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Approach to the quantification of the sustainable value in industrial buildings

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Abstract

In recent years, there have been advances in favour of buildings being more environmental friendly. Basically, sustainable construction has centred on residential and office buildings. It could be said that there is a lack of sustainable aspects in the construction field of industrial buildings.

This article aims to analyse the sustainable environmental requisites demandable for an industrial building, by defining a system of specific indicators to assess building behaviour against these requisites generating an assessment model as a base for measuring the building "environmental sustainability index".

Keywords: Industrial Building; Methodology; Sustainable; Index

1. Introduction

The technological progress occurred in the short period of time since the industrial revolution to the present day, has been accompanied by a series of appreciable changes in the planet. Not only are today's generations the heirs to this technological progress and advance but also the environmental alterations derived thereof, some of which are irreversible. Environment protection and social and economic development are essential to achieve sustainable development [1].

Centering on this need for change and work pending execution in the construction sector, the sustainable development era must demand radical changes. The globalization of the construction industry [2] has promoted the incorporation of a relative new universal vision of this sector: the sustainability, already used in the 1970s referred to "sustainable economic growth". Construction action is one of the causes with great impact on the environment, according to the conclusions of the *Vital Signs 2005* report drafted by the Worldwatch Institute of Washington [3], which points out the construction sector consumes up to 60% of the materials extracted from the earth. Furthermore, their use in construction generates half the CO_2 emissions dispersed in the atmosphere. Therefore, the architecture and engineering professions must include environmental protection in their daily tasks to fully comply with their work [4]. Today, it is no longer possible to carry out (design and construction) building projects without assessing their impact on the environment. These disciplines must use tools, which provide them with knowledge on the affections associated with their work [5,6], and assist them in taking decisions resulting in more environmental friendly projects.

In recent years, numerous countries, have with greater or lesser success launched initiatives to achieve more environmental friendly buildings throughout their life cycle: from extracting materials to their demolition [7]. Thus we have terms like: *sustainable construction, building energetic efficiency, bioclimatism, passive architecture*, etc. aiming to provide new trends to achieve the target of reducing the

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Fig. 1. General concept of sustainability in the construction sector.

construction activity impact. The incorporation of these design criteria in construction has acquired special relevance with the incorporation of the so-called sustainable development concepts within politically correct and desirable practices for society as a whole [8]. Thus, the advance in the research and development of new knowledge systems concerning sustainable construction has been constant (Fig. 1).

It must be mentioned the advances made in the residential construction field have not continued in the industrial building design process, whose specific characteristics make them different. It can be claimed definition of sustainable aspects is lacking in the industrial plant construction field. The industrial building sustainable conception should be tackled in the same way as residential or office buildings. The relation extant today between industry and sustainability represents a rich interesting research field, give the complexity and amount of study areas, not to mention the importance of identifying factors making industrial building architectural requisites compatible and compliance thereof sustainable.

2. Determining factors of industrial buildings when comparing with other typologies

The industrial construction sector is part of the non-residential Building sub-sector. It comprises[1] "the development of industrial building construction activities, including new designs, enlargements, modifications, maintenance and reforms" [9]. The construction of installations for developing production activities, whose production processes do not need a building for their execution, such as incineration plants, cement plants, blast furnaces and other similar structures; are also included in this sector. Generally speaking, the participating agents are: construction contractors, construction companies, industrial building design companies and projection direction firms.

As a definition of factory or industrial building we could adopt Prof. Losada's[2] "a space where industrial production and storage tasks are performed. The term factory as alternative for industrial buildings includes generic aspects of industrial production. Nevertheless, both terms have in common the existence of constructions, i.e., man-designed spaces materialized via the use of natural or artificial products, elements and construction systems within a controlled environment".

Traditionally, the industrial building was considered an isolated container inside which certain production activity occurs. Sustainable industrial building aspects considered today refer mainly to the production process performed inside. Attention is focussed on aspects like contamination caused by the production process or activity throughout the building life cycle (air, noise, water, etc.) and process waste deposition or recycling dedicating very few resources to research on the building itself. A more sustainable vision considers the same as an architectural element permanently interacting with sustainability requisites.

The building design through a systemic approach entails making an integrated study of the industrial plant that it is defined as main system. Likewise, this system consists of several subsystems or subdivisions interrelated to each other. The optimal integration of all subsystems must, therefore, be explored with the aim of obtaining the most suitable solution. The main subsystems of the industrial plant are as follows: the industrial process, the auxiliary services necessary for the correct performance of the process, the building or structural frame, the production control system and the lay-out or activity distribution.

The architecture implies the spatial arrangement in such a way that a separation between the external arrangements of the industrial area, which is characteristic of the urbanism [10,11], and the inner arrangement of the building or place defined by the layout could be established. An enveloping system, borne by a structural frame, defines the latter separation. The enveloping system, together with the structural frame, forms the building.

The industrial building typology should be adapted to the productive process and to the necessary auxiliary services. Each process has special features and there exists infinity of processes. In other words, groups of industries should be established in such a way that perform similar characteristics in respect to materials, building shapes, spans among columns, more habitual illumination types and ventilation or storage zones particularities. Among the

[1] Definition as per the US Census Bureau. The North American Industry Classification System (NAICS).

[2] Losada Rodríguez, Ramón. Escuela Superior de Ingenieros de Bilbao. First version of the book "sustainability via value analysis applied to industrial building".

distinguishing features of the industrial building, the following ones could be mentioned:

- There are different possibilities in shapes and typologies of the industrial building since the final solution depends on the lay-out and the distribution of the different activities to be performed, as well as on the great variety of processes that could take place in its inner space. In residential buildings, however, the activities in the inner space are always focused on giving their inhabitants for accommodation to fixed room conditions.
- In the industrial building, the loads associated with the productive process or with the flow of materials are usually quite more relevant (higher loads) than those in residential structures. Therefore, the structural system will be influenced by the loads to be borne.
- Today's industries are characterised by rapid technological changes, which implies that the industrial building should allow flexibility for either future adaptation to new distributions or expansion needs of the industrial plant. The flexibility of the facilities, therefore, is also an important feature to be taken into account when designing these typologies.
- The accessibility in industry, as well as considering people accessibility, must take on account the dimensions and the physical characteristics of the raw materials and the manufactured products in order to perform the raw materials movement.
- Unlike in residential uses where the energy consumption depends on the type of housing, in industry it depends on the available machinery. In this context, there is a great range of possibilities to save energy consumption; for example, the energy generated in some stages of the production process can be used for other phases. On the other hand, the atmospheric conditions of the inner space are also different when dealing with residential or industrial typologies.
- From a social point of view, the industrial plant generates wealth, creates employment, fosters commercial activities and develops the surrounding area.
- In some cases, as consequence of the trademark image of some companies, the industrial buildings have a high aesthetic value that contributes to increase the architectonic heritage of the surrounding area.

3. Systematic approach of the sustainability concept in an industrial building

This more innovative vision considers industrial building design should be tackled bearing in mind certain macro criteria or "sustainable requisites" [12]. Sustainable global aspects to be met by the building [13], defining as such the targets and needs which should be present in any building, are to be considered, i.e. conception, materialization, use and reintegration, require a sustainable vision at all their possible levels: environment, economic, social, safety and

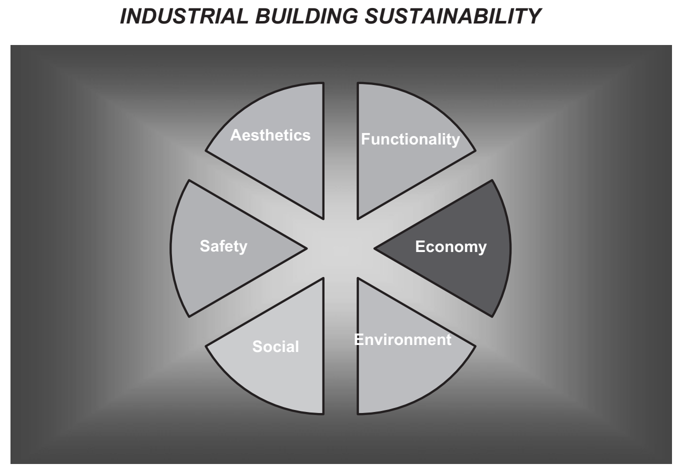

Fig. 2. Systematic approach of the sustainability concept in an industrial building.

industrial risk prevention, functional and even aesthetical (Fig. 2).

Environment: The different locations and integration alternatives of an industrial plant in the environment should be considered. Furthermore, the different possibilities of using "ecological" materials, whose manufacture generates a lower environmental impact, reducing energy consumption, should be considered; likewise the use of recycled materials or which can be recycled. The construction process originates affections in the environment, as emissions in to atmosphere, spills into the water, occupation and contamination of soils, use of natural resources and waste generation. Throughout the useful life of a building, during its use stage, it will also have impacts on the environment, via water and electricity consumptions, not to mention generation of process waste. Furthermore, at the end of its useful life, one must study the possibilities of its reuse or benefiting from the materials comprising the same, likewise promoting selective demolition activities and waste management as per the recycling possibilities thereof.

Economy: A condition to be borne in mind is the building economical requisite, not only during its construction stage but also the maintenance and preservation actions during its useful life. From the sustainability viewpoint, co-ordination of resources to be consumed by a building throughout its useful life acquires great importance. This aspect refers mainly to energy consumptions, chiefly: electricity for lighting, ventilation and air conditioning of the same, likewise the process water consumption. A further opportune energy consumption to be considered is that corresponding to machinery transport of materials inside the building. This requisite could be assessed using analysis techniques of life cycle costs "life cycle costing (LCC)" [14].

Social: Building social component as an economic support or activity, makes it an employment generator; likewise human relations among workers, quality of the inner environment or mobility facilities inside.

Safety and industrial risk prevention: Safety understood as the physical integrity of people, particularly in construction and deconstruction process; likewise maintenance works, which must be particularly relevant to minimize industrial accidents.

Functionality: Building functionality with a view to correct execution of the activity for which it was designed. The capacity of building adaptation to the process should be studied to prevent using new enlargements in the event of company growth, reducing the employment of new materials, economic costs and waste generated.

Aesthetics: Building aesthetics is another value to be born in mind with a view to maintain the architectural asset; likewise preservation of the city, industrial area or company image. The aesthetic degree should be considered implicit in the industrial construction, and not sacrificed given its productive nature. Often, the owner company promotes constructing the building with the corporate image, i.e. identifying and granting it greater prestige, thereby identifying the aesthetical requisite as a sustainable aspect to be considered.

Each of the requisites demanded of a sustainable industrial building are related to the rest to a greater or lesser extent. The proposal, therefore, is for new sustainable study scopes to arise combining the different assessment requisites among themselves, besides analysing each of the sustainability requisites.

These sustainable requisites will be applicable in the different stages of the building life cycle, from conception thereof, passing through its useful life, to the demolition stage and management of the waste generated (Fig. 3).

4. Methodology for valuing a sustainable industrial building

4.1. A model defining environmental indicators based on performance

Sustainable assessment of an industrial bay should not be understood solely as a quantification of the environmental impacts originated by the materials used in its construction. Although this building study area is the most significant, other aspects with enormous influence should not be omitted. Thus, selection of the building location and its environmental repercussion is evident; therefore, environmental assessment will play notable role. Likewise, there are analysis areas to be considered, i.e. introduction of energy and water consumption saving measures in the building, dust, noise, soil and water contamination reduction techniques, etc., used in the construction process, waste management and minimization measures adopted during construction, use and demolition, including the adoption of construction element design measures to achieve a greater degree of material reuse and recycling during the reintegration phase. These analysis and study areas are complementary to the impacts caused by the construction materials used in the building.

Industrial plant environmental behaviour may be assessed as per the aforementioned different study scopes. An assessment model comprising a hierarchical structure of levels and sub-levels is proposed (Fig. 4). To define this model, it is necessary to define different analysis frameworks or more detailed or developed ‘‘criteria’’. To do this, the need for structuring is proposed via the so-called ‘‘requirement tree’’ [15], designed to act as identification and arrangement base of the system criteria.

Fig. 3. Whole life vision in the construction sector.

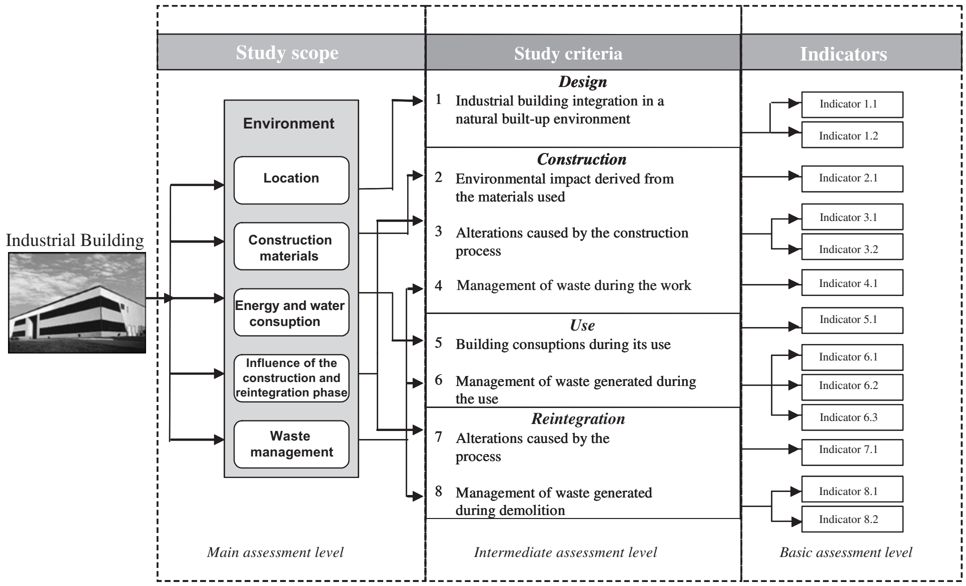

Fig. 4. Assessment model for an industrial building.

The different study scopes will be developed via continuous branching of the said tree, as per desired degree of development.

Analysis frameworks, or sustainable criteria, constitute different possible building environmental information organizations, whose ultimate use depends on the end use of the same. Likewise, a criterion itself divides into a series of assessment ''indicators'' constituting the last hierarchy level established for the requirement tree. Those criteria covering a very wide study scope, and as an intermediate step between criteria and indicators, it would be good idea to define a set of ''sub-criteria''. This organization will depend on the use the indicators are to render the final objective of the problem posed.

Criteria selection as key parameters, and sub-criteria as help elements in the specification of the indicators, will form the situation status for each study scope, enabling formulation of dimensional objectives and assessing advances registered in the sustainable plant conception. Selection of appropriate criteria is a complex task given its importance regarding results to be obtained.

Once the set of criteria have been defined for the different study scopes, a set of indicators is established appropriate for assessing the degree of environmental sustainability.

The Organization for Economic Cooperation and Development [16], defines an indicator as ''a parameter or resulting value of a set of parameters providing information on a phenomenon, and with a wider meaning than that strictly associated with parameter configuration''. Indicators may be considered variables whose purpose is to facilitate the election of alternatives, and may contribute to providing quantitative and qualitative information on aspects considered relevant in a specific stage of an industrial building life cycle. They enable identification of perspectives and problems, likewise analysing and interpreting favourable or unfavourable situations from an environmental viewpoint and associated synergies. The diversity and flexibility implicit in the indicator formulation process and transcendence of the information collected and filed, has great relevance when selecting a sustainability strategy.

However, this transcendence comes up against an important difficulty, typical of the construction sector covering it, since the starting parameters for each building are considered different each time, whereby obtaining reference levels for indicators is virtually an insurmountable obstacle.

4.2. Multicriteria assessment of alternatives

A decision-making problem is posed using multiple criteria or multicriteria (MCDM) when a decision is obliged to choose among a set of continuous or discreet alternatives, bearing in mind different criteria or points of view [17]. In an industrial building environmental assessment, all the possible alternatives can be numbered and they are not many, i.e. the problem decision is discreet [18]. Furthermore, as the problem is posed with certainty, i.e. the decider's preferences regarding the indicators posed are known,[3] the MCDM becomes part of the so-called multi-attribute utility theory (MAUT), sometimes included in the MCDM structure, and occasionally, particularly when risk and uncertainty play a relevant role it is considered a separate discipline. The classic

[3]A classical problem analysis and resolution model of multiple criteria decision making (MCDM) which assumes a function can be built, called utility should uncertainty exist, or value in the case of certainty, which reflects the decider's preferences, from which the multi-target mathematical problem programming is set out.

MAUT focus when information on the decider's preferences is available, i.e., when his/her preferences are expressed regarding all the alternatives $x \in X$, then one may assume the existence of a value function: $V : Z \rightarrow \Re$ whereby $z > z' \Leftrightarrow V(z) > V(z')$. Should X be a discreet set and the context certain, the problem consists of building the value function, which reflects the decider's preferences and includes all the criteria. The existence and decomposability conditions of this value function were studied by Keeney and Raifa [19], Rios et al. [20].

The degree of objective compliance by the alternatives or decisions possible $x \in X$ is characterized by a series of attributes $z = (z_1, \ldots, z_n)$. One cannot compare the magnitudes of the different z_i attributes, because in most cases each criterion reflects totally different units. This approach is similar to the problem posed, since quantitative and qualitative criteria will exist.

Thus, the value function is defined as a function:

$$V : Z \rightarrow \Re \quad Z = Z_1 \times Z_2 \times, \ldots, Z_N,$$

where by:

$$z > z' \Leftrightarrow V(z) > V(z') \text{ with } z(x) = (Z_1(x) \times Z_2(x) \times, \ldots, Z_N(x)) \in Z \subset \Re^n.$$

An important characteristic of the function thus defined, is decomposability since it enables obtainment of a global value via the sum of partial values associated with the different attributes, each measured in different units and scales.

$$V(z_1, \ldots z_N) = F[f_1(z_1), \ldots, f_N(z_N)].$$

Thus, the value function may be built as the sum of value functions corresponding to each attribute, giving rise to the additive value function (1).

$$V(z_1, \ldots, z_N) = v_1(z_1) + v_2(z_2) + \cdots + v_N(z_N) = \sum_{i=1}^{N} v_i(z_i). \quad (1)$$

It is usually convenient to reduce V and each individual value function of each attribute to values between 0 and 1. This allows a value function to be obtained with the form:

$$V(z) = \sum_{i=1}^{N} \lambda_i v_i(z_i), \quad (2)$$

where λ_i are factors representing the preference of some indicators against others, i.e. which we have defined in our problem as *sustainability weights*, and $v_i(z_i)$ represents the value associated with each indicator, via application of an individual value function. v, v_i, $i = 1,2, \ldots, N$ have values between 0 and 1 and $\lambda_1 + \lambda_2 + \cdots + \lambda_N = 1, \quad \lambda_i > 0$.

4.3. Assignation of sustainability weights λ_i

In recent years, various works have been carried out regarding preference assignation of some criteria in relation to others, based on attributes where complete information is lacking [21–28]. The method used to obtain sustainability weights λ_i, is based on the decision method "analytic hierarchy process (AHP)" [29].

The method enables the relative priority of each alternative according to scale to be quantified, emphasizing the importance of the decider's intuitive criteria and the consistency of comparisons between alternatives based on his/her judgement. The methodology not only shares the principle that the decider always bases his/her judgements on knowledge and experience, but also, organizes both tangible and intangible factors systematically providing a simple structured solution to the decider's problems. This methodology as already mentioned constitutes a numerical assessment of alternatives based on systematic assessment of a set of decision alternatives.

Therefore, associated to each of the requirement tree hierarchical levels, there will be a valuation process associated to an added value function $V(z)$, comprising the sum of the sustainability products λ_i or weights and individual value functions $v_i(z_i)$ associated to each indicator. Said valuation process will be at the lower level (indicators), and enable assignation of a sustainability value to each hierarchical level on a specific scale of values (0–1) (Fig. 5).

5. Adaptability of existing tools to the industrial building

At present, several bodies and organizations worldwide are promoting development lines for the construction sector within the sustainable development framework. Several countries within the European Union and others like the USA, have designed different plans of action in the sustainable construction field, via the preparation of tools, guides and support documents for building assessment from different viewpoints. Majority of the existing tools are focused on residential buildings and analysing economic and environmental factors. As it has already pointed out, there are remarkable differences between the industrial building typologies and others such as the residential ones. Building assessment methodologies developed to date [30] may be grouped as per the following classification [31]:

(1) Based on impact criteria-indicator weighting on complete life cycle analysis, such as: GBC-GBTool, PromisE (FIN), BREEAM (ENG), ESCALE (FRA), Eco/Quantum (NLD), and EcoEffect (SWE), VERDE (ESP).
(2) Based on action assessment (Check-List) like LEED (USA).
(3) Based on impact assessment using "eco-points" (number of eco-points obtained acting as a comparison element and improved environmental design) like ENVEST (BRE-UK) or using the eco-efficiency concept like CASBEE (JPN).

All above tools have their own calculus methodologies, which are easy to manage in some cases and in other ones, are based on complex algorithms.

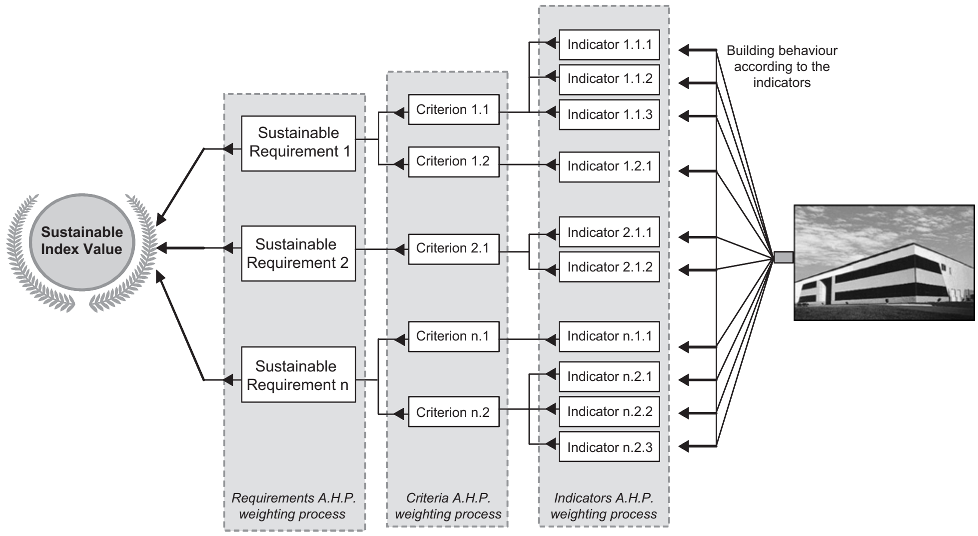

Fig. 5. Methodology for the numerical quantification.

6. Conclusions

This article centres on the environmental requisites as the study framework for the identification, analysis and assessment of sustainable aspects within the industrial building conception.

The industrial building sustainable conception implies attending certain macrocriteria or sustainability requisites in its different stages of design, construction, use and demolition. An advanced vision of the sustainable construction concept centred on the industrial bay includes: safety and industrial health, functionality and aesthetic requisites applied to those usually considered generically in any construction type, such as environment, economy and society.

The environment requisite weight against the rest is appreciable, and assessment of environmental repercussions the industrial building might have, is already considered necessary, not only in the material manufacturing phase and construction thereof, but also, a priori, i.e. throughout its entire life cycle. A detailed study of the building environmental particularities requires a breakdown of the requisite within a set of study scopes, like building location, materials used, construction and deconstruction processes, energy and water savings, and waste management actions. Likewise, each one contemplates a criterion, sub-criterion and indicator structure comprising the building life cycle sustainable assessment model.

This assessment model may be contemplated as another component of the assessment methodology of the "sustainable environmental index" of buildings [32,33], which on the one hand would include a developed assessment model, and on the other a convenient mathematical methodology to assign an industrial building an environmental conformity value regarding the model presented here. Thus, this work settles the bases for developing a mathematical methodology which adopting the reference values established for each of the proposed indicators, homogenizes the sustainable values at all hierarchical levels, unifying them in a single index or global sustainability value for the industrial building.

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