ASSESSMENT OF EARTH BLOCKS BY MEANS OF A CONSTRUCTION FEASIBILITY STUDY (CFS)

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EVALUACIÓN DEL BLOQUE DE TIERRA MEDIANTE UN ESTUDIO DE VIABILIDAD CONSTRUCTIVA (EVC)

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RESUMEN

Aunque la construcción con bloques de tierra (BT) está avalada por numerosos trabajos científicos, existe una desconfianza sobre su viabilidad constructiva, agravada por la falta de formación técnica específica. Ante esta incertidumbre, muy presente en el ámbito español, es preciso dar respuestas técnicas fundamentadas. En esa dirección, este artículo expone el diseño y validación de una herramienta para la evaluación de la viabilidad constructiva del BT. Con ese fin, se seleccionan 29 casos de estudio en España, con los que se establecen las determinaciones constructivas y los indicadores para la evaluación de un grado de idoneidad técnica. Este parámetro, como resultado de la herramienta propuesta, sirve como apoyo a la toma de decisiones, la mejora del diseño y la eficiencia de las soluciones que emplean BT. Se concluye con la validación de la herramienta que demuestra su fiabilidad y adaptabilidad a cualquier situación. Finalmente, a partir del análisis de casos, se expone cómo la calidad del producto unida a condiciones externas adversas, aún con diseños constructivos correctos, define una situación común por la que el grado de idoneidad de la solución es reducida. Por lo tanto, es necesario exigir también productos con avales y prescripciones que garanticen y ofrezcan suficiente seguridad técnica.

Palabras clave
construcción sostenible, materiales tradicionales, bioconstrucción, cerramiento de la edificación

ABSTRACT

Although earth block construction (EB) is supported by numerous scientific works, there is a lack of confidence in its constructive viability, aggravated by the lack of specific technical training. In view of this uncertainty, which is widespread in Spain, it is necessary to provide well-founded technical responses. This article, considering these aspects, presents the design and validation of a tool to assess the constructive viability of EB. For this purpose, 29 case studies are chosen in Spain, which establish the constructive use determinations and indicators to assess a degree of technical suitability. This parameter, as a result of the proposed tool, acts as a support for decision-making, the improvement of the design and, the efficiency of the solutions that use EB. It concludes by validating the tool, demonstrating its reliability and adaptability to any situation. Finally, the case analysis shows how the quality of the product combined with adverse external conditions, even with correct construction designs, defines a common situation where the degree of suitability of the solution is reduced. Therefore, it is also necessary to demand products with guarantees and prescriptions that ensure and offer sufficient technical safety.

Keywords
Sustainable construction, traditional materials, bio-construction, building envelope.

NOMENCLATURE

CFS	Construction feasibility study
EB	Earth block
CEB	Compressed earth block
EEB	Extruded earth block
C-CA	Reference to the quality of the product
C-RC	Reference to the construction requirements
C-AE	Reference to the external actions
CFS	Construction feasibility study
GI_i	Degree of suitability for *i* aspects
NET_q	Technical assessment level of the *q* indicators
$NETP_i$	Weighted technical assessment level for *i* aspects
W_i	Weighted coefficient for the *i* aspects

INTRODUCTION

Over the last two decades, the international environmental and economic situation is generating the need and interest to develop suitable construction solutions for the environmental, energy and social demands. In this context, the use of adobe and earth blocks (EB), that mainly includes compressed earth blocks (CEB), as manufactured masonry, may be a more sustainable construction alternative.

To support this statement, the current EB research framework has focused on studies about their mechanical (Gandia, Gomes, Corrêa, Rodrigues & Mendes, 2019; Mahmood, Habeeb & Al-Jumaili, 2019), thermal (Mosquera, Canas, Cid-Falceto & Marcos, 2014; Molar-Orozco, Velázquez-Lozano & Vázquez-Jimánez, 2020; Miloudi *et al*, 2019; Wati, Bidoung, Damfeu, & Meukam, 2020) and durability (Fernandes, Peixoto, Mateus & Gervásio, 2019; Lavie Arsène, Frédéric & Nathalie, 2020; Jové Sandoval, Muñoz de la Calle & Pahíno Rodríguez, 2011) properties. Others support the use of EB, arguing economic aspects, low toxicity and, even, as a product that benefits indoor air quality (Fernandes et al., 2019). It also uses natural local materials, freeing, to a great extent, the environmental impact associated to transportation (Deboucha & Hashim, 2011).

From the application point of view of the product, it is necessary that EB reaches a higher level of acceptance, similar to that of other construction materials, and that certain factors that negatively affect the decision-making of technicians are overcome: the production cost, the low availability of technical data of the product to justify regulatory requirements, added to the bad practice on not knowing the application conditions of the material. As a result, it is necessary to establish a framework that better defines the construction, economic or environmental determinations of using EB. These must serve as the basis for its choice to be viable and guaranteed with technical data and for the trusts of all the agents involved in the construction grows, with the purpose of setting directives on the correct use, and in line with the technical-construction requirements.

The feasibility of using CEB and adobe has been analyzed by Maldonado Ramos, Castilla Pascual, Vela Cossio and Rivera Gómez (2001) demonstrating that, for a small to mid-sized scale project, it is an economic solution, as well as being an improvement for thermal insulation compared to other materials like concrete, bricks or steel. Likewise, in the international regulatory sphere, there are several documents that regulate the use and application of EB, such as the Brazilian (1986-1996), Colombian (2004), Peruvian (2000) or Spanish (2008) regulations, all of them reviewed and analyzed by Cid-Falceto, Mazarrón and Cañas (2011). However, none of the contributions mentioned offer a tool that allows analyzing the feasibility of applying EB in buildings, reason why its applicability is reduced on being subjected to a technical criterion without enough or suitable knowledge regarding its qualities and performance.

As for the assessment methodologies, those that use quantitative or qualitative indicators have been extensively developed in literature. In terms of those focused on earth construction, the contribution of Canivell for the evaluation of adobe brick factories stands out (Canivell, Rodríguez-García, González-Serrano & Romero Girón, 2020; López-Zambrano, Canivell & Calama, 2019). Although its purpose is focused on the evaluation of the physical risk, certain operating capacity of the indicators have been taken as reference. However, no methodological tools that are useful to evaluate the suitability of certain construction products like EB, have been developed.

This work focuses on the construction aspects that affect the suitability of EB as a product, for which its physical, chemical and mechanical characteristics have been defined, as have the production phases and construction techniques for the sake of adopting solutions adapted to different contexts. In this case, the framework of the requirements to analyze the feasibility of EB is the Spanish building regulation (Spain, 2008). The goals of this article are (I) establishing the construction determinations of EB and its associated indicators; (II) presenting and validating the methodological procedure of a tool to evaluate the construction aspects of an architectonic design at the level of basic project developed using EB; (III) presenting the results of said tool in the case studies considered; and (IV) analyzing the response of the indicators used. It is estimated that this task, namely, clearly establishing the demands and determinations of this tool, offering an analysis of the indicators, will facilitate decision-making in this aspect and, subsequently, will contribute towards optimizing the applicability of EB as a sustainable construction solution.

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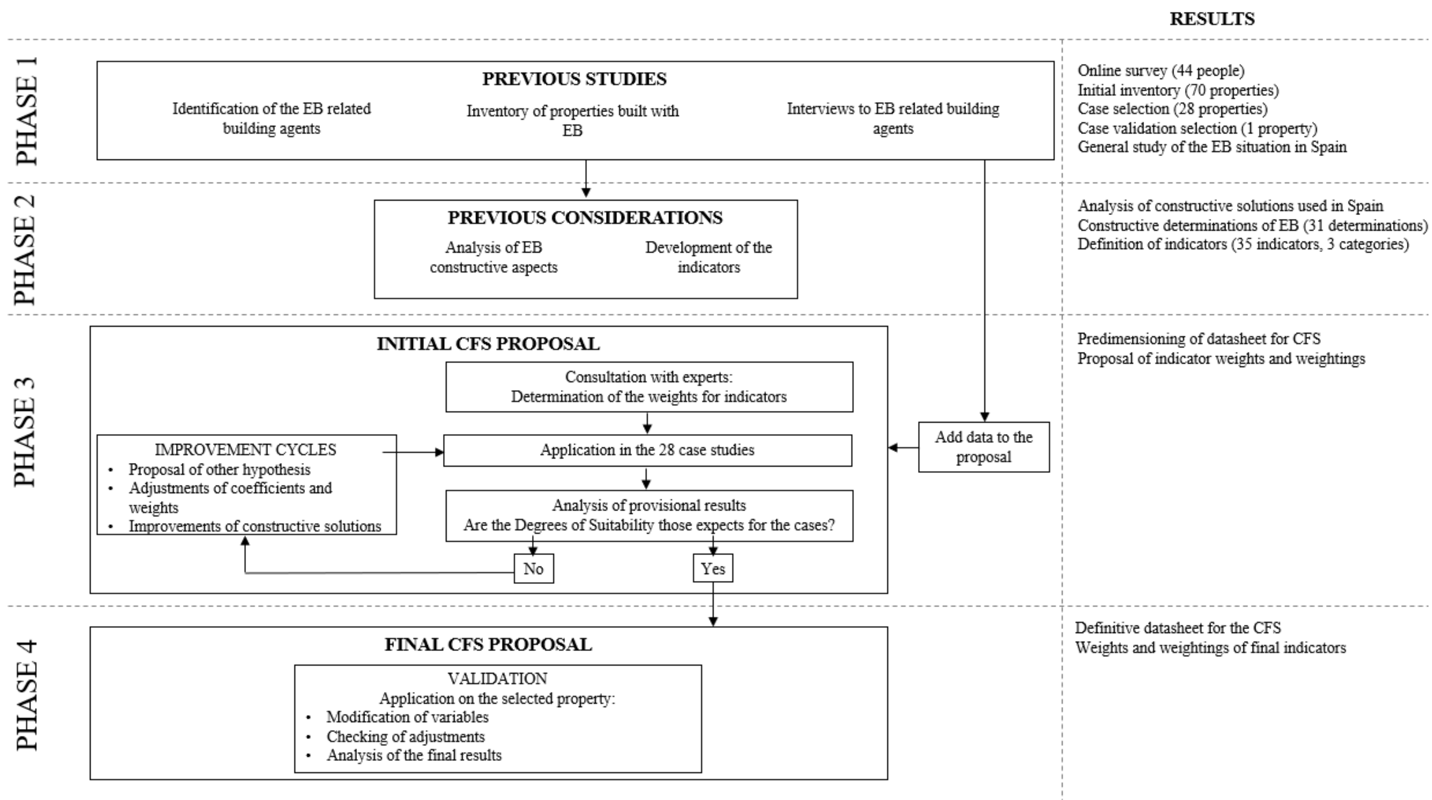

Figure 1. Methodological procedure set out to establish the CFS. Source: Preparation by the authors.

METHODOLOGICAL PROCEDURE OF THE RESEARCH. INDICATORS

The methodological process carried out to set up the tool, which will be called construction feasibility study (CFS), has been compartmentalized in the phases and contents that are detailed in Figure 1.

Starting from the inventory made on buildings that have used EB in their design in Spain, in a first phase, a set of 70 cases are chosen and analyzed, which correspond to 59 dwellings (residential use) and another 11 properties for tertiary, education or industrial use. Later, with fieldwork, the most relevant cases are chosen, leaving a total of 28 out of the 70 studied ones, which are divided in 15 cases of single-family residential use, 5 of multi-family use, 6 of third-party use and 2 educational buildings. In the second phase, the construction determinations associated to EB are cataloged (Table 1). In the third one, the tool is implemented in the 28 cases mentioned and, using improvement cycles, their optimal response is adapted. In the last phase, the operation of the CFS is validated in a case study not included in the 28 previous ones.

The first key aspect of CFS consists in setting out the construction determinations (second phase), which are organized considering the three categories developed in Table 1: the characteristics of the product (quality), the construction requirements (requirements of the construction system itself), and the external conditions (external actions). Thus, the product's quality considers the physical, chemical and mechanical characteristics of the EB, defined and/or stated by the manufacturer and established in the project. Secondly, the construction requirements are associated to the product to respond to certain aspects regarding compliance of the current regulations (Ministry of Development, 1999), fundamentally the structural stability of the factory and the inhabitability of the spaces. And, regarding the third category, it will have to consider the analysis of external actions that may affect the EB factory throughout its service life, which depend on the function that the wall has (load bearing or enclosure), its location and orientation, and the aggressiveness of the environment it is exposed to (Soronis, 1992).

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INDICATORS: Product quality (C-CA)				DETERMINATIONS: Product quality
C-CA-AF Physical aspects -002 -003 -004 -005 -006 -007 -008 -009		-001	Density	Apparent and dry density for sound requirements
		Mechanical resistance	Resistance to simple compression (UNE 41410)	
		Resistance to dry/wet cycles	Resistance to the cycles under severe outdoor conditions	
		Resistance to erosion	Resistance to the cycles under severe outdoor conditions	
		Capillary water absorption	Resistance to the cycles under severe outdoor conditions	
		Resistance to freeze/thaw cycles	Resistance assessed and/or declared in risk areas	
		Product's thermal properties	Characterization of thermal conductivity and specific heat	
		Water vapor permeability	Characterization of the permeability-resistance to water vapor	
		Adherence to shearing	Shear strength (load-bearing walls)	
C_CA-AQ Chemical aspects -002 -003		-001	Chemical characterization: earth and additives	Chemical stabilizers: cement, lime, plaster, silicate
		Water	Water: composition, salt and organic content	
		Reaction to fire	Piece's reaction to fire	
C-CA-AG Geometric aspects -002		-001	Dimensions and tolerances	Description of the type, dimensions, sizing and tolerances
		Appearance	Evenness, defects and cells	
INDICATORS: Constructive Requirements (C-RC)				**DETERMINATIONS: Constructive requirements**
C-RC-S Safety	Structural	-001.1	Load transmission	Type of wall, composition and thickness of the pointing, type of fiber, slenderness and load distribution
		-001.2	Transmission to the ground	
		-001.3	Bearing capacity	
		-001.4	Spatial configuration	Symmetries and rigidities of the wall and corners
		-001.5	Configuration of the openings	Opening distribution and size
	Fires	-002	Safety in case of fire	Evaluation and/or declaration of the reaction to fire
	Damage	-003	State of existing damage	
C-RC-H Inhabitability -002 -003		-001	Health and sanitation	Suction, absorption, open porosity or diffusiveness of water vapor
		Sound insulation	Sound reduction index or airborne sound insulation value	
		Thermal behavior	Evaluation of the wall's thermal resistance	

INDICATORS: External actions (C-AE)				DETERMINATIONS: External actions
C-AE-F Physical	Meteorology	-001.1	Rain	Rainfall intensity, prevailing winds and designed protections
		-001.2	Wind	
		-001.3	Temperature	
	Land	-002	Land morphology	Drainage capacity of surrounding land
	Natural agents	-003	Seismic	Local seismic risk
C-AE-M Mechanical	Anthropic agents	-001	Use of the space	Impact of human activities
C-AE-Q Physical-chemical	Organisms	-001	Vegetation and animals..	Impact of animal and vegetation activities
	Anthropic agents	-002	Environment	Impact of human activities that contaminate the air or water
	Natural agents of the environment and the land	-003.1	Land humidity	Impact of phreatic water
		-003.2	Environmental humidity	Risk of condensation
		-003.3	Solar radiation	Degradation by UV radiation

Table 1. Determinations considered and associated indicators. Source: Preparation by the Authors.

The determinations presented in Table 1 are used to establish a total of 35 associated indicators. The indicators are identified using a code (C-CA: quality constructive indicators; C-RC: constructive requirements; C-AE: external actions) and are evaluated using numeric values based on concepts and appreciations. The quantitative and/or qualitative valuation of each indicator is called Technical Assessment Level (NET in Spanish) and requires its basic definition following: (I) a description of its three possible levels (1, 2 or 3), and (II) the references and sources used, as suggested by the UNE 21929-1:2010 (AENOR, 2009) to define sustainability indicators for buildings. The three levels of indicators are expressed as: 1 (low assessment level, negative valuation); 2 (medium level, moderate valuation); and 3 (high level, positive valuation) (Figure 2).

Concept: Resistance to dry/wet cycles **Code: C-CA-AF-003**

Root: Product quality>Physical aspects

Parameter description: Knowing beforehand the EB's resistence to dry and wet cycles, will provide data about possible constructive solutions that do not imply a deterioration of the material when facing severe exposure.

Technical considerations:
Is it interesting for us to know about the resistance to dry and wet cycles?

In the test, on facing severe exposure, the wall must be capable of bearing six dry and wet cycles without seeing a series of conditions (specific test of UNE 41410:2008).

The deterioration caused by these cycles on the survey, means the material decomposes more quickly (Falceto, 2012).

Levels:

Color	Level	Explanation
Low	1	**External production**, the manufacturer does not state any aspect about the resistance to dry and wet cycles. In the onsite **production**, the declaration of resistance to dry and wet cycles will not be possible.
Medium	2	**External production**, the manufacturer does state about the resistance to dry and wet cycles. In the onsite **production**, the declaration of resistance to dry and wet cycles will be possible, but not its certification.
High	3	**External production**, the manufacturer does state and certify the resistance to dry and wet cycles. In the onsite **production**, the declaration and certification of the product will be possible.

Standard:
Page 14 - UNE 41410:2008 - (**UNE 41410**, 2008)
ASTM D599: 1989 - Wetting and drying test.
Reference:
(Guettala, Abibsi, & Houari, 2006)

Figure 2. Basic definition of the NET for the indicator of resistance to wet/dry cycles. Source: Preparation by the authors based on the UNE 41410 (2008) and ASTM D559 (1989) standards.

METHODOLOGICAL PROPOSAL FOR THE CFS

The CFS is designed to be applied in the first stage of preparation of the architectonic project. In this phase, the goal is to consider possible strategies in the constructive design of the enclosure non-load bearing wall. The assessment procedure (Figure 3) comprises three differentiated stages: data entry, establishing indicator levels, and evaluation which, for its part, is developed in two concatenated stages.

In the first stage, the information sources having been considered, the constructive determinations of the case study are compiled and classified following

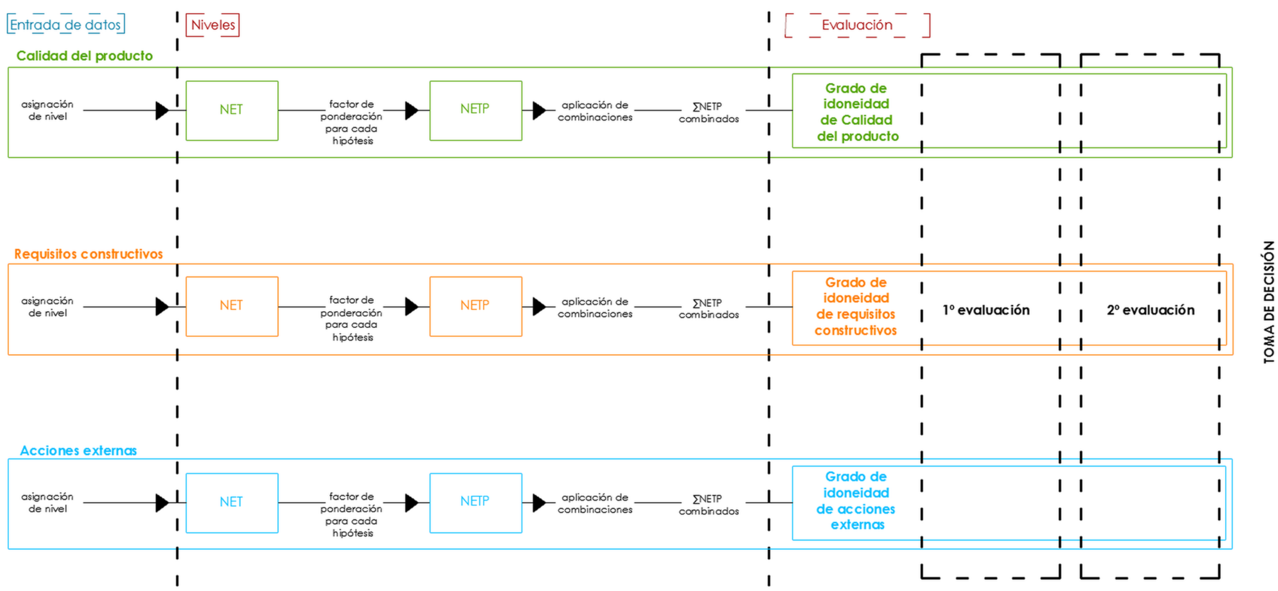

Figure 3. CFS procedure stages. Source: Preparation by the Authors.

	Aspects of application of EB on the wall										
	Foundation	Base	Openings	Lintel	Jambs	Sill	Finishes	Inside	Outside	Installation	Crown
	Weighting by weight (Wi)										
	W1	W2		W3	W4	W5		W6	W7	W8	W9
C-CA Product quality											
C-CA-AF-001 Density	10,00	6,90		4,35	4,35	4,55		4,55	4,76	8,00	10,53
C-CA-AF-002 Mechanical resistance	10,00	6,90		13,04	4,35	4,55		4,55	4,76	12,00	10,53
C-CA-AF-003 Resistance to dry/wet cycles	5,00	6,90		4,35	8,70	9,09		9,09	9,52	4,00	5,26
C-CA-AF-004 Resistance to erosion	5,00	10,30		4,35	4,35	4,55		9,09	4,76	8,00	5,26
C-CA-AF-005 Capillary water absorption	15,00	6,90		4,35	8,70	9,09		9,09	9,52	8,00	5,26
C-CA-AF-006 Resistance to freeze/thaw cycles	10,00	6,90		4,35	4,35	4,55		4,55	9,52	4,00	5,26
C-CA-AF-007 Product's thermal properties	5,00	6,90		8,70	8,70	9,09		4,55	4,76	4,00	5,26
C-CA-AF-008 Water vapor permeability	5,00	6,90		8,70	8,70	9,09		13,64	14,29	4,00	5,26
C-CA-AF-009 Adherence	5,00	6,90		4,35	4,35	4,55		4,55	4,76	12,00	5,26
C-CA-AO-001 Characteristics of constituent parts - Stabilizers	5,00	6,90		4,35	4,35	4,55		9,09	4,76	8,00	10,53
C-CA-AO-002 Water as constituent part	5,00	6,90		4,35	4,35	4,55		4,55	4,76	8,00	5,26
C-CA-AO-003 Reaction to fire	5,00	6,90		13,04	13,04	9,09		13,64	14,29	4,00	10,53
C-CA-AG-001 Dimensions and tolerances	5,00	6,90		13,04	13,04	13,64		4,55	4,76	8,00	10,53
C-CA-AG-002 Appearance	10,00	6,90		8,70	8,70	9,09		4,55	4,76	8,00	5,26
TOTALS (%)	100,00	100,00		100,00	100,00	100,00		100,00	100,00	100,00	100,00
C-RC Constructive requirements											
C-RC-S-001.1 Load transmission	17,65	15,00		11,11	7,69	7,14		5,88	6,67	15,00	10,53
C-RC-S-001.2 Transmission to earth	17,65	5,00		11,11	7,69	7,14		5,88	6,67	15,00	10,53
C-RC-S-001.3 Load-bearing capacity	17,65	15,00		16,67	7,69	7,14		5,88	6,67	10,00	15,79
C-RC-S-001.4 Spatial configuration	5,88	10,00		11,11	15,38	14,29		11,76	20,00	5,00	10,53
C-RC-S-001.5 Openings	5,88	5,00		16,67	23,08	21,43		5,88	13,33	10,00	5,26
C-RC-S-002.1 Fire safety	5,88	10,00		11,11	7,69	7,14		17,65	6,67	10,00	10,53
C-RC-S-003.1 Stabilization of existing damages	11,76	10,00		5,56	7,69	7,14		11,76	6,67	10,00	10,53
C-RC-H-001.1 Environmental protection, health and safety	5,88	10,00		5,56	7,69	7,14		11,76	6,67	5,00	5,26
C-RC-H-001.2 Noise insulation	5,88	10,00		5,56	7,69	7,14		11,76	13,33	10,00	10,53
C-RC-H-001.3 Thermal behavior	5,88	10,00		5,56	7,69	14,29		11,76	13,33	10,00	10,53
TOTALS (%)	100,00	100,00		100,00	100,00	100,00		100,00	100,00	100,00	100,00
C-AE External actions											
C-AE-F-001.1 Rain	9,52	14,29		7,69	20,00	20,00		6,67	15,79	7,69	13,33
C-AE-F-001.2 Wind	4,76	9,52		7,69	6,67	6,67		6,67	15,79	7,69	6,67
C-AE-F-001.3 Temperature	4,76	4,76		7,69	6,67	6,67		6,67	5,26	7,69	6,67
C-AE-F-002.1 Land	14,29	9,52		7,69	6,67	6,67		6,67	5,26	7,69	6,67
C-AE-F-003.1 Seismic	14,29	9,52		15,38	13,33	13,33		13,33	10,53	15,38	13,33
C-AE-M-001 Use of the space by animals, people...	9,52	9,52		7,69	6,67	6,67		13,33	10,53	7,69	6,67
C-AE-O-001.1 Biological agents	9,52	9,52		7,69	6,67	6,67		6,67	5,26	7,69	6,67
C-AE-O-002.1 Type of environment	9,52	9,52		7,69	6,67	6,67		13,33	10,53	7,69	6,67
C-AE-O-003.1 Land humidity	14,29	9,52		7,69	6,67	6,67		6,67	5,26	15,38	6,67
C-AE-O-003.2 Environmental humidity	4,76	9,52		15,38	13,33	13,33		13,33	10,53	7,69	13,33
C-AE-O-003.3 Solar radition	4,76	4,76		7,69	6,67	6,67		6,67	5,26	7,69	13,33
TOTALS (%)	100,00	100,00		100,00	100,00	100,00		100,00	100,00	100,00	100,00
Note:		Slight			Moderate				Decisive		

Figure 4. Result of the survey to experts to establish the weight averages (Wi) in each wall aspect of all the indicators. Source: Preparation by the Authors.

Combinations (j)	Indicators with reduction of valuation by combination			K* coefficient for the aspects (i)								
				O-01A	O-01B	O-01C-01	O-01C-02	O-01C-03	O-01D-01	O-01D-02	O-01E	O-01F
	Quality (CA)	Constructive Requirements (RC)	External actions (AE)	Foundation	Base	Lintel	Jambs	Sill	Inside	Outside	Installation	Crown
Nº 01			C-AE-F-001.1/ C-AE-F-001.2	0	**0,5**	**0,5**	**0,5**	**0,5**	0	**0,5**	**0,5**	**0,5**
Nº 02			C-AE-F-001.1/ C-AE-F-002.1/ C-AE-Q-003.1/ C-AE-M-001	**0,5**	**0,5**	0	0	0	0	0	0	0
Nº 03			C-AE-Q-001.1	**0,5**	**0,5**	**0,5**	**0,5**	**0,5**	**0,5**	**0,5**	0	**0,5**
Nº 04		C-RC-S-001.4	C-AE-F-002.1/ C-AE-F-003.1	0	0	**0,5**	**0,5**	0	0	0	0	**0,5**
Nº 05		C-RC-ES-001	C-AE-Q-003.2	0	0	**0,5**	**0,5**	**0,5**	**0,5**	**0,5**	0	0
Nº 06	C-CA-AF-005/ C-CA-AF-008	C-RC-ES-001	C-AE-F-001.3/ C-AE-Q-003.2	0	**0,5**	**0,5**	**0,5**	**0,5**	0	0	0	**0,5**
Nº 07		C-RC-S-001.1/ C-RC-S-001.4/ C-RC-S-001.5		0	**0,5**	**0,5**	0	0	0	0	0	**0,5**

(*) K=1 for the rest of the indicators not included in the combinations

Figure 5. Critical combinations following the survey to experts and their Kj weight coefficients considering the established aspects. Source: Preparation by the authors.

the categories of Table 1, which is used to later value the associated indicators, following the *NET* for each one of the 35 indicators of the three categories. It is worth clarifying that on each indicator being of a different nature and the application settings within a wall being different, not all the indicators will have the same degree of influence on the assessment, as such their values must not be added directly. For this reason, weighing methods are established, following the UNE-ISO/TS 21929 (AENOR, 2009), through the application of correction coefficients or weights, prepared from surveys to experts (see Figure 1, phase 3), emphasizing in the valuation of the degree of determination of each indicator, following nine application aspects of the EB defined as enclosure elements (these consider: foundation, wall base, parts of an opening – lintel, jambs, sill -, finishing – indoor and outdoor – installations and crowning of the wall) (Figure 4). Three types of indicators are also included in these surveys, determined considering the associated weights: decisive, moderate or slight. The ranges of the *NET* (1 to 3) are weighted in terms of the relationship between the proposed indicators and the nine defined aspects of the wall. Thus, the *NET* will reduce or maintain its value proportionally through the product with the coefficient, obtaining the weighted technical assessment level *(NETP)*

Therefore, as there are nine aspects, just as Figure 4 shows, nine sets of NETP are obtained, after applying the following equation [1]:

$$NETP_i = \frac{NET \times W_i}{100} \quad [1]$$

where W_i is the weight for each one of the nine aspects studied.

The surveys to experts are also used to consider which circumstances are the most adverse when there are certain critical combinations. Starting from these, seven critical combinations of indicators that reduce the valuations of the *NETPi* are established. In this way, for each one of the nine aspects, some of the seven possible combinations that are outlined in Figure 5 would develop. On establishing the condition that, for *NET* < 3 of the indicators associated to the combinations, the valuations of their corresponding *NETP* will be reduced 50% through the K_j coefficient, leaving the weighing of *NET* following equation [2].

$$NETP_{i,j,q} = \frac{NET_q \times W_i}{100} \times K_j \quad [2]$$

Next, all the *NETP* of each block are added (C-CA, C-RC and C-AE) and by combination, within each one of the nine aspects of the wall, as is detailed in the graph of Figure 6. The degree of suitability of each aspect (hereinafter GI_i) would correspond to the minimum of the combinations made, obtaining with the average of the nine GI_i, the *GI* for each block (C-CA, C-RC, C-AE), through which the two levels of assessment will be developed.

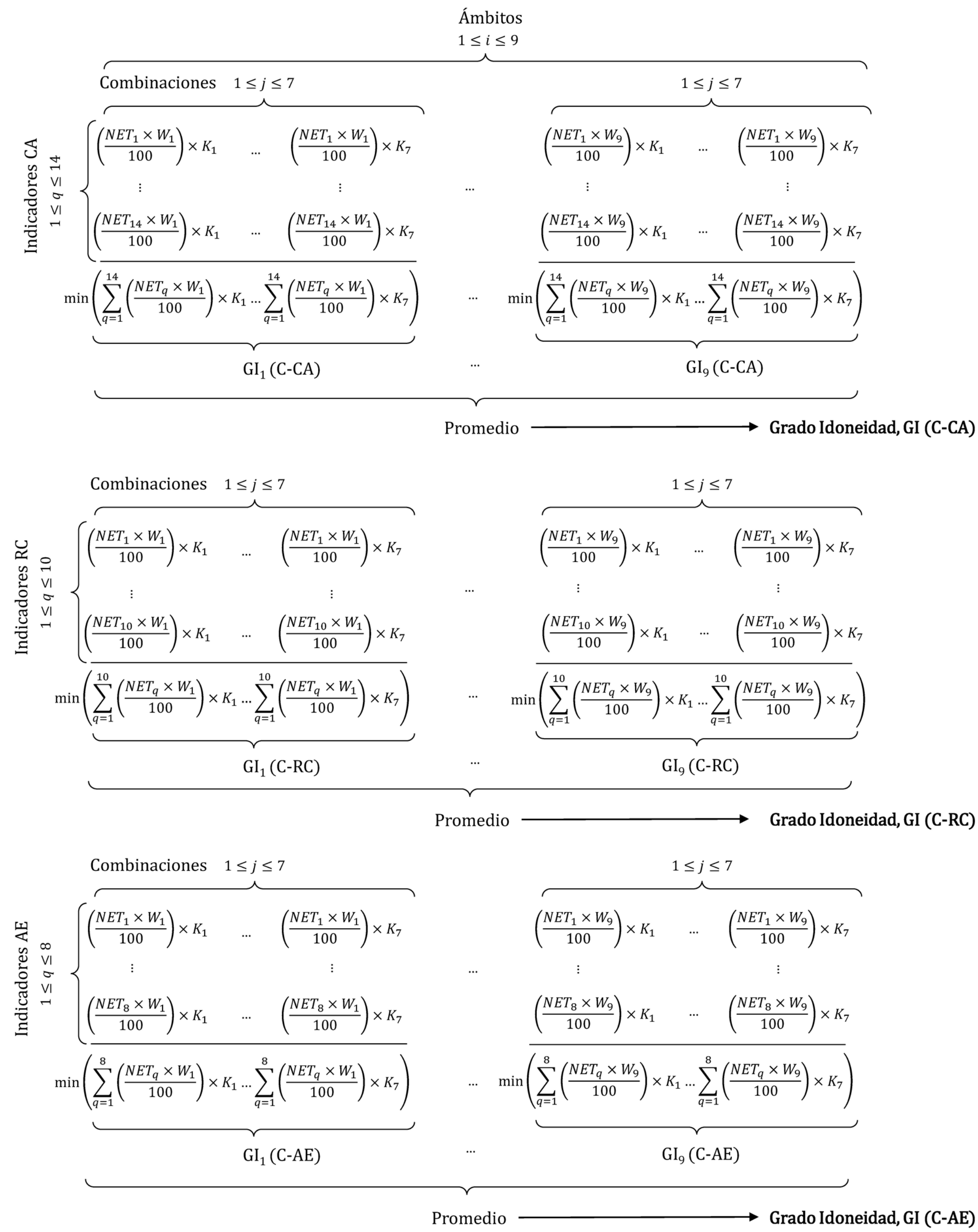

Figure 6. Sequence of stages in the NET assessment. Source: Preparation by the authors.

The first assessment level of the *GI* allows obtaining an affirmative ("Suitable") or negative ("Unsuitable") response on the constructive feasibility of the EB. For this, a final criterion is established depending on the *GI*, evaluated as "Suitable" as long as the average *GI* of the three blocks (*GI(C-CA)* = 1.5, *GI(C-RC)* = 2.3, *GI(C-AE)* = 2.5) is higher than or equal to the preset *GI* thresholds (also see Figure 11). The rating of "Suitable" implies that the constructive solutions are feasible from a constructive point of view and could be implemented in the execution project. However, the negative response of "Unsuitable" would imply making a second assessment level.

In that second assessment level, the indicators are studied in greater detail based on two lines of analysis, to identify deficiencies and to propose improvements. The first analysis corresponds to the product's quality

Aspect	Block (*)	GI low		GI moderate		GI high	
		Min	Max	Min	Max	Min	Max
Foundation	RC	0	2,32	2,33	2,69	2,7	3
	AE	0	2,32	2,33	2,69	2,7	3
Wall base	RC	0	2,29	2,3	2,53	2,54	3
	AE	0	2,1	2,11	2,59	2,6	3
Openings - Lintel	RC	0	2,18	2,19	2,59	2,6	3
	AE	0	1,99	2	2,59	2,6	3
Openings - Jambs	RC	0	2,18	2,19	2,58	2,59	3
	AE	0	1,99	2	2,59	2,6	3
Openings - Sill	RC	0	2,24	2,25	2,58	2,59	3
	AE	0	1,98	1,99	2,59	2,6	3
Finish - Indoor	RC	0	2,25	2,26	2,45	2,46	3
	AE	0	1,99	2	2,58	2,59	3
Finish - Outdoor	RC	0	2,32	2,33	2,58	2,59	3
	AE	0	2,19	2,2	2,58	2,59	3
Technical resources	RC	0	2,29	2,3	2,7	2,71	3
	AE	0	2,29	2,3	2,7	2,71	3
Crown	RC	0	2,39	2,4	2,59	2,6	3
	AE	0	2,18	2,19	2,58	2,59	3
Partition	RC	0	2,29	2,3	2,59	2,6	3
	AE	0	2,29	2,3	2,69	2,7	3

(*) RC: Constructive requirements; AE: external actions

Figure 7. Classification of GI according to the intervals established for the second assessment level. Source: Preparation by the Authors.

indicators, as such the corresponding *NET* are cross checked with the demands of the current standards in force (essentially UNE 41410:2008) and shortcomings are detected in the technical specifications of the manufacturer's statements, which, at the same time, can be resolved or at least proposals of alternative measures could be allowed. For this purpose, some conditional algorithms have been designed in the CFS that link these indicators with the data entry values related to the product's quality. The second analysis is focused on the GI_i of the constructive requirements and on the external actions that affect all aspects of the wall where EB is used. In this case, three classifications of the GI_i ranges have been established: optimal (green), moderate (yellow) or low (red). This classification is made from the GI_i intervals of the 28 case studies implemented (Figure 7). Depending on the classification of each GI_i, possible solutions can be established to improve the aspects considered as deficient.

Once the methodology procedure of the CFS is developed, a variation is made through the implementation of the method on a case study not included in the list of the 28 ones chosen as the basis to make the tool.

VALIDATION AND RESULTS

The goal of the proposed tool's validation is to verify that the procedure is suitable for the constructive assessment of EB walls as part of an architectonic project. With said purpose, it is confirmed whether the results of the CFS or any case study are those estimated in terms of their *GI*. To validate the CFS, a sufficiently sized building is chosen (approximately 700m^2 built) with available technical documentation, where the constructive solutions are varied and that uses EB with technical certification on the enclosure walls.

With these starting conditions, the La Font del Rieral Municipal Primary School in Santa Eulàlia de Ronçana (Barcelona) is chosen, designated as BAR-001. In one sector, CEB are used, with a size of 29x14.5x9.5 cm, from a manufacturer that provides product datasheets, where the regulatory requirements are justified, although without official standardization. The main characteristics of the walls' constructive solutions appear on the building's south-facing façade, comprised by a double CEB sheet load-bearing wall (each sheet with a thickness of 14.5 cm), anchored to each other with zinc-coated steel pins, with a natural cork insulation layer (2 cm) and inner air chamber (5 cm). These walls, towards the inside have a visible CEB with a baseboard covered with laminate panels up to the window sills; and on the outside, these are treated with water repellant that is coated with lime and cement mortar. The openings are designed with suitably waterproofed wood carpentry. The support of the load-bearing wall to the foundation is made using cement mortar block course, connected with corrugated metal bars to the reinforced concrete strip footing; the waterproofing sheet is placed on the base of the CEB wall above

Product quality		
Product		**CEB - Bioterre**
Production	Onsite / external	External
Type of EB and block composition foreseen	Type of stabilizer	Cement
	Declaration of stabilizer	Yes
	Certification of stabilizer	Yes
	Density foreseen	Yes
	Use of fibers	No
	Water composition indication	No
	Organic matter or salts.	No
Declaration of data	Density	Yes
	Compressive strength	Yes
	Resistance to dry/wet cycles	Yes
	Resistance to erosion	Yes
	Capillary water absorption	Yes
	Resistance to freeze/thaw cycles	Yes
	Product's thermal properties	Yes
	Water vapor permeability	Yes
	Fire reaction	Yes
	Dimensions	Yes
	Tolerances	Yes
	Evenness	Yes
	Defects	Yes
	Cells	Yes
Certification through standardized tests	Density	Yes
	Compressive strength	Yes
	Resistance to dry/wet cycles	Yes
	Resistance to erosion	Yes
	Capillary water absorption	Yes
	Resistance to freeze/thaw cycles	Yes
	Product's thermal properties	Yes
	Water vapor permeability	Yes
	Fire reaction	Yes
External agents		
Environmental aspects	Average rainfall in area (CTE)	III
	Prevailing wind of the area	East and west
	Wind (km/h)	-
	Wind Area	C
	Minimum temperature	<0°C
	Environmental humidity	>70%
	Risk of microorganisms	Yes
Aspects of the land	Description of the land profile considering the intervention site	Slightly sloped
	Height of the phreatic level	Unknown
	Ag coefficient of the area (Seismic)	0.09
Heritage aspects	Catalog	No
	Specific standards	No
	Degree of protection	-
	Sustainability strategies	No
	Specific construction standards	No
Others	Type of surrounding vegetation	Sheet ending on south facade which provides shade in summer and light, in winter
	Type of possible contamination	None
	Use of surrounding space	Playground

Constructive requirements		
General characteristics of the property	Height	3 meters approx.
	N° of floors	1
	Spatial composition	Non-symmetrical / curve
	Building use	Education
Characteristics of the wall	Location of block on facade	Outside
	Type of wall or visible face covering.	Covering
	Type of mortar being used.	Lime mortar
	Wall composition.	Double 30 cm CEB wall with chamber and 2 cm natural cork insulation
	Height foreseen of wall support.	15 cm
	Type of wall support on the foundation.	Wall elevated by concrete block and anchored to the foundation
	Foundation foreseen.	Concrete strip footing supported directly on firm ground
	Wall bracing	Crowning beam
	Slenderness.	2.5 meters high
	Symmetric or irregular volume.	Irregular
	Openings	With openings
	Thickness foreseen.	30 cms
	Continuity of the elements	Yes
	Joints foreseen	Yes
	Analysis foreseen of holding mortar used	Yes
Protection elements	Use of baseboard	No
	Use of cornice	Yes
General constructive characteristics	Structural typology	Load-bearing
	Constructive system: load or non-load bearing	Walls
	Structure: identification of loads and overloads 1	Vertical
	Structure: identification of loads and overloads 2	N/A
Requirements	Severe exposure?	No
	Visible face?	No/Yes
	Thermal insulation requirements?	Yes
	External parameter?	Yes
	Noise requirements	Yes
	Structural requirements	Yes
	Fire resistance requirements	Yes

Name	**Escuela Santa Eulalia de Rονçana**	**BAR-001**
Aspects		
Foundation		No
Wall base		Yes
Openings in the wall	Lintel	Yes
	Jambs	Yes
	Sill	Yes
Finishes	Inside	Yes
	Outside	Yes
Installation of technical resources		Yes
Wall crown		Yes

Figure 8. Initial data entry for BAR-001 case study. Source: Preparation by the authors.

ground level. A reinforced concrete truss beam crowns the wall, where the roof's sawn wooden beam rests. The project considers the requirements of the Technical Building Code (Spain).

Upon analyzing the available information on the project, data entry is made (Figure 8), looking to obtain an optimal CFS response for the first assessment level, given that the starting parameters for the three blocks considered are favorable. All indicators have a *NET* of three, except for C-RC-S-001.4 (Spatial configuration), C-RC-S-0021 (Fire safety) and C-AE-F-001.3 (Temperature), which are valued with two; and C-CA-AQ-002 (water as constituent part) which has a value of 1, on not having proof of the tempering water requirements, as per UNE 41410.

The first result of the CFS (Figure 9) shows the *NETP* and GI_i corresponding to the different aspects of the studied wall, as well as the average *GI*, which makes it possible to pass the first assessment level. The initial hypothesis is thus confirmed, where it was estimated

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	Initial Hypothesis										Hypothesis 1	Hypothesis 2
	EB application aspects on the wall											
Indicator	Foundation	Base	Lintel	Jambs	Sill	Inside	Outside	Installation	Crown	Average GI	Average GI	Average GI
C-CA-AF-001 Density	0.00	0.21	0.13	0.13	0.14	0.14	0.14	0.24	0.32			
C-CA-AF-002 Mechanical resistance	0.00	0.21	0.39	0.13	0.14	0.14	0.14	0.36	0.32			
C-CA-AF-003 Resistance to dry/wet cycles	0.00	0.21	0.13	0.26	0.27	0.27	0.29	0.12	0.16			
C-CA-AF-004 Resistance to erosion	0.00	0.31	0.13	0.13	0.14	0.27	0.14	0.24	0.16			
C-CA-AF-005 Capillary water absorption	0.00	0.21	0.13	0.26	0.27	0.27	0.29	0.24	0.16			
C-CA-AF-006 Resistance to freeze/thaw	0.00	0.21	0.13	0.13	0.14	0.14	0.29	0.12	0.16			
C-CA-AF-007 Product's thermal properties	0.00	0.21	0.26	0.26	0.27	0.14	0.14	0.12	0.16			
C-CA-AF-008 Water vapor permeability	0.00	0.21	0.26	0.26	0.27	0.41	0.43	0.12	0.16			
C-CA-AF-009 Adherence	0.00	0.21	0.13	0.13	0.14	0.14	0.14	0.36	0.16			
C-CA-AO-001 Characteristics of constituent	0.00	0.21	0.13	0.13	0.14	0.27	0.14	0.24	0.32			
C-CA-AO-002 Water as constituent part	0.00	0.07	0.04	0.04	0.05	0.05	0.05	0.08	0.05			
C-CA-AO-003 Reaction to fire	0.00	0.21	0.39	0.39	0.27	0.41	0.43	0.12	0.32			
C-CA-AG-001 Dimensions and tolerances	0.00	0.21	0.39	0.39	0.41	0.14	0.14	0.24	0.32			
C-CA-AG-002 Appearance	0.00	0.21	0.26	0.26	0.27	0.14	0.14	0.24	0.16			
GI_i (C-CA)	**0,00**	**2,86**	**2,91**	**2,91**	**2,91**	**2,91**	**2,90**	**2,84**	**2,89**	**2,89**	**2,52**	**2,89**
C-RC-S-001.1 Load transmission	0.00	0.45	0.33	0.23	0.21	0.18	0.20	0.45	0.32			
C-RC-S-001.2 Transmission to ground	0.00	0.15	0.33	0.23	0.21	0.18	0.20	0.45	0.32			
C-RC-S-001.3 Load-bearing capacity	0.00	0.45	0.50	0.23	0.21	0.18	0.20	0.30	0.47			
C-RC-S-001.4 Spatial configuration	0.00	0.20	0.22	0.31	0.29	0.24	0.40	0.10	0.21			
C-RC-S-001.5 Configuration of openings	0.00	0.15	0.50	0.69	0.64	0.18	0.40	0.30	0.16			
C-RC-S-002 .1 Fire safety	0.00	0.20	0.22	0.15	0.14	0.35	0.13	0.20	0.21			
C-RC-S-002.2 State of existing damages	0.00	0.30	0.17	0.23	0.21	0.35	0.20	0.30	0.32			
C-RC-H-001.1 Environmental protection.	0.00	0.30	0.17	0.23	0.21	0.35	0.20	0.15	0.16			
C-RC-H-001.2 Noise insulation	0.00	0.30	0.17	0.23	0.21	0.35	0.40	0.30	0.32			
C-RC-H-001.3 Thermal insulation	0.00	0.30	0.17	0.23	0.43	0.35	0.40	0.30	0.32			
GI_i (C-RC)	**0,00**	**2,80**	**2,78**	**2,77**	**2,79**	**2,71**	**2,73**	**2,85**	**2,79**	**2,78**	**2,70**	**2,20**
C-AE-F-001.1 Rainfall	0.00	0.43	0.23	0.60	0.60	0.20	0.47	0.23	0.40			
C-AE-F-001.2 Wind	0.00	0.29	0.23	0.20	0.20	0.20	0.47	0.23	0.20			
C-AE-F-001.3 Temperature	0.00	0.10	0.15	0.13	0.13	0.13	0.11	0.15	0.13			
C-AE-F-002.1 Land profile	0.00	0.29	0.23	0.20	0.20	0.20	0.16	0.23	0.20			
C-AE-F-003.1 Seismic	0.00	0.29	0.46	0.40	0.40	0.40	0.32	0.46	0.40			
C-AE-M-001 Use of space by animals.	0,00	0,29	0,23	0,20	0,20	0,40	0,32	0,23	0,20			
C-AE-O-001.1 Biological agents	0.00	0.29	0.23	0.20	0.20	0.20	0.16	0.23	0.20			
C-AE-O-002.1 Activities of man	0.00	0.29	0.23	0.20	0.20	0.40	0.32	0.23	0.20			
C-AE-O-003.1 Land humidity	0.00	0.29	0.23	0.20	0.20	0.20	0.16	0.46	0.20			
C-AE-O-003.2 Environmental humidity	0.00	0.29	0.46	0.40	0.40	0.40	0.32	0.23	0.40			
C-AE-O-003.3 Solar Radiation	0.00	0.14	0.23	0.20	0.20	0.20	0.16	0.23	0.40			
GI_i (C-AE)	**0,00**	**2,95**	**2,92**	**2,93**	**2,93**	**2,93**	**2,95**	**2,92**	**2,93**	**2,93**	**2,93**	**2,93**
GI (Feasibility)										**Accepted**	**Accepted**	**Not accepted**

Figure 9. Results of NETP and GI (first assessment level) of the chosen case study. Source: Preparation by the authors.

that the type of EB used was viable for the project's solutions.

In the second assessment level, all requirements are met (Figure 10) for the block in terms of quality indicators (C-CA). Regarding the GI_i of the C-RC and C_AE blocks, values close to 3 are determined and, therefore, they also show an excellent constructive viability for the proposed constructive solutions.

Below, in the interest of gaining different responses of the tool, hypothetical constructive variations are assigned. Thus, variants are established, where it is analyzed which *GI* is not suitable, and it is verified which solutions are proposed. The first hypothesis focuses on altering the product's quality, assuming that it does not have certain technical declarations: resistance to wetting cycles (indicator C-CA-AF-003, *NET*=1), resistance to erosion (indicator C-CA-AF-004, *NET*=1) and resistance to freeze-thaw cycles (indicator C-CA-AF-006, *NET*=1). In addition, it is assumed that the external sheet of the CEB wall is uncoated, changing the entry data considering these same criteria. Consequently, the result of the second assessment level in terms of quality, reflects a non-compliance of the three aspects required by UNE 41410, which would guarantee an optimal quality for an elevated degree of exposure; capillary water absorption, resistance to freeze/thaw cycles and water vapor permeability tests. The GI_i (C-RC) are slightly changed on having altered the C-RC-H-001 indicator, that controls the hygroscopic response of the enclosure, now exposed. Meanwhile the GI_i (C-AE) are unaltered on not having changed the conditions (Figure 10). It can also be confirmed that these changes do not imply a non-compliance of the first assessment (Figure 9).

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SUITABILITY REGARDING PRODUCT QUALITY AND REQUIREMENTS				
Product quality indicators	**Requirements - UNE 41410:2008**	**Initial**	**Hypothesis 1**	**Hypothesis 2**
C-CA-AF-001 Density	For noise requirements	Complies	Complies	Complies
C-CA-AF-002 Mechanical Resistance C-CA-AF-009 Adherence to shearing	Structural requirements. Compressive strength	Complies	Complies	Complies
C-CA-AF-003 Resistnace to dry/wet cycles	Declaration/test required with severe exposure	Complies	Complies	Complies
C-CA-AF-004 Resistance to erosion	Declaration/test required with severe exposure	Complies	Complies	Complies
C-CA-AF-005 Capillary water absorption	Declaration/test required with visible walls	Complies	**Does not comply**	Complies
C-CA-AF-006 Resistance to freeze/thaw cycles	Declaration/test required with visible walls	Complies	**Does not comply**	Complies
C-CA-AF-007 Product's thermal properties	Thermal requirements. Thermal conductivity (λ)	Complies	Complies	Complies
C-CA-AF-008 Water vapor permeability	Declaration/test required with outside walls	Complies	**Does not comply**	Complies
C-CA-AQ-001 Chemical characterization: earth and additives	Declaration/test for presence of microorganisms	Complies	Complies	Complies
C-CA-AQ-002 Water	Declaration/test of organic contents, salts and pH	Complies	Complies	Complies
C-CA-AQ-003 Reaction to fire	Declaration of fire reaction rating	Complies	Complies	Complies

SUITABILITY ABOUT CONSTRUCTIVE REQUIREMENTS AND EXTERNAL ACTIONS								
		Degrees of Suitability	**GI_i (C-RC)**	**GI_i (C-AE)**	**GI_i (C-RC)**	**GI_i (C-AE)**	**GI_i (C-RC)**	**GI_i (C-AE)**
Aspects of the Wall	O-01A	Foundation	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
	O-01B	Base	**2,80**	**2,95**	**2,70**	**2,95**	**2,10**	**2,95**
	O-01C-01	Lintel	**2,78**	**2,92**	**2,72**	**2,92**	**1,89**	**2,92**
	O-01C-02	Jambs	**2,77**	**2,93**	**2,69**	**2,93**	**2,38**	**2,93**
	O-01C-03	Sills	**2,79**	**2,93**	**2,71**	**2,93**	**2,43**	**2,93**
	O-01D-01	Indoor	**2,71**	**2,93**	**2,59**	**2,93**	**2,53**	**2,93**
	O-01D-02	Outdoor	**2,73**	**2,95**	**2,67**	**2,95**	**2,47**	**2,95**
	O-01E	Installation	**2,85**	**2,92**	**2,80**	**2,92**	**2,50**	**2,92**
	O-01F	Crown	**2,79**	**2,93**	**2,74**	**2,93**	**2,16**	**2,93**

Figure 10. Results of the second assessment level for the case study. Source: Preparation by the authors.

In the second hypothesis, starting from the initial status, some constructive solutions are altered, which imply an eccentric transmission of loads on the foundation (C-RC-S-001.1, *NET*=2), an unsuitable wall slenderness (>1:10), and the presence of elements that reduce the wall's load-bearing capacity (for example, unsuitable filling mortar of joints) (C-RC-S-001-3, *NET*=2). In addition, the openings would have dimensions that are greater than those recommended for building with earth (Walker, 2001) (C-RC-S-001.5, *NET*=1). As for the first assessment level (Figure 9), a non-compliance will be seen, as the GI_i (C-RC) is lower than the established mean (2.3). Considering the second level, the requirements of UNE 41410 are met, as the product's quality is not altered (Figure 10). Likewise, as the external circumstances do not alter either, the GI_i (C-AE) continue to be favorable. However, the GI_i (C-RC) show low or medium valuations, specifically in the most critical aspects: base, crown and lintels, so it would be necessary to review the proposed constructive solutions, fundamentally in these aspects.

Finally, in summary, Figure 11 reflects the results obtained for the first assessment level of all the case studies used in the design of this tool.

It is concluded that, of the 28 cases analyzed, diverse results are obtained that can reproduce, at a general level, certain common guidelines in a building project. Consequently, despite these cases not being statistically representative, they allow generating a valid feedback tool. The compliance of the first assessment level occurs in most cases, although the causes of pathologies are much more diverse and reflect that the problems reside, be it in the quality of the product supplied or in the adverse conditions of the context (or even in both simultaneously).

CONCLUSIONS

The methodological procedure of the research has allowed validating the operation of the CFS tool to assess the design determinations of EB walls, as the results obtained are coherent with the constructive reality of the case study used. In this way, CFS could be implemented in any architectonic design that uses EB, which would help its use with a better technical support that is capable of ensuring better results and favoring the use of materials with a low environmental impact, such as this product.

It is insisted that the use of indicators, with an objective weighting that fits the constructive reality and that of the material, contributes to technical decision-making being impartial and objective, and not influenced by social prejudices or by a lack of knowledge regarding use of EB.

	Degree of Suitability (GI)			
	C-CA Product quality	C-RC Constructive requirements	C- AE External actions	
GI mean value	1,5	2,3	2,5	Results 1st assessment level
Case studies				
Andalucía				
ALM-001	2,31	2,83	2,80	**Suitable**
ALM-002	2,52	2,40	2,49	**Not Suitable**
GRA-001	1,27	2,56	2,52	**Not Suitable**
MAL-001	1,28	2,11	1,81	**Not Suitable**
SEV-001	2,52	2,83	2,87	**Suitable**
SEV-002	1,16	2,60	2,87	**Not Suitable**
SEV-003	1,17	2,69	2,50	**Not Suitable**
Aragón				
ZAR-001	1,42	2,72	2,92	**Not Suitable**
ZAR-002	2,52	2,72	2,72	**Suitable**
HUE-001	2,52	2,83	2,72	**Suitable**
Baleares				
BAL-001	3,00	3,00	3,00	**Suitable**
Castilla y León				
PAL-001	1,41	2,82	2,52	**Not Suitable**
PAL-002	1,43	2,73	2,93	**Not Suitable**
PAL-003	1,43	3,00	2,84	**Not Suitable**
SEG-001	2,70	2,81	2,66	**Suitable**
Catalonia				
BAR-002	3,00	2,80	2,70	**Suitable**
GER-001	3,00	2,93	2,71	**Suitable**
GER-002	3,00	2,75	2,70	**Suitable**
Madrid				
MAD-001	2,44	2,78	2,63	**Suitable**
MAD-002	2,45	2,70	2,55	**Suitable**
MAD-003	2,45	2,68	2,34	**Not Suitable**
MAD-004	2,45	2,68	2,34	**Not Suitable**
MAD-005	2,45	2,62	2,31	**Not Suitable**
MAD-006	2,45	2,91	3,00	**Suitable**
MAD-007	2,45	2,68	2,79	**Suitable**
MAD-008	2,44	2,81	2,39	**Not Suitable**
MAD-009	2,52	2,70	3,00	**Suitable**
C. Valenciana				
ALI-001	3,00	3,00	3,00	**Suitable**

Figure 11. Results of the first CFS assessment level for all case studies. Source: Preparation by the authors.

The possibility offered to establish an accessible tool for this decision-making, allows that products with a more environmentally sustainable and friendly consideration are brought to the market, which also provide a variety to normal solutions for the construction of non-load bearing enclosure walls. This strategy could be implemented in the rest of the constructive solutions and for the rest of the products that are being generated with environmentally friendly criteria, that can imply elements not trusted by building technicians.

In particular, from the CFS results in the 28 case studies, the following can be highlighted:

- EB quality, considering the categories established for the indicators, closely conditions the constructive feasibility of an architectonic solution. The results show that, when the EB does not have certified/declared durability requirements (in terms of resistance to dry/wet cycles, erosion, freeze/thaw cycles or capillary water absorption), and is exposed to unfavorable conditions, the *GI* indicate that the design must be revised for the suitable constructive layout.
- The values established for the weights and combinations are valid for a broad geographical context, on having been designed by international experts, although they could be adapted for other situations that were not considered.
- On analyzing the three categories of indicators set out, it can be highlighted that the constructive requirements provide the highest proportion of decisive indicators for the design of the wall's stable structure.
- Starting from the indicators used, it is confirmed that, as in any factory design, the start at the base or at its join with the foundation, the finishing of the outside wall and the design of openings are the singular points where the most decision

weights are accumulated and, therefore, are aspects to look out for to obtain the best degree of suitability.

In brief, it is concluded that this CFS can be used as a basic resource to make decisions in projects of new works or building retrofits where one wishes to use EB. To develop a set of criteria with greater applicability, economic, environmental or social indicators must be considered, which could be included in a methodological procedure that complements the one presented here.

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BIBLIOGRAPHICAL REFERENCES

AENOR (2009). UNE-ISO/TS 21929-1. Sostenibilidad en construcción de edificios. Indicadores de sostenibilidad. Parte 1: Marco para el desarrollo de indicadores para edificios.

ASTM D559 (1989). *Standard Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures*. ASTM International.

Canivell, J., Rodríguez-García, R., González-Serrano, A. M. y Romero Girón, A. (2020). Assessment of heritage rammed-earth buildings. The Alcázar of King Don Pedro I (Spain). *Journal of Architectural Engineering*, *6*(2). DOI: https://doi.org/10.1061/(ASCE)AE.1943-5568.0000400

Cid-Falceto, J., Mazarrón, F. R. y Cañas, I. (2011). Las normativas de construcción con tierra en el mundo, *63*(523), 159–169. *Informes de la construcción*. DOI: https://doi.org/10.3989/ic.10.011

Deboucha, S. y Hashim, R. (2011). A review on bricks and stabilized compressed earth blocks. *Scientific Research and Essays*, *6*(3), 499–506.

Fernandes, J., Peixoto, M., Mateus, R. y Gervásio, H. (2019). Life cycle analysis of environmental impacts of earthen materials in the Portuguese context: Rammed earth and compressed earth blocks. *Journal of Cleaner Production*, *241*. DOI: https://doi.org/10.1016/j.jclepro.2019.118286

Gandia, R. M., Gomes, F. C., Corrêa, A. A. R., Rodrigues, M. C. y Mendes, R. F. (2019). Physical, mechanical and thermal behavior of adobe stabilized with glass fiber reinforced polymer waste. *Construction and Building Materials*, *222*, 168–182. DOI: https://doi.org/10.1016/j.conbuildmat.2019.06.107

Guettala, A., Abibsi, A. y Houari, H. (2006). Durability study of stabilized earth concrete under both laboratory and climatic conditions exposure. *Construction and Building Materials*, *20*(3), 119–127. DOI: https://doi.org/10.1016/j.conbuildmat.2005.02.001

Jové Sandoval, F., Muñoz de la Calle, D. y Pahíno Rodríguez, L. (2011). Ensayos de erosión hídrica sobre muros de tierra (fábrica de BTC). Método, resultados y discusión. En *Construcción con tierra. Tecnología y Arquitectura. Congresos de Arquitectura de Tierra.* (pp. 193–204). Valladolid: Cátedra Juan de Villanueva. Universidad de Valladolid.

Lavie Arsène, M.-I., Frédéric, C. y Nathalie, F. (2020). Improvement of lifetime of compressed earth blocks by adding limestone, sandstone and porphyry aggregates. *Journal of Building Engineering*, *29*. DOI: https://doi.org/10.1016/j.jobe.2019.101155

López-Zambrano, M. J., Canivell, J. y Calama-González, C. (2019). Sistema de evaluación de soluciones de rehabilitación energética para edificios bien de interés cultural (SESREBIC). Su aplicación a monasterios BIC. *Informes de la Construcción*, *71*(555), e300. DOI: https://doi.org/10.3989/ic.63532

Mahmood, O. I., Habeeb, A. A. y Al-Jumaili, H. T. (2019). Characteristic properties of CEB made of gypsum soil. *International Journal of Advanced Science and Technology*, *28*(12), 36–45.

Maldonado Ramos, L., Castilla Pascual, F., Vela Cossío, F. y Rivera Gómez, D. (2001). Rendimiento y coste energético en la construcción de cerramientos de fábrica de adobe y bloque de tierra comprimida. *Informes de la Construcción*, *53*(473). DOI: https://doi.org/10.3989/ic.2001.v53.i473.669

Miloudi, Y., Fezzioui, N., Labbaci, B., Benidir, A., Roulet, C. A. y Oumeziane, Y. A. (2019). Hygrothermal characterization of compressed and cement stabilized earth blocks. *International Review of Civil Engineering*, *10*(4), 177–187. DOI: https://doi.org/10.15866/irece.v10i4.15975

Ministerio de Fomento (1999). *Ley de Ordenación de la Edificación (Ley 38/1999)*. Madrid: Oficial del Estado. España. Recuperado de https://www.boe.es/eli/es/l/1999/11/05/38/con

Molar-Orozco, M., Velázquez-Lozano, J. y Vázquez-Jimánez, M. (2020). Comportamiento térmico de tres prototipos en Saltillo, Coahuila (bloques de tierra, concreto y tapa de huevo). *Hábitat Sustentable*, *10*(1), 22 - 31. DOI: https://doi.org/10.22320/07190700.2020.10.01.02

Mosquera, P., Canas, I., Cid-Falceto, J. y Marcos, F. (2014). Determination of the thermal conductivity in adobe with several models. *Journal of Heat Transfer*, *136*(3). DOI: https://doi.org/10.1115/1.4025560

Soronis, G. (1992). The problem of durability in building design. *Construction and Building Materials*, *6*(4), 205–211. DOI: https://doi.org/10.1016/0950-0618(92)90039-2

UNE 41410 (2008). *Bloques de tierra comprimida para muros y tabiques. Definiciones, especificaciones y métodos de ensayo*. Madrid: Ministerio de Industria, Turismo y Comercio.

Walker, P. (2001). *The Australian Earth building handbook*. Sydney, Australia: Standards Australia International.

Wati, E., Bidoung, J. C., Damfeu, J. C. y Meukam, P. (2020). Energy performance of earthen building walls in the equatorial and tropical climates: a case study of Cameroon. *Energy Efficiency*, *13*, 735–750. DOI: https://doi.org/10.1007/s12053-020-09856-6