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A MODEL FOR THE EVALUATION OF BUILDING SUSTAINABILITY IN AGRI-FOOD INDUSTRY

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ABSTRACT This study aims at defining a method for sustainability building evaluation in the specific context of agri-food industry. As a matter of fact, from an environmental point of view, this is one of the most critical industrial sectors and, consequently, sustainability evaluation is needed for the whole production chain, including all the aspects related to the design, use, remodelling, dismantling or reuse of the building facilities. A global building sustainable index was defined so as to appropriately and synthetically consider both the interaction of the many concurring factors and the specific aspects related to the agri-food production cycles.

Keywords: Membership function, Fuzzy rule, Building sustainability index, Agri-food industry.

INTRODUCTION The constant increase in energy consumption, the growing level of pollution emissions and the uncontrolled use of environmental resources threaten the future of the Earth. Over the last decade, the most industrialized countries have realized that the serious environmental situation demands a sustainable development of global economy. Each of them is implementing specific political actions to curb both energy consumption and pollution emissions and to use environmental resources more cautiously. The world community considers the building industry as a sector demanding a priority intervention. Studies, conducted by the United Nations Environment Programme (U.N.E.P.) have shown that building structures account for 30-40% of energy consumption, of which about 90% occurs during their use, while the remaining part is consumed during the life cycle of the building materials (UNEP, 2007). Energy consumption is even higher in the case of agri-food industry, where the microclimate control assumes a particular significance for both the workers' safety and the production and preservation processes of agri-food products. On the one hand, the curb on the environmental impact and on greenhouse emissions has become a priority objective in the environmental policies the agri-food industry must adopt; on the other hand, the quality and safety of food products is an issue of international interest. In its latest *Implementation Action Plan* (European Technology Platform, 2008), the European

Technology Platform (ETP) "Food for Life", created under the auspices of the EU's Confederation of the Food and Drink Industries (CIIA), states that the achievement of a sustainable food chain is a bet for the sector of productions and that the development of tools for the definition and demonstration of the borderline of sustainability must concern all the phases of the production chain and constitute one of the major future challenges of research. Within this overall objective, it is important to develop and give also the world of agri-food building specific sustainability building evaluation models.

Sustainability building evaluation is an issue widely discussed on an international level; several methods and procedures have been proposed and developed in order to parameterize, by means of synthetic indexes, the building sustainability value. The main methods are fully applied to the residential and tertiary building sectors and cannot be properly adapted to different and more specific contexts of application, such as the agri-food industry. The buildings of this productive sector have to ensure performances different from those of the residential or tertiary building sectors.

A building for the agri-food industry has to provide an environment which can favour the preservation and processing of agri-food products and respect workers' health and consumers' sanitary safety. Other important factors concurring to the agri-food building sustainability concern the environmental characteristics of the site where the building structure is located; the technologies and equipment used in the productive process; the productive flexibility; the adaptability and the possibility of an easy conversion of the building to different productive typologies and the adjustment to changes in the sector regulatory standards. Furthermore, the intrinsic socio-cultural, architectural and aesthetic aspects of the building are also significant and play an important role for the corporate image and communication and marketing strategies. It is evident that the problem of sustainability agri-food building evaluation is particularly complex, since elements, which are not always measurable and quantifiable but can often be only qualitatively evaluated, must be taken into account. Such considerations give rise to a need to develop specific sustainability evaluation models which allow to use qualitative judgements and vague and imprecise evaluations. To that end, this paper proposes an evaluation method that, on the basis of an internationally recognised procedure of building sustainability analysis and through the fuzzy logic, allows to consider the inevitable inaccuracy and vagueness of the evaluation of the factors which determine the building sustainability in the agri-food industry.

MATERIALS AND METHODS Among the international sustainability building evaluation procedures and methods, the SBMethod, developed and managed by the non-profit organization iiSBE, is one of the most commonly used. It was developed within the international project Sustainable Building Challenge which involved over 20 countries from all the continents. The objective of the project was to develop and propose a sustainability evaluation method able to combine a world common evaluation standard with the possibility of its complete contextualization in the single national contexts of application, as well as to analyse generic buildings in all the phases of their life cycle. The model is based on a rating system which allows to evaluate and certify the energy performance of buildings according to a number of specific criteria. In Italy, the SBMethod (Larsson, 2007) has been adapted with the development of a tool of analysis and certification called Protocollo Itaca. Though a model, able to analyse the performances of generic buildings, has been developed within the Protocollo Itaca, the lack of certain performance requirements, typical of the agri-food building, does not allow to satisfactorily apply it to this building type. In fact, agri-food buildings have to meet the specific needs of the activities and of the productive cycle carried out inside them. By taking into account the performances the building has to ensure and, however, referring to the structure of the SBMethod and of the Protocollo Itaca, this paper proposes a model, for the evaluation of the Building Sustainable Index (BSI), which can be applied to agri-food buildings. In particular, such a model has a hierarchical structure (fig.1) and includes the evaluation of six "sustainable requisites" (San-José et al., 2005): Environment, Economy, Functionality, Socio-cultural aspects, Safety and Hygiene, Aesthetics. Moreover, a series of categories, indicating how agri-food buildings influence the sustainability of the whole productive cycle, are defined for each sustainable requisite (tab. 1).

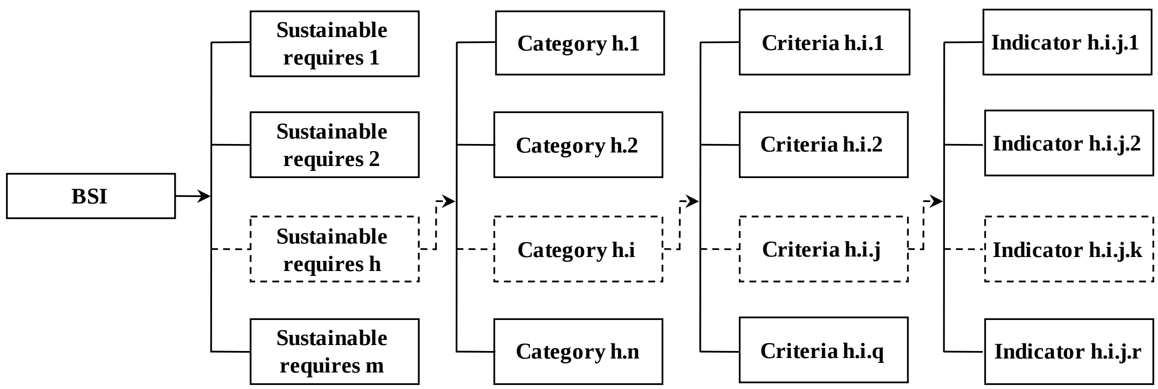

Figure 1. Hierarchical structure of the proposed evaluation model.

Table 1. List of the sustainable requisites and analysed categories.

Sustainable requisites	Categories
1. Environment	1.1 Quality of the site; 1.2 Consumption of environmental resources; 1.3 Environmental loads
2. Economy	2.1 Energy consumption; 2.2 Production costs; 2.3 Cost of materials handling inside the building; 2.4 Development of local economy
3. Functionality	3.1 Correct dimensioning; 3.2 Environment favourable to the productive cycle; 3.3 Internal environmental quality for operators; 3.4 Flexibility in the use and adjustment of the production line; 3.5 Convertibility; 3.6 Conformity to production rules and general conditions
4. Socio-cultural aspects	4.1 Development of socialisation; 4.2 Development of the economy of the area; 4.3 Cultural aspects
5. Safety and hygiene	5.1 Safety for workers; 5.2 Sanitary safety of products
6. Aesthetics	6.1 Visual impact; 6.2 Landscaping; 6.3 Enhancement of product image

The model allows to calculate the sustainability degree of each requisite starting from the sustainability value of the related categories. For instance, the environmental aspect is evaluated on the basis of specific elements that allow to analyse the impact of the productive facility on the external environment in terms of pollution, consumption of resources and environmental quality of the site. Economic sustainability is evaluated by referring to the costs incurred by the company for the production and preservation of the food products and considering the advantages it gives the development of the local economy. The functionality of the building is evaluated by taking into account the correct dimensioning of the company environment and the maintenance of internal environmental conditions favourable to both productive cycle and operators, as well as to the respect of production rules and general conditions. The convertibility of the facility to other productive activities is also considered. From a socio-cultural point of view, the sustainability building evaluation takes into account the adequacy of the indoor environment to favour socialization activities, the potential cultural value and the economic development of the area concerned. The safety evaluation also becomes crucial for the overall sustainability, since the operational conditions, the safety for workers and the sanitary safety of products are priority objectives for the whole community. Finally, the Aesthetic requisite is evaluated considering the analysis of the visual impact of the building, of the impact on the landscape where it is located and of the image of the company and of the product as perceived by consumers. In their turn, categories are evaluated by taking into account sets of criteria, each set representing a specific category. The lowest hierarchical level of the model is represented by these criteria. They are calculated on the basis of the measurement of certain indicators typical of the examined building. Therefore, indicators measure the building performances, e.g. the value of the indoor thermal comfort and air quality, or the energy consumption for lighting, or the value of the bacterial load in the air, etc. In the case of agri-food buildings, it is necessary to evaluate certain performances which are difficult to quantify and yet can be evaluated by means of qualitative judgements. The use of the fuzzy logic allows to cope with the qualitative judgements and the degree of inaccuracy, which is inevitable in the measurement of the value of an indicator. To this end, in the proposed BSI evaluation model (fig. 2) the theory of fuzzy logic (Zadeh, 1976) was applied. According to this theory, the sets have fuzzy limits and it is possible to assign a grade of membership $\mu(x)$ to the set to each input value x, unlike the classic Boolean logic where limits of membership are rigid and each element x of the universe can be assigned only the “true” or “false” value, depending on whether it is or not a member of the set. In particular, in the proposed model, the calculation of the value of the criteria is divided into three successive phases: the phase of the Fuzzification of the measured crisp numerical value or of the assigned judgement; the inference of the criterion and the calculation of the relative weight. The first phase allows to transform the values of the indicators into membership functions and to make the different judgement scales homogeneous. The second phase allows to determine the membership function of the generic criterion through the definition of logic rules and the aggregation of the respective outputs. Finally, the third phase allows to calculate the value of the relative weight of each criterion in relation to the overall sustainability value of the building.

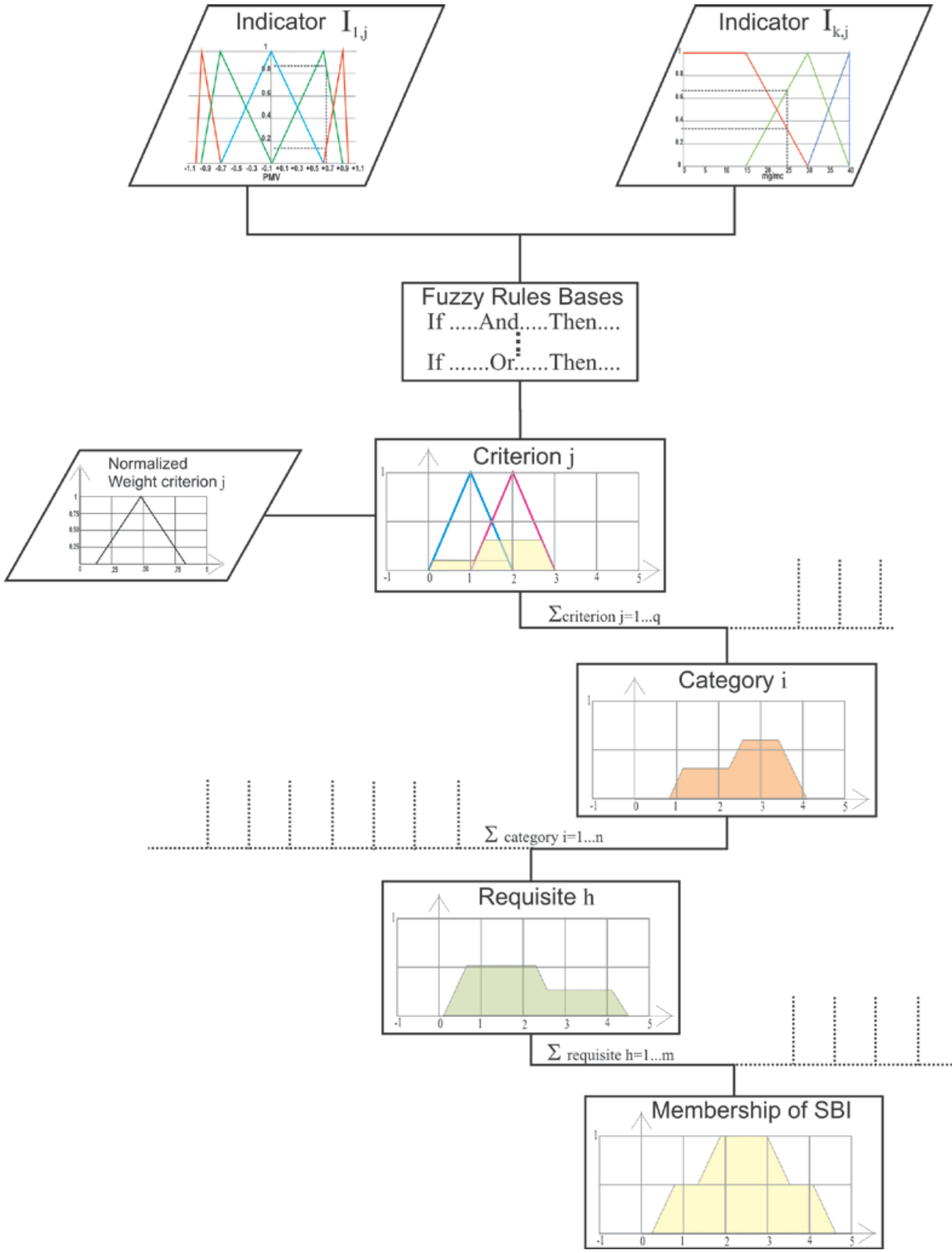

Figure 2. Flow chart of the method proposed for the definition of the BSI.

Fuzzification of the indicators A set of fuzzy membership functions is proposed for each indicator and defined on the interval of the values that the indicator can assume as a result of a quantitative or qualitative evaluation and that include the benchmark value. Particularly, each *s*-th set, made up of a range of values of the indicator, is associated to a membership function μ_s which allows to assign a grade of membership, included in the interval [0,1], to each input value *x*. If the degree of truth $\mu_s(x)=0$, then the value *x* belongs to the *s*-th set. On the contrary, if $\mu_s(x)=1$, then the value *x* belongs completely to the *s*-th set; while if $0<\mu_s(x)<1$, then the value *x* belongs to the *s*-th set only to a certain extent. The application of the Fuzzification method allows to consider the vagueness and inaccuracy that emerge when evaluating whether indicators belong to an interval, as well as to standardize, and then compare, the different evaluation scales.

Logic rules and fuzzy inference In order to define the membership function of the sustainability degree of the generic criterion, a decision-making process, based on the aggregation of inference rules, was applied (Mamdani and Assilian, 1999). This procedure consists in correlating, by means of logic relations, the membership functions assigned to the indicators and whose ranges include the registered input values, with the membership functions of the ratings to assign to the examined criterion (fig. 3). Each of the above-mentioned inference rules uses the following syntax:

IF <premise> *THEN* <consequence>

The premise is composed of clauses, meant as sentences expressed in a certain language (e.g. x is P) and characterised by the presence of a subject x and of a predicate P. In the proposed model, the subject is the input value related to the scale of fuzzy evaluation of the indicator, while the predicate is the fuzzy function belonging to the scale of fuzzified evaluation of the criterion (fig. 3) and intersected by the input value x. The clauses of the premise are connected with each other by *AND* or *OR* Boolean logic operators. The connection *AND* means that the premise is satisfied if all its clauses are verified. On the contrary, in the case of the *OR* operator, the premise is verified if at least one clause is valid. Therefore, the result of the clauses composing the premise defines the subject of the clause for the consequence. The choice of the grade of membership in the consequence membership function is made according to the meaning that the logic operator assumes. In fact, in the case of the operator *AND*, which is associated to intersection in the set theory, the resulting grade of membership is equal to the lowest among all the grades of membership resulting from the clauses (Klement et al., 2000). On the contrary, in the case of the operator *OR*, which is associated to the union in set theory, the grade of membership is the highest among all the grades of membership resulting from the clauses of the premise. More specifically, considering $\mu_A(x)$ and $\mu_B(x)$ as the degrees of truth resulting from two clauses, the following output of the premise will be obtained for each rule, depending on whether the logic operator *AND* or *OR* is used.

$$AND \quad \Rightarrow \quad \mu_C(x)=min[\mu_A(x);\ \mu_B(x)]$$
$$OR \quad \Rightarrow \quad \mu_C(x)=max[\mu_A(x);\ \mu_B(x)]$$

The same syntax can be used for the definition of the consequence but with certain variations in the meaning of the elements composing it. In fact, in this case the subject is the truth value resulting from the premise, while the predicate is a fuzzy function which belongs to the membership functions related to the judgement scale of the reference criterion, which was previously weighed. This scale was divided into seven fuzzy judgement variables with triangular membership (fig. 3) and maximum values ranging from -1 to 5, where the value -1 corresponds to a unsatisfactory sustainability evaluation of the criterion; the value 0 is associated to the elements of the evaluation scale with an acceptable minimum sustainability level that can also coincide with a best practice situation and corresponding to the values of a benchmark building. Higher values represent qualitative sustainability levels of growing importance.

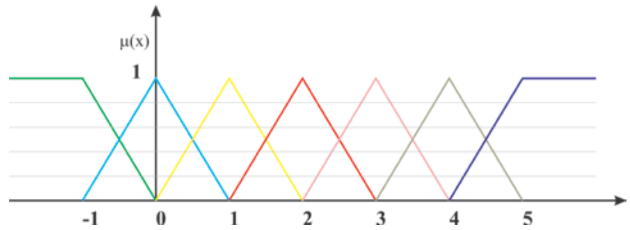

Figure 3. Membership fuzzy set of the output of the generic criterion.

The output of the generic rule is given by the fuzzy function considered as the predicate of the consequence and truncated at the degree of truth of the premise output. The process of fuzzy inference ends with the aggregation of the membership functions, obtained as the output of the satisfied rules, and with the obtainment of a compound membership function representing the building sustainability degree associated to the analysed criterion. It is important to bear in mind that the applied rules imitate human reasoning and that their composition derives from experience. Therefore, the different combinations of rules allow to describe at best the events which can really occur. Their definition is crucial in the application of the method since they allow to treat and analyse building performances which could not be otherwise evaluated.

Weight calculation As established by the SBMethod, each element (criterion, category and requisite) is weighed within its hierarchical level so as to take into account the different relative level of importance it has in the calculation of the global SBI of the building. As regards sustainable requisites and categories, the level of importance is expressed in terms of relative percentage and must be constant for homogeneous areas. In fact, these weights must consider the social, environmental, territorial and economic peculiarities of the area where the building is situated. On the contrary, the weight of each criterion is calculated as the product of the intensity of the impacts of the criterion on the environment. In particular, these impacts will be evaluated on the application of the method by assigning a judgement according to the potential effect of the criterion on the environment, to its extension, intensity and duration. The impact of each environmental effect will be evaluated by assigning a judgement on a scale characterised by three linguistic variables, each represented by means of a fuzzy set (fig. 4). The product of the three values of environmental impact is finally multiplied by the relative values of the weights of the sustainable requisites and of their respective categories, thus obtaining the membership function of the relative weight of each criterion in the evaluation of the BSI.

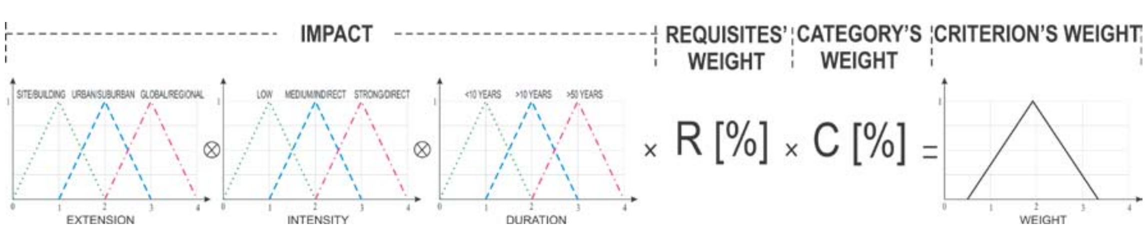

Figure 4. Membership function for the evaluation of the level of importance of the criterion

In a compact form, the weight w_j of the j-th criterion can be defined through the following expression:

$$w_j = R_h \times A_{hi} \times \tilde{P}_{hij}$$

Where the meaning of symbols is as follows:

R_h = importance of the h-th sustainable requisite expressed by a crisp number.
A_{hi} = importance of the i-th category belonging the h-th sustainable requisite, expressed by a crisp number.
$\tilde{P}_{hij}$ = potential of the effects on the environment provoked by the j-th criterion belonging to the i-th category and to the h-th sustainable requisite, expressed by a triangular fuzzy membership function.

Construction of the BSI membership function The final calculation of the BSI is carried out by adding up all the membership functions of each criterion (Bocharnikov and Sveshnikov, 2009), which were previously weighed with the normalised value of the relative weight calculated as described above. This sum is first extended to each category, thus obtaining a relative sustainability index value of the category, and then to all the various sustainable requisites. A further sum of the membership functions of the sustainable requisites allows to obtain the final membership function of the BSI (fig. 5). Finally, a synthetic value of the BSI can be calculated by applying the procedure of defuzzification through the barycentre method.

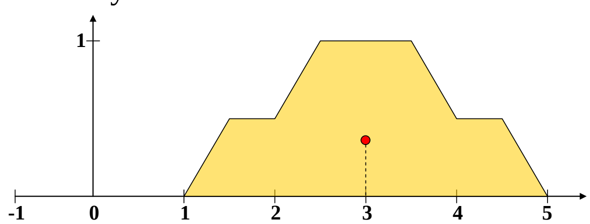

Figure 5. Representation of the sum of fuzzy functions for the calculation of the BSI.

CONCLUSIONS The proposed model for the evaluation of the Building Sustainable Index, which can be applied to agri-food facilities, allows to overcome some of the difficulties implied by the evaluation models based on the in situ measurement of the values of the building performance indicators. The measurement of the indicators, the attribution of a sustainability value to each range of values of the indicator and the definition of a precise benchmark value are not always possible and simple. These evaluations are often influenced by the subjectivity of the judgement and do not take into account the uncertainty and vagueness typical of this method. Moreover, if, on the one hand, the model proposed in the SBMethod can be adjusted to the different local situations, by assigning weights to the different hierarchical levels of the model and by choosing benchmark values; on the other hand, it is not an adequate tool for the sustainability building evaluation in the agri-food industry. In fact, the original model does not include the evaluation of some of the fundamental performances which characterise these buildings. Performances, in terms of hygiene, workers' safety and quality of cultural and social products, are not adequately considered. In order to overcome these critical factors, the model for the sustainability building evaluation in the agri-food industry, which is proposed in this paper, includes a series of criteria specific for the agri-food sector and introduces the use of fuzzy logic in the evaluation and measurement of the building performance indicators. Such a model allows to obtain a "function of sustainability index", that is, a function which represents the grades of membership of the index in an interval of possible sustainability values. Though the final result of the model is not the numerical value of a synthetic index but is expressed by a membership function, the analysis of the course of the function allows to obtain further information about the tendency to sustainability of the building. For instance, a more compact form of the final membership function shows a lower dispersion of the values of the criteria and, therefore, a greater certainty of the sustainability index value. In contrast, a more "flattened" form shows a higher dispersion of the values. A careful interpretation can allow to identify the building elements on which it is possible to intervene in order to improve the overall sustainability value. The BSI functions of different buildings cannot be directly compared because it is necessary to follow a specific procedure of hierarchical arrangement. Finally, the computational complexity of the proposed model for the calculation of the BSI requires the development of a specific computerised procedure which can simplify the application of the method also for the benefit of non-expert operators and allow a larger diffusion and validation in different contexts. In this sense, the future development of this work will focus on the construction of a logic algorithm for the implementation of the model in a specific data processing system.

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