-no-bio* house has the same shape and characteristics as the *Vitrohouse*, but has not a bioclimatic design. Therefore, the remaining characteristics are not important.

In Barcelona, the average power required for heating and air conditioning systems is at least 70 W/m², although systems are typically sized with an average power of 90 W/m². Therefore, the *Vitrohouse-no-bio* house should incorporate a heating and air conditioning system with a minimum power of 8,820 W (126 m² * 70 W/m² = 8,820 W). In this way, the total power of *Vitrohouse-no-bio* devices would be at least 12,226 W (8,820 W + 3,406 W) (Table 1), and their energy consumption (per m²) would be 77.65 kWh/m²/year (Table 3).

Therefore, *Vitrohouse* consumes only 55.85% of the consumption of *Vitrohouse-no-bio* (43.37 kWh/m²/year/77.65 kWh/m²/year = 55.85%), so the *bioclimatic design* of *Vitrohouse* has generated a minimum energy saving of 44.15%.

### *3.4 Comparative Evaluation of Vitrohouse and Vitrohouse-No-Bio*

The evaluation of *Vitrohouse*, and *Vitrohouse-no-bio* was carried out using a selection of the most important and representative existing GBRSs (*Green Building Rating Systems*). GBRSs are multivariate tools in which a set of indicators, grouped into categories, can evaluate various ecological and sustainable aspects of buildings. The 11 GBRSs chosen for the evaluation are among the 16 most important and internationally representative ones [46].

3.4.1 Choice of the Most Emblematic GBRS

We chose 11 of the most important and globally well-known GBRSs and with which we have the most experience: ASGB [47], BEAM [48], BREEAM [49-52], CEDES [53, 54], DNGB [55], GBI [56], GG [57], GS [58], IGBC [59], LEED [60] and SBTools [61] (whole words of GBRS names in references).

3.4.2 Comparative Evaluation Results of *Vitrohouse*, and *Vitrohouse-No-Bio*

To evaluate the contribution of the *bioclimatic design* to the general level of sustainability, an evaluation of *Vitrohouse* with respect to *Vitrohouse-no-bio* was carried out using the chosen GBRS. As it is a comparative evaluation, only the indicators whose score is different in each case were taken into account. We will call the set of indicators whose score varies

**Table 3 Total energy consumption per m$^2$ *Vitrohouse-no-bio.***

| | Power W (watts) | active time (hours) | energy year (kwh-year) | energy year/m$^2$ (kwh/m$^2$/year) |
|---|---|---|---|---|
| Fridge (average power) | 75 | 24 h. * 365 | 657 | 5.21 |
| Induction hob | 900 | 2 h. * 365 | 657 | 5.21 |
| Microwave | 200 | 1 h. * 365 | 73 | 0.57 |
| Washing machine | 800 | 1 h. * 365 | 292 | 2.31 |
| TV | 150 | 8 h. * 365 | 438 | 3.47 |
| PC's | 100 | 8 h. * 365 | 292 | 2.07 |
| Lighting | 196 | 8 h. * 365 | 572.3 | 4.54 |
| Water purification | 985 | 1 h. * 365 | 359.5 | 2.85 |
| Heating/cooling (soft temp.) | 2,000 | 12 h. * 90 | 2,160 | 17.14 |
| Heating/cooling (hard temp.) | 4,000 | 12 h. * 90 | 4,320 | 34.28 |
| Total energy consumed per m$^2$: 77.65 kwh/m$^2$/year | | | | |

when comparing a bioclimatic building with another that is not a "bio-group".

The evaluation tables first show for both designs:

- The score given to each indicator;
- 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).

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 in the total score. Adding the score of all the indicators of the "bio-group" gives the total score of each group to both *Vitrohouse* and *Vitrohouse-no-bio*. By subtracting both scores, the contribution of the *bioclimatic design* is obtained in the final score provided by each GBRS.

It should be noted that not all systems have a similar structure, so that the structure of the different tables is not the same. But essentially all the tables show the same: the final score of each indicator on a scale from 0 to 100, and the total score.

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 4).

The ASGB indicator "optimized design for natural ventilation (O.D.F.N.V.)" has a maximum score of 8 points. This indicator has a weight of 8/100 within the "Health and Comfort (H.C.)" category, and in turn this category has a weight of 10 out of 110 (ASGB has a total evaluation range of 0 to 110).

- In the case of *Vitrohouse*, the maximum score (8) was given to the O.D.F.N.V. indicator, so that the percentage score is ((8/8) = 1). By multiplying this value (1) by the weight of the O.D.F.N.V indicator in the H.C. category, a value of ((1) * (8/100)) is obtained, i.e. 0.08. Multiplying this value by the weight of the H.C. category in the total score gives (0.08 * (10/100)) = 0.008, based on a score of (0-110). Converting this percentage to a common base of (0-100), the final score is (0.008 * (100/110)) = 0.0073, i.e. 0.73%.
- In the case of *Vitrohouse-no-bio*, it was given a score of 1 out of a maximum of 8, so the percentage score is, ((1/8) = 0.125). Multiplying this value (0.125) by the weight of the O.D.F.N.V indicator in the H.C. category gives a value of (0.125 * (8/100)), that is, 0.01. Multiplying this value by the weight of the H.C. category in the total score gives (0.01 * (10/100)) = 0.001, percentage based on a score of (0-110). Converting this percentage to a common base of (0-100), the final score is (0.001 * (100/110)) = 0.0009, i.e. 0.09%.

Repeating the process for the 5 indicators for the "bioclimatic design" of a building in ASGB (Table 4), *Vitrohouse* has a score of 5.74%, compared to 3.72% for *Vitrohouse-no-bio*, i.e. according to ASGB, a bioclimatic house like *Vitrohouse-no-bio* has a higher sustainability level of 2% (5.74-3.72) than a conventional building (Table 4).

*3.4.2.1 ASGB Evaluation*

ASGB contains 5 *bioclimatic design* indicators, each of which gave different scores when evaluating *Vitrohouse*, and *Vitrohouse-no-bio*. This difference in both cases was only 2% because ASGB does not consider many important aspects of *bioclimatic design* (such as: bioclimatic architectural design, solar energy, waste and emissions generated in maintenance and increased health and quality of life).

**Table 4 ASGB indicators involved in bioclimatic design. Score differences between *Vitrohouse* and *Vitrohouse-no-bio*.**

| Involved indicators | | *Vitrohouse* | | | | | | *Vitrohouse-no-bio* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Indicators | Category | Score | Max. score | Indicator weight (*9) | Category weight | Result (0-110) | Result (0-100) | Score | Max. score | Indicator weight | Category weight | Result (0-110) | Result (0-100) |
| ODFNV (*1) | H.C. (*6) | 8 | 8 | 8/100 | 10% | 0.80 | 0.73 | 1 | 8 | 8/100 | 10% | 0.10 | 0.09 |
| UODTRSI (*2) | H.C. (*6) | 9 | 9 | 9/100 | 10% | 0.90 | 0. 82 | 1 | 9 | 9/100 | 10% | 0.90 | 0.82 |
| T.E.P.O. (*3) | R.C. (*7) | 15 | 15 | 15/200 | 20% | 1.50 | 1.36 | 12 | 15 | 15/200 | 20% | 1.20 | 1.09 |
| MRBEC (*4) | R.C. (*7) | 10 | 10 | 10/200 | 20% | 1.00 | 0.91 | 6 | 10 | 10/200 | 20% | 0.60 | 0.55 |
| MFRHSC (*5) | I.I. (*8) | 40 | 40 | 40/190 | 10% | 2.11 | 1.92 | 25 | 40 | 40/190 | 10% | 1.32 | 1.20 |
| Partial score | | | | | | | 5.74% | | | | | | 3.74% |
| Difference | | | | | | | | | | | | | 2.00% |

*1 optimized design for natural ventilation, *2 use of devices to regulate shade inside, *3 thermal envelope performance optimization, *4 measures to reduce building energy consumption, *5 measures to further reduce heating system consumption, *6 health and comfort, *7 resource conservation; *8 improvement and innovation, *9 this system does not assign a weight to the indicator, but is determined by the maximum score of the indicator divided by the maximum score of the category.

**Table 5 BEAM indicators involved in bioclimatic design. Score differences between *Vitrohouse* and *Vitrohouse-no-bio*.**

| Involved indicators | | *Vitrohouse* | | | | | | *Vitrohouse-no-bio* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Indicators | Category | Score | Max. score | Indicator weight (*10) | Category weight | Result (0-110) | Result (0-100) | Score | Max. score | Indicator weight | Category weight | Result (0-110) | Result (0-100) |
| D.C.C.A. (*1) | S.S. (*7) | 2 | 2 | 2/39 | 15% | 0.77 | 0.70 | 1 | 2 | 2/39 | 15% | 0.38 | 0.35 |
| L.C.P.D. (*2) | E.U. (*8) | 6 | 6 | 6/44 | 29% | 3.94 | 3.59 | 2 | 6 | 6/44 | 29% | 1.31 | 1.20 |
| R.$CO^2$.E. (*3) | E.U. (*8) | 15 | 15 | 15/44 | 29% | 9.89 | 8.99 | 7 | 15 | 15/44 | 29% | 4.61 | 4.20 |
| P.E.D. (*4) | E.U. (*8) | 3 | 3 | 3/44 | 29% | 1.91 | 1.79 | 1 | 3 | 3/44 | 29% | 0.66 | 0.60 |
| E.V. (*5) | H.W (*9) | 4 | 4 | 4/29 | 22% | 3.04 | 2.76 | 0 | 4 | 4/29 | 22% | 0.00 | 0.00 |
| I.V. (*6) | H.W (*9) | 1 | 1 | 1/29 | 22% | 0.75 | 0.68 | 0 | 1 | 1/29 | 22% | 0.00 | 0.00 |
| Partial score | | | | | | | 18.50% | | | | | | 6.34% |
| Difference | | 12.17% | | | | | | | | | | | |

*1 design for climate change adaptation, *2 low carbon passive design, *3 reduction of $CO^2$ emissions, *4 peak electricity demand, *5 enhanced ventilation, *6 indoor vibration, *7 sustainable site, *8 energy use, *9 health and wellbeing, *10 this system does not assign a weight to the indicator but is determined by the maximum score of the indicator divided by the maximum score of the category.

**Table 6 BREEAM indicators involved in bioclimatic design. Score differences between *Vitrohouse* and *Vitrohouse-no-bio*.**

| Involved indicators | | *Vitrohouse* | | | | | | *Vitrohouse-no-bio* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Indicators | Category | Score | Max. score | Indicator weight | Category weight | Result (0-110) (*5) | Result (0-100) | Score | Max. score | Indicator weight | Category weight | Result (0-110) | Result (0-100) |
| ENE 01 (*1) | ENE | 13 | 31 | 41.93% | 16% | 6.71 | 6.10 | 0 | 31 | 0% | 16% | 0 | 0 |
| ENE 04 (*2) | ENE | 3 | 31 | 9.68% | 16% | 1.55 | 1.41 | 1 | 31 | 3.23% | 16% | 0.52 | 0.47 |
| ENE 05 (*3) | ENE | 2 | 31 | 6.45% | 16% | 1.03 | 0.94 | 1 | 31 | 3.23% | 16% | 0.52 | 0.47 |
| INN (*4) | INN | 5 | 10 | 50% | 10% | 5 | 4.55 | 2 | 10 | 0.20% | 10% | 2.00 | 1.82 |
| Partial score | | | | | | | 13.00% | | | | | | 2.76% |
| Difference | | 10.24% | | | | | | | | | | | |

*3.4.2.2 BEAM Evaluation*

BEAM contains 6 *bioclimatic design* indicators, each of which gave different scores when evaluating *Vitrohouse*, and *Vitrohouse-no-bio*. This difference in both cases was only 12.17 % because BEAM does not consider many important aspects of *bioclimatic design* (such as: bioclimatic architectural design and solar energy) (Table 5).

*3.4.2.3 BREEAM Evaluation*

BREEAM contains 4 *bioclimatic design* indicators, each of which gave different scores when evaluating *Vitrohouse*, and *Vitrohouse-no-bio*. This difference in both cases was only 10.24 % because BREEAM does not consider many important aspects of *bioclimatic design* (such as: bioclimatic architectural design, waste and emissions generated in maintenance and increased health and quality of life) (Table 6).

*3.4.2.4 CEDES Evaluation*

CEDES contains 4 *bioclimatic design* indicators, each of which gave different scores when evaluating *Vitrohouse*, and *Vitrohouse-no-bio*. This difference in both cases was 24.07 % because CEDES is very complete and considers all the possible aspects and advantages of *bioclimatic design* (Table 7).

*3.4.2.5 DNGB Evaluation*

DNGB contains 7 *bioclimatic design* indicators, each of which gave different scores when evaluating *Vitrohouse*, and *Vitrohouse-no-bio*. The score difference for both cases is very high, 17.69% despite the fact that DNGB does not take into account many basic aspects of *bioclimatic design* (such as: bioclimatic architectural design, waste and emissions generated in maintenance and increased health and quality of life) (Table 8).

**Table 7 CEDES indicators involved in bioclimatic design. Score differences between *Vitrohouse* and *Vitrohouse-no-bio.***

| Involved indicators | | *Vitrohouse* | | | | | | *Vitrohouse-no-bio* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Indicators | Category | Score | Max. score | Indicator weight | Category weight | Result | Result (0-100) | Score | Max. score | Indicator weight | Category weight | Result | Result (0-100) |
| 2.6 | BD (*1) | 5 | 5 | 45.8% | 36% | 0.1648 | 16.48 | 1 | 5 | 45.8% | 36% | 0.0329 | 3.29 |
| 3.1 | SE (*2) | 5 | 5 | 60% | 13% | 0.078 | 7.8 | 2 | 5 | 60% | 13% | 0.0156 | 1.56 |
| 4.5 | WEM (*3) | 5 | 5 | 20% | 12% | 0.0192 | 1.92 | 2 | 5 | 20% | 12% | 0.0048 | 0.48 |
| 5 | HE (*4) | 5 | 5 | 100% | 8% | 0.064 | 6.4 | 2 | 5 | 100% | 8% | 0.032 | 3.2 |
| Partial score | | | | | | | 32.6% | | | | | | 8.53% |
| Difference | | 24.07% | | | | | | | | | | | |

*1 BD: Bioclimatic architectural design, *2 SE: Solar energy, *3 WEM: Waste and emissions generated in building maintenance, *4 HE: Increased health and quality of life of building residents.

**Table 8 DNGB indicators involved in bioclimatic design. Score differences between *Vitrohouse* and *Vitrohouse-no-bio.***

| Involved indicators | | *Vitrohouse* | | | | | | *Vitrohouse-no-bio* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Indicators | Category (*1) | Score | Max. score | Indicator weight (*2) | Category weight | Result | Result (0-100) | Score | Max. score | Indicator weight | Category weight | Result | Result (0-100) |
| ENV 1.1 | ENV | 122.5 | 130 | 10/24 | 25% | - | 9.82 | 60 | 130 | 10/24 | 25% | - | 4.81 |
| ENV 1.2 | ENV | 110 | 135 | 5/24 | 25% | - | 4.24 | 65 | 135 | 5/24 | 25% | - | 2.51 |
| ECO 1.1 | ECO | 110 | 130 | 4/10 | 25% | - | 8.46 | 47.50 | 130 | 4/10 | 25% | - | 3.65 |
| ECO 2.6 | ECO | 100 | 110 | 2/10 | 25% | - | 4.55 | 70 | 110 | 2/10 | 25% | - | 3.18 |
| SOC 1.1 | SOC | 85 | 105 | 2/10 | 25% | - | 4.05 | 45 | 105 | 2/10 | 25% | - | 2.14 |
| SOC 1.2 | SOC | 105 | 110 | 2/10 | 25% | - | 4.77 | 75 | 110 | 2/10 | 25% | - | 3.41 |
| SOC 1.4 | SOC | 100 | 100 | 2/10 | 25% | - | 5.00 | 70 | 100 | 2/10 | 25% | - | 3.50 |
| Partial score | | | | | | | 40.89% | | | | | | 23.20% |
| Difference | | 17.69% | | | | | | | | | | | |

*1 Category is named as Topic on Criteria set of DNGB, *2 This system does not assign a weight to the indicator, but is determined by the maximum score of the indicator divided by the maximum score of the category.

**Table 9 GBI indicators involved in bioclimatic design. Score differences between *Vitrohouse* and *Vitrohouse-no-bio.***

| Involved indicators | | *Vitrohouse* | | | | | | *Vitrohouse-no-bio* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Indicators | Category | Score | Max. score | Indicator weight | Category weight | Result | Result (0-100) | Score | Max. score | Indicator weight | Category weight | Result | Result (0-100) |
| EE3 | EE (*1) | 5 | 5 | - | - | - | 5 | 3 | 5 | - | - | - | 3 |
| EQ1 | IEQ (*2) | 2 | 2 | - | - | - | 2 | 1 | 2 | - | - | - | 1 |
| IN1 (*4) | INN (*3) | 1 | 1 | - | - | - | 1 | 0 | 1 | - | - | - | 0 |
| Partial score | | | | | | | 8% | | | | | | 4% |
| Difference | | 4% | | | | | | | | | | | |

*1 energy efficiency, *2 indoor environment quality, *3 innovation, *4 external shading devices.

**Table 10 GG indicators involved in bioclimatic design. Score differences between *Vitrohouse* and *Vitrohouse-no-bio.***

| Involved indicators | | *Vitrohouse* | | | | | | *Vitrohouse-no-bio* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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) |
| 3.1 EP (*1) | Energy | 180 | 180 | - | - | 180 | 18 | 90 | 260 | - | - | 90 | 9 |
| 3.4 RSE (*2) | Energy | 30 | 30 | - | - | 30 | 3 | 15 | 260 | - | - | 15 | 1.5 |
| Partial score | | | | | | | 21% | | | | | | 10.5% |
| Difference | | 10.5% | | | | | | | | | | | |

*1 energy performance, *2 renewable sources of energy.

*3.4.2.6 GBI Evaluation*

GBI contains 3 *bioclimatic design* indicators, each of which gave different scores when evaluating *Vitrohouse*, and *Vitrohouse-no-bio*. This difference in both cases was only 4% because GBI does not consider many important aspects of *bioclimatic design* (such as: bioclimatic design, solar energy, and waste and emissions generated in maintenance). (Table 9).

*3.4.2.7 GG Evaluation*

GG contains 2 *bioclimatic design* indicators, each of which gave different scores when evaluating *Vitrohouse*, and *Vitrohouse-no-bio*. This difference in both cases was only 10.50 % because GG does not consider many important aspects of *bioclimatic design* (such as: bioclimatic architectural design, solar energy, waste and emissions generated in maintenance and increased health and quality of life) (Table 10).

*3.4.2.8 GS Evaluation*

GS contains 10 *bioclimatic design* indicators, each of which gave different scores when evaluating *Vitrohouse*, and *Vitrohouse-no-bio*. The score difference for both cases is very high, 19.09 %, despite the fact that GS does not take into account some basic aspects of *bioclimatic design* (such as: bioclimatic architectural design and increased health and quality of life) (Table 11).

*3.4.2.9 IGBC Evaluation*

IGBC contains 2 *bioclimatic design* indicators, each of which gave different scores when evaluating *Vitrohouse*, and *Vitrohouse-no-bio*. This difference in both cases was only 9.33 % because IGBC does not consider many important aspects of *bioclimatic design* (such as: bioclimatic design, solar energy, waste and emissions generated in maintenance). (Table 12).

*3.4.2.10 LEED Evaluation*

LEED is the most limited GBRS when assessing bioclimatic design since it contains only 1 *bioclimatic design* indicator, which gave different scores when evaluating *Vitrohouse*, and *Vitrohouse-no-bio*. This difference in both cases was only 8.18 % because LEED does not consider many important aspects of *bioclimatic design* (such as: bioclimatic architectural design, solar energy, waste and emissions generated in maintenance and health and quality of life.). (Table 13).

**Table 11 GS indicators involved in bioclimatic design. Score differences between *Vitrohouse* and *Vitrohouse-no-bio.***

| Involved indicators | | *Vitrohouse* | | | | | | *Vitrohouse-no-bio* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | 1.82 | 1 | 2 | - | - | 1 | 0.91 |
| 9 | IEQ (*2) | 4 | 4 | - | - | 4 | 3.64 | 2 | 4 | - | - | 2 | 1.82 |
| 10 | IEQ | 3 | 3 | - | - | 3 | 2.73 | 1 | 3 | - | - | 1 | 0.91 |
| 13 | IEQ | 2 | 2 | - | - | 2 | 1.82 | 1 | 2 | - | - | 1 | 0.91 |
| 14 | IEQ | 2 | 2 | - | - | 2 | 1.82 | 1 | 2 | - | - | 1 | 0.91 |
| 15 | ENE (*3) | 20 | 20 | - | - | 20 | 18.18 | 10 | 20 | - | - | 10 | 9.09 |
| 16 | ENE | 2 | 2 | - | - | 2 | 1.82 | 1 | 2 | - | - | 1 | 0.91 |
| 25 | LU (*4) | 1 | 1 | - | - | 1 | 0.91 | 0 | 1 | - | - | 0 | 0.00 |
| 28 | EMI (*5) | 1 | 1 | - | - | 1 | 0.91 | 0 | 1 | - | - | 0 | 0.00 |
| 29 | EMI | 1 | 1 | - | - | 1 | 0.91 | 0 | 1 | - | - | 0 | 0.00 |
| Partial score | | | | | | | 34.55% | | | | | | 15.45% |
| Difference | | 19.09% | | | | | | | | | | | |

*1 management, *2 indoor environment quality, *3 energy, *4 land use, *5 emissions, *6 green star scores up to 100 points and adds 10 for innovation.

**Table 12 Indicators of IGBC involved in bioclimatic design. Score differences between *Vitrohouse* and *Vitrohouse-no-bio.***

| Involved indicators | | *Vitrohouse* | | | | | | *Vitrohouse-no-bio* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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) |
| EE C1 | EE | 7 | 10 | - | - | 7 | 9.33 | 6 | 10 | - | - | 6 | 8 |
| IEQ C6 | IEQ | 4 | 4 | - | - | 4 | 5.33 | 2 | 4 | - | - | 2 | 2.67 |
| Partial score | | | | | | | 20% | | | | | | 10.67% |
| Difference | | 9.33% | | | | | | | | | | | |

**Table 13 LEED indicators involved in bioclimatic design. Score differences between *Vitrohouse* and *Vitrohouse-no-bio.***

| Involved indicators | | *Vitrohouse* | | | | | | *Vitrohouse-no-bio* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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) |
| AEU (*1) | EA (*2) | 36 | 36 | - | - | 36 | 32.72 | 27 | 36 | - | - | 27 | 24.54 |
| Partial score | | | | | | | 32.72% | | | | | | 24.54% |
| Difference | | 8.18% | | | | | | | | | | | |

Indicators of the manual for single-family housing. *1 EAC annual energy use, *2 energy and atmosphere.

*3.4.2.11. SBTools Evaluation*

SBTools contains 18 *bioclimatic design* indicators, each of which gave different scores when evaluating *Vitrohouse*, and *Vitrohouse-no-bio*. This difference in both cases was only 4.83 % because SBTools does not consider many important aspects of *bioclimatic design* (such as: bioclimatic design, solar energy, waste and emissions generated in maintenance). (Table 14).

3.4.3 Results

The contributions of the bioclimatic design of *Vitrohouse* to its sustainable level, as measured by the eleven GBRS considered, are as follows: ASGB (2%), BEAM (12.17%), BREEAM (10.24%), CEDES (24.07%), DNGB (17.69%), GBI (4%), GG (10.5%), GS (19.09%), IGBC (9.33%), LEED (8.18%), and SBTools (4.83%) (Table 15).

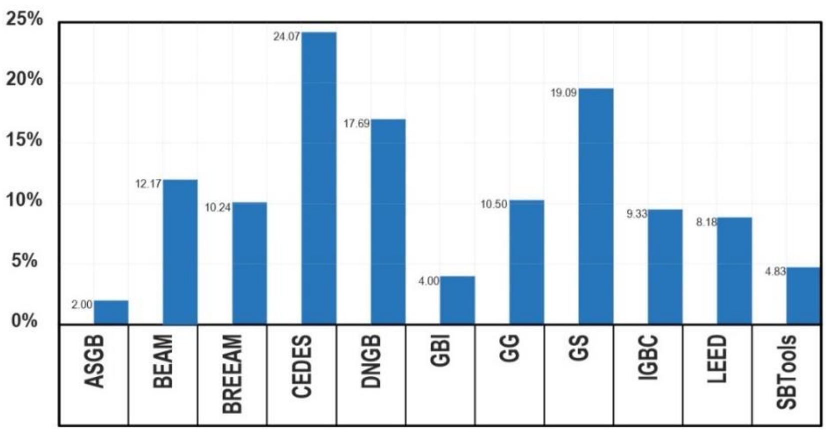
Therefore, all GBRSs detected that *Vitrohouse*, due to its good bioclimatic design, despite being built solely with glass, has a higher sustainability level than a conventional home of the same size.

**Table 14 SBTools indicators involved in bioclimatic design. Score differences between *Vitrohouse* and *Vitrohouse-no-bio.***

| Involved indicators | | *Vitrohouse* | | | | | | *Vitrohouse-no-bio* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Indicators | Category | Score | Max. score | Indicator weight (*9) | Category weight | Result | Result (0-100) | Score | Max. score | Indicator weight | Category weight | Result | Result (0-100) |
| A 2.3 | USIS (*1) | 5 | 5 | 1.62% | - | - | 1.62 | 0 | 5 | 1.62% | - | - | 0 |
| A 2.5 | USIS | 5 | 5 | 0.81% | - | - | 0.81 | 0 | 5 | 0.81% | - | - | 0 |
| A 2.6 | USIS | 5 | 5 | 0.20% | - | - | 0.20 | 0 | 5 | 0.20% | - | - | 0 |
| B 2 | ERC (*2) | 5 | 5 | 1.60% | - | - | 1.60 | 0 | 5 | 1.60% | - | - | 0 |
| D 1.6 | IEQ (*3) | 5 | 5 | 0.20% | - | - | 0.20 | 0 | 5 | 0.20% | - | - | 0 |
| D 1.7 | IEQ | 5 | 5 | 0.20% | - | - | 0.20 | 0 | 5 | 0.20% | - | - | 0 |
| D 1.8 | IEQ | 5 | 5 | 0.10% | - | - | 0.10 | 0 | 5 | 0.10% | - | - | 0 |
| D 1.9 | IEQ | 0 | 5 | 0.10% | - | - | 0 | 3 | 5 | 0.10% | - | - | 0.06 |
| D 1.10 | IEQ | 0 | 5 | 0.10% | - | - | 0 | 3 | 5 | 0.10% | - | - | 0.06 |
| D 2.1 | IEQ | 0 | 5 | 0.05% | - | - | 0 | 5 | 5 | 0.05% | - | - | 0.05 |
| D 2.2 | IEQ | 5 | 5 | 0.05% | - | - | 0.05 | 3 | 5 | 0.05% | - | - | 0.03 |
| D 3.1 | IEQ | 5 | 5 | 0.10% | - | - | 0.10 | 3 | 5 | 0.10% | - | - | 0.06 |
| D 3.2 | IEQ | 5 | 5 | 0.05% | - | - | 0.05 | 0 | 5 | 0.05% | - | - | 0 |
| D 3.3 | IEQ | 5 | 5 | 0.05% | - | - | 0.05 | 5 | 5 | 0.05% | - | - | 0.05 |
| D 4.1 | IEQ | 5 | 5 | 0.10% | - | - | 0.10 | 3 | 5 | 0.10% | - | - | 0.06 |
| D 4.2 | IEQ | 5 | 5 | 0.10% | - | - | 0.10 | 3 | 5 | 0.10% | - | - | 0.06 |
| D 4.3 | IEQ | 5 | 5 | 0.10% | - | - | 0.10 | 3 | 5 | 0.10% | - | - | 0.06 |
| D 4.4 | IEQ | 5 | 5 | 0.10% | - | - | 0.10 | 3 | 5 | 0.10% | - | - | 0.06 |
| Partial score | | | | | | | 5.38% | | | | | | 0.55% |
| Difference | | 4.83% | | | | | | | | | | | |

*1 urban, site and infrastructure systems, *2 energy and resource consumption, *3 indoor environmental quality. The system score involves multiplying the project score by the indicator weight divided by the maximum score.

**Table 15 Contribution of *bioclimatic design* to a building's sustainability level, using 11 GBRSs.**




Taking into account the average scores of the 11 GBRSs, (Table 15), the contribution of the bioclimatic design to the level of sustainability of *Vitrohouse* is 10.28% ((2.00 + 12.17 + 10.24 + 24.07 + 17.69 + 4.00 + 10.50 + 19.09 + 9.33 + 8.18 + 4.83) / 11 = 10.28).

However, if only CEDES, DNGB and GS are taken into account, the contribution of bioclimatic design of *Vitrohouse* to the level of sustainability of buildings is 13.91% ((24.07 + 17.69 + 19.09) / 3 = 20.28).

## 4. Contribution of Demountability to *Vitrohouse*'s Sustainable Level

To accurately quantify the contribution of flat glass *demountable construction* to its sustainable level, *Vitrohouse* was compared with a *baseline*: its non-demountable hypothetical version, called *ND-Vitrohouse*.

The evaluation was conducted using the 11 GBRSs following the same assessment process described in the previous section. To simplify the study, only those indicators whose scores varied from one household 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.

### *4.1 Comparative Evaluation Methodology*

To evaluate the contribution of *demountable construction* to its general level of sustainability, *Vitrohouse* was compared with *ND-Vitrohouse* using the eleven 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".

### *4.2 Comparative Evaluation Results of Vitrohouse, and Vitrohouse-No-Bio*

4.2.1 ASGB Evaluation

ASGB has 5 indicators involved in *demountable construction* and therefore, their scores vary in the evaluation of *Vitrohouse*, and *ND-Vitrohouse*. The score difference for both cases is only 2.06 % because ASGB does not consider many important factors such as: economic cost, resources needed, level of exploitation of resources, energy consumption in building construction and in demolishing, or disassembling. (Table 16).

4.2.2 BEAM Evaluation

BEAM has only 3 indicators involved in *demountable construction* and therefore, their score varies in the evaluation of *Vitrohouse*, and *ND-Vitrohouse*. The score difference for both cases is only 1.40% and this is because BEAM does not consider many important factors such as: economic cost, resources needed, level of exploitation of resources, energy consumption in building construction and in demolishing/disassembling (Table 17).

**Table 16 ASGB indicators involved in modular and demountable construction. Score differences between *Vitrohouse*and *ND-Vitrohouse.***

| Demountable group | | *Vitrohouse* | | | | | | *ND-Vitrohouse* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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) | 18 | 18 | 18/100 | 10% | 1.80 | 1.64% | 12 | 18 | 18/100 | 10% | 1.20 | 1.09% |
| 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 | | | | | | | 4.85% | | | | | | 2.79% |
| 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 17 BEAM indicators involved in modular and demountable construction. Score differences between *Vitrohouse* and *ND-Vitrohouse.***

| Demountable group | | *Vitrohouse* | | | | | | *ND-Vitrohouse* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Indicators | Category | Score | Max. score | Indicator weight | Category weight | Result | Result (0-100) | Score | Max. score | Indicator weight | Category weight | Result | Result (0-100) |
| MSD (*1) | MW (*4) | 2 | 2 | 2/35 | 9% | 0.51 | 0.47% | 1 | 2 | 2/35 | 9% | 0.26 | 0.23% |
| PREF (*2) | MW | 4 | 4 | 4/35 | 9% | 1.03 | 0.93% | 1 | 4 | 4/35 | 9% | 0.26 | 0.23% |
| AD (*3) | MW | 2 | 2 | 2/35 | 9% | 0.51 | 0.47% | 0 | 2 | 2/35 | 9% | 0.00 | 0.00% |
| Partial score | | | | | | | 1.87% | | | | | | 0.47% |
| Difference | | 1.40% | | | | | | | | | | | |

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.

**Table 18 BREEAM indicators involved in modular and demountable construction. Score differences between *Vitrohouse* and *ND-Vitrohouse*.**

| Removable group | | *Vitrohouse* | | | | | | *ND-Vitrohouse* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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) |
| MAN02 | 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) | 3 | 5 | 45.45% | 6% | 1.64 | 1.49% | 0 | 5 | 45.45% | 6% | 0 | 0% |
| WST06 | WST | 1 | 2 | 18.18% | 6% | 0.55 | 0.50% | 0 | 2 | 18.18% | 6% | 0 | 0% |
| Partial score | | | | | | | 4.87% | | | | | | 0.47% |
| Difference | | 4.40% | | | | | | | | | | | |

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) materials, (*3) waste.

**Table 19 CEDES indicators involved in modular and demountable construction. Score differences between *Vitrohouse* and *ND-Vitrohouse.***

| Demountable group | | *Vitrohouse* | | | | | | *ND-Vitrohouse* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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) | 5 | 5 | 0.072 | 18% | - | 1.30% | 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 | 4 | 5 | 0.225 | 18% | - | 3.24% | 3 | 5 | 0.225 | 18% | - | 2.43% |
| 2.4 | ECIC (*2) | 5 | 5 | 0.115 | 34% | - | 3.91% | 2 | 5 | 0.115 | 34% | - | 1.56% |
| 2.7 | ECID (*3) | 5 | 5 | 0.024 | 34% | - | 0.82% | 1 | 5 | 0.024 | 34% | - | 0.16% |
| 4 | WE (*4) | 5 | 5 | 1 | 12% | - | 12% | 1 | 5 | 1 | 12% | - | 2.4% |
| 6 | EC (*5) | 5 | 5 | 1 | 10% | - | 10% | 5 | 5 | 1 | 10% | - | 10% |
| Partial score | | | | | | | 35.68% | | | | | | 18.17% |
| Difference | | | | 17.51% | | | | | | | | | |

(*1) resources optimization, (*2) energy consumption in building construction, (*3) energy consumption in demolishing/disassembling, (*4) reduction of waste and emissions, (*5) economic cost.

4.2.3 BREEAM Evaluation

BREEAM has only 4 indicators involved in *demountable construction*, each of which gave different scores when evaluating both homes. The score difference in both cases is only 4.40% because BREEAM does not consider many important factors such as: economic cost, energy consumption in building construction and in demolishing/disassembling (Table 18).

4.2.4 CEDES Evaluation

CEDES is the best-performing GBRS and has 7 indicators involved in *demountable construction* and therefore their scores vary in the evaluation of *Vitrohouse*, and *ND-Vitrohouse*. The score difference for both cases is 17.51% (Table 19).

4.2.5 DNGB Evaluation

DNGB has 6 indicators involved in *demountable construction*, each of which gave different scores when evaluating *Vitrohouse*, and *ND-Vitrohouse*. The score difference in both cases was 14.79% and this was because DNGB does not consider some factors such as: economic cost, resources needed, level of exploitation of resources (Table 20).

4.2.6 GBI Evaluation

GBI has 4 indicators involved in *demountable construction*, each of which gave different scores in evaluating *Vitrohouse*, and *ND-Vitrohouse*. The score difference in both cases was 7% because GBI does not consider many important factors such as: economic cost, resources needed, level of exploitation of resources, energy consumption in building construction and demolishing/disassembling (Table 21).

4.2.7 GG Evaluation

GG has 6 indicators involved in *demountable construction*, each of which gave different scores when evaluating *Vitrohouse*, and *ND-Vitrohouse*. The score difference in both cases was 6.80% because GG does not consider some factors such as: economic cost, and energy consumption in construction (Table 22).

4.2.8 GS Evaluation

GS has only 3 indicators involved in *demountable construction*, each of which gave different scores when evaluating *Vitrohouse*, and *ND-Vitrohouse*. The score difference in both cases was only 5.46% because GS does not consider many important factors such as: economic cost, resources needed, level of exploitation of resources (Table 23).

4.2.9 IGBC Evaluation

IGBC has only 2 indicators involved in *demountable construction*, each of which gave different scores when evaluating *Vitrohouse*, and *ND-Vitrohouse*. The score difference in both cases was only 1.33% because IGBC does not consider many important factors such as: economic cost, resources needed, level of exploitation of resources, energy consumption in building construction, and demolishing/disassembling (Table 24).

**Table 20 DNGB indicators involved in modular and demountable construction. Score differences between *Vitrohouse* and *ND-Vitrohouse.***

| Demountable group | | *Vitrohouse* | | | | | | *ND-Vitrohouse* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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) | 70 | 130 | 4/10 | 25% | - | 5.38% | 47,5 | 130 | 4/10 | 25% | - | 3.65% |
| 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 | | | | | | | 37.16% | | | | | | 22.38% |
| Difference | | 14.79% | | | | | | | | | | | |

(*1) environmental quality, (*2) economic quality, (*3) technical quality, (*4) process quality.

**Table 21 GBI indicators involved in modular and demountable construction. Score differences between *Vitrohouse* and *ND-Vitrohouse.***

| Demountable group | | *Vitrohouse* | | | | | | *ND-Vitrohouse* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 22 GG indicators involved in modular and demountable construction. Score differences between *Vitrohouse* and *ND-Vitrohouse.***

| Demountable group | | *Vitrohouse* | | | | | | *ND-Vitrohouse* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | 11 | 22 | - | - | 11 | 1.10% | 0 | 22 | - | - | 0 | 0% |
| 5.5.2 MROS | MAT | 8 | 8 | - | - | 8 | 0.80% | 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 | | | | | | | 8.00% | | | | | | 1.20% |
| Difference | | 6.80% | | | | | | | | | | | |

(*1) project management, (*2) materials.

**Table 23 GS indicators involved in modular and demountable construction. Score differences between *Vitrohouse* and *ND-Vitrohouse.***

| Demountable group | | *Vitrohouse* | | | | | | *ND-Vitrohouse* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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.

**Table 24 IGBC indicators involved in modular and demountable construction. Score differences between *Vitrohouse* and *ND-Vitrohouse.***

| Demountable group | | | | *Vitrohouse* | | | | | | *ND-Vitrohouse* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Indicators | Category | Score | Max. score | Indicator weight | Category weight | Result (0-75) | Result (0-100) | Score | Max. score | Indicator weight | Category weight | Result (0-75) | Result (0-100) |
| C2 | MR (*1) | 1 | 1 | - | - | 1 | 1.33% | 0 | 1 | - | - | 0 | 0% |
| C3 | MR | 2 | 2 | - | - | 2 | 2.66% | 2 | 2 | - | - | 2 | 2.66% |
| Partial score | | | | | | | 3.99% | | | | | | 2.66% |
| Difference | | 1.33% | | | | | | | | | | | |

IGBC provides a maximum score of 75, therefore, the total score ranges from 0 to 75. (*1) material resources.

**Table 25 LEED indicators involved in modular and demountable construction. Score differences between *Vitrohouse* and *ND-Vitrohouse.***

| Demountable group | | | | *Vitrohouse* | | | | | | *ND-Vitrohouse* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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) |
| EPP (*1) | MR (*3) | 4 | 5 | - | - | 4 | 3.64% | 3 | 5 | - | - | 3 | 2.73% |
| CDWM (*2) | MR | 1 | 2 | - | - | 1 | 0.91% | 0 | 2 | - | - | 0 | 0 |
| Partial score | | | | | | | 4.55% | | | | | | 2.73% |
| Difference | | 1.82% | | | | | | | | | | | |

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 single-family housing. (*1) environmentally preferable products, (*2) construction and demolition waste management, (*3) materials and resources.

**Table 26 Indicators of SBTool involved in modular and demountable construction. Score differences between *Vitrohouse* and *ND-Vitrohouse.***

| Demountable group | | *Vitrohouse* | | | | | | *ND-Vitrohouse* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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) | 5 | 5 | 6.48% | - | - | 6.48% | 3 | 5 | 6.48% | - | - | 3.89% |
| B 1.2 | ERC | 5 | 5 | 3.24% | - | - | 3.24% | 3 | 5 | 3.24% | - | - | 1.94% |
| B 3.3 | ERC | 5 | 5 | 0.20% | - | - | 0.20% | 0 | 5 | 0.20% | - | - | 0.00% |
| B 3.5 | ERC | 5 | 5 | 0.20% | - | - | 0.20% | 3 | 5 | 0.20% | - | - | 0.12% |
| B 3.6 | ERC | 5 | 5 | 0.20% | - | - | 0.20% | 0 | 5 | 0.20% | - | - | 0.00% |
| C 1.1 | EL (*2) | 5 | 5 | 4.86% | - | - | 4.86% | 3 | 5 | 4.86% | - | - | 2.92% |
| C 1.2 | EL | 3 | 5 | 4.86% | - | - | 2.92% | 0 | 5 | 4.86% | - | - | 0.00% |
| 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 | 3 | 5 | 0.05% | - | - | 0.03 | 0 | 5 | 0.05% | - | - | 0.25% |
| G 1.1 | CEA (*4) | 5 | 5 | 0.10% | - | - | 0.10% | 0 | 5 | 0.10% | - | - | 0.00% |
| G 1.2 | CEA | 5 | 5 | 0.10% | - | - | 0.10% | 0 | 5 | 0.10% | - | - | 0.00% |
| G 1.3 | CEA | 5 | 5 | 0.10% | - | - | 0.10% | 3 | 5 | 0.10% | - | - | 0.06% |
| Partial score | | | | | | | 18.89% | | | | | | 9.46% |
| Difference | | 9.43% | | | | | | | | | | | |

(*1) energy and resources consumption, (*2) environmental loadings, (*3) service quality, (*4) cost and economic aspects.

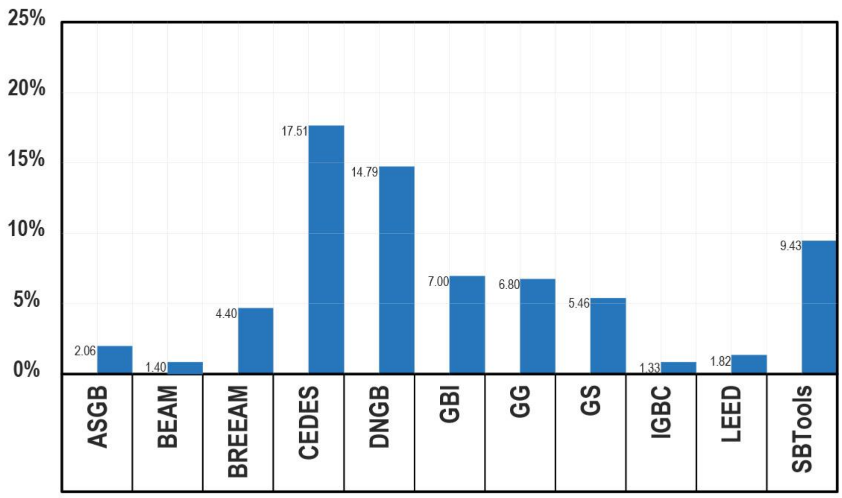
4.2.10 LEED Evaluation

LEED has only 2 indicators involved in *demountable construction*, each of which gave different scores in evaluating *Vitrohouse*, and *ND-Vitrohouse*. The score difference in both cases was only 1.82% because LEED does not consider many important factors such as: economic cost, resources needed and level of exploitation of resources, energy consumption in building construction, demolishing/disassembling (Table 25).

4.2.11 SBTools Evaluation

SBTools has 13 indicators involved in *demountable construction*, each of which gave different scores in evaluating *Vitrohouse* and *ND-Vitrohouse*. The score difference in both cases was only 9.43% because SBTools does not consider some factors such as: economic cost, resources needed, level of exploitation of resources. (Table 26).

**Table 27 Contribution of *demountable construction* to a building's sustainability level, using 11 GBRSs.**




*4.3 Results*

The results of the comparative evaluation by each GBRS have been the following: ASGB: 2.06%, BEAM: 1.40%, BREEAM: 4.40%, CEDES: 17.51%, DNGB: 14.79%, GBI: 7%, GG: 6.80%, GS: 5.46%, IGBC: 1.33%, LEED: 1.82% and SBTool: 9.43% (Table 27).

Therefore, all GBRS detected that *Vitrohouse*, due to the fact that it is demountable and despite being built solely with flat glass, has a higher level of sustainability than a conventional home of the same size.

Taking into account the average scores of the 11 GBRSs, the contribution of demountability to the level of sustainability of *Vitrohouse* is 6.54% ((2.06 + 1.40 + 4.40 + 17.51 + 14.79 + 7.00 + 6.80 + 5.46 + 1.33 + 1.82 + 9.43) / 11 = 6.54).

However, if only CEDES, DNGB and SBTools are taken into account, the contribution of demountability of *Vitrohouse* to the level of sustainability of buildings is 13.91% ((17.51 + 14.79 + 9.43) / 3 = 13.91).

## 5. Discussion

This study demonstrates the feasibility of constructing habitable spaces using flat glass by analyzing the first all-glass house: *Vitrohouse*. The construction of *Vitrohouse* was designed to show that glass can be used to manufacture any building component, including its primary supporting structure.

The first objective of this work is to demonstrate the technical feasibility of using flat glass to create safe and habitable spaces that comply with international building codes. The second objective is to show that, despite being built with glass, *Vitrohouse* exhibits strong thermodynamic and bioclimatic performance. Its careful design enables a comfortable internal temperature with lower energy consumption than most conventional houses of similar size. The third objective is to demonstrate that the inherent demountability of the construction system gives *Vitrohouse* a higher level of sustainability than conventional houses of the same size. Vitrohouse is undoubtedly a radical construction experiment that has had to overcome numerous challenges, demonstrating the vast potential of flat glass.

The primary objective behind *Vitrohouse* was to promote demountable construction, enabling buildings to be easily assembled and disassembled. This approach allows components to be easily recovered, repaired, and reused, maximizing their lifespan and minimizing their environmental impact over time. The underlying premise is that if a completely demountable building can be constructed using only flat glass, it is far easier to build demountable structures using more common and suitable materials.

## 6. Conclusions

This paper analyzes *Vitrohouse*, a demountable house built entirely from flat glass.

The project's goal was to promote demountable construction as a paradigm of sustainable construction. Glass was chosen as the sole material to pose a significant construction challenge; if a demountable building can be constructed using only glass, and without mortar, adhesives, nails, or screws, then demountable buildings can be constructed more easily using any other material. The project overcame three primary challenges. First, the all-glass structure had to be robust, stable and durable, capable of withstanding external stresses and meeting habitability requirements. Second, the house required a specialized bioclimatic design to maintain a comfortable interior temperature. Third the house had to be fully demountable.

This study's analysis of *Vitrohouse*'s technical and construction solutions confirms that its bioclimatic design makes it more sustainable than a conventional house. Furthermore, its demountable design provides and additional, quantifiable sustainability advantage, proving that innovative materials and methods can lead to highly efficient and circular building practices.

## Data Availability Statement (DAS)

The data that support the findings of this study are available from the corresponding autor (De Garrido, Luis), upon reasonable request.

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