A web tool to support decision making in the housing market using hesitant fuzzy linguistic term sets

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Abstract

In this paper we present a linguistic multiple-expert multi-criteria decision making model and a web tool to support it, that is centred on the housing market. The web tool is integrated with the usual catalogue of resources for rental or for sale, enriched with the possibility of ranking a subset of properties according to the client’s preferences and the internal knowledge associated to the properties. Usually the description of a property is quantitative, thought in our case we add qualitative information corresponding to assessments made by housing agents. These agents are considered experts in the market conditions.

We apply the 2-tuple linguistic representation model to keep accuracy in the processes of Computing with Words and the hesitant fuzzy linguistic term sets to qualify in situations of uncertainty and hesitation in the assessments. The software helps the agents in the process of the elicitation of the linguistic expression based on the fuzzy linguistic approach and the use of context-free grammars, and the web clients in the decision of visiting a property.

Article Info

1. Introduction

Every day people are challenged with multiple acts of decision. It is a natural human activity that is prompt to be subjective in its basis, but also to be uncertain and precise. Sometimes we are not aware of the implicit complexity of a problem, except when we try to make decisions with computational models. Problems defined under uncertain conditions are common in real world, but quite challenging to be modelled in a computer program due to the difficulty of dealing with uncertain information. Computing with Words (CW) is a methodology for reasoning and computing with perceptions rather than measurements. CW is able to empower applications that involve people expressing their preferences which happens in linguistic Decision Making (DM): the experts assess the potential of an alternative through qualitative values rather than quantitative ones.

Some models have been proposed to operate with linguistic information. In this work we operate with the fuzzy linguistic approach, that represents qualitative aspects as linguistics values by means of linguistics variables. These models are preferable because experts are allowed to evaluate closer to natural language and the way people reason. Criteria in different problems may vary, for example, if we describe a car, the criteria would involve price, fuel consumption or comfort. On the other hand, it is sometimes difficult to give an opinion as an exact single label, though we could allow to work with some possible set of values for decision makers.

To manage linguistic information in DM a well known computational model that carries out CW processes without loss of information is the 2-tuple Linguistic Computational Model. This model uses a pair of values called linguistic 2-tuple to represent the linguistic information. Many extensions to the 2-tuple linguistic model have been developed: to deal with unbalanced linguistic information where the linguistic labels in the terms set are not evenly distributed around a central term, or to deal with multi-granular label sets. A generalization of the 2-tuple representation, the proportional 2-tuple models were developed by Wang and Hao. Also, Dong et al. explored the concept of numerical scale, which extends the linguistic 2-tuple and the proportional 2-tuple.

Recently it has been enabled in DM problems the possibility of provide inaccurate rates and comparative linguistic expressions by means of the use of a context-free grammar represented by a hesitant fuzzy linguistic term set (HFLTS). This way to deal with uncertainty and hesitation in the context of fuzzy decision making, derives from the original idea of Torra’s hesitant fuzzy sets, has been applied in many recent works.
Particularly, the group decision making (GDM) problem is an area of application of CW to achieve a collective decision, that could benefit from the use of hesitant linguistic assessments [19] or consensus models [5].

In the housing market, a common problem is to describe a property accurately. When the owner fills the description form to upload a new record, the description he/she makes is usually over positive deliberately omitting deficiencies. The price tends to be too high because the owner lacks the knowledge of the area. Additionally the customer could get disappointed when visit the place because it may not fulfil the expectations. The first issue could be resolved with the counselling to the owner. For example, in some Real Estate agencies, a new order of for sale or to rent is taken by a realtor that describes the property after interviewing the owner and advises on the price. In our knowledge for the second issue, there is currently no automated solution to advise a buyer about what property should visit in person according the expectations.

The agents of a Real Estate agency are experts in the housing market and can be involved in a multi-expert multi-criteria decision making model. Criteria are attributes that helps in the description of a house. The benefit from the application of the model could consist in the valuation of candidates, in this case, a list of properties (houses, flats, garages, etc.). Usually agencies have an online catalogue, offering properties for sale and to rent to online customers around the world to increase the opportunities of business. Data and customers are online, thus a convenient solution would imply a web tool integrated within the catalogue.

The aim of this paper is to present a practical application in decision making of a 2-tuple linguistic fuzzy model with hesitant information. It represents a Real Estate web site with information of properties for sale or to rent. The novelty of the portal is the possibility of using linguistic expressions to assess a set of qualitative criteria. We have added eight criteria not so commonly used to describe the property, but that we think of relevance to the client following the suggestions of Real Estate agents. The evaluation of the properties is done by the realtors who possess the expertise over the housing market. DM processes that run over the server portal will use this internal information to propose a visitation order to its web clients based on their preferences. Also, a client of a Real Estate web site could assign a preference degree to each criteria in its profile area. The rest of this paper is structured as follows. In Section 2, some preliminaries related with the representation of qualitative data and the grammar used to evaluate are reviewed. In Section 3, a Multi-Criteria Multi-Expert Decision Making problem for the housing market is presented based on 2-tuple fuzzy representation of hesitant expressions. In Section 4, an illustrative example is presented. In Section 5, some conclusions are given.

2. Preliminaries

The fuzzy linguistic approach manipulate qualitative information by using linguistic variables as a representation of those values. Words are not numbers and thus they are more imprecise, but thanks to linguistic models, computations can be carried out using this type of information. In the literature we find a methodology to apply CW in decision making [6], that was introduced by Zadeh in the seminal paper [28] and in the definition of a linguistic variable [29]. We have chosen to apply the 2-tuple linguistic computational model as it represents a transformation of a linguistic variable which is suitable for computations without any lost of information.

In this section we give some general definitions of the 2-tuple representation model and a description of how the HFLTS enables a flexible way of elicit linguistic information.

2.1. A computational 2-tuple fuzzy linguistic model

A linguistic variable can take values only in a finite set of eligible values that are defined by the linguistic term set $S = \{s_0, \ldots, s_g\}$, in which $g + 1$ is called the cardinality of $S$ and usually is an odd number. The more terms in $S$ the more precise an evaluation could be, but on the contrary, it also imposes hesitation to the expert. The linguistic terms $s_i \in S$ are defined by triangular membership functions uniformly distributed. These assumptions guarantee that the 2-tuple linguistic computational model [8] is precise and effective.

**Definition 1.** [8] Let $S$ be a linguistic term set, and $\beta \in [0, g]$. Then the 2-tuple is defined as:

$$\Delta : [0, g] \rightarrow S \times [-0.5, 0.5]$$

$$\Delta(\beta) = (s_i, \alpha), \text{ with } \left\{ \begin{array}{l}
\alpha = \beta - i \\
\end{array} \right.$$

The 2-tuple becomes an equivalent representation of any term $s_i \in S$. The inverse function $\Delta^{-1} : S \times [-0.5, 0.5] \rightarrow [0, g]$ is defined in [8] by $\Delta^{-1}(s, \alpha) = i + \alpha = \beta$. The value of $\alpha \in [-0.5, 0.5]$ it is known as the symbolic translation. So, a linguistic term $s_i \in S$ transforms into $(s_i, 0)$ in CW processes.

When rating two alternatives assessed with a linguistic variable represented with a 2-tuple, a comparison rule is needed. We find in [8] a valid comparison rule:

1. if $n < m$, then $(s_n, \alpha_n)$ is smaller than $(s_m, \alpha_m)$
2. if $n = m$, then
   (a) if $\alpha_1 = \alpha_2$, then $(s_n, \alpha_1)$ and $(s_m, \alpha_2)$ are the same
   (b) if $\alpha_1 < \alpha_2$, then $(s_n, \alpha_1)$ is smaller than $(s_m, \alpha_2)$
   (c) if $\alpha_1 > \alpha_2$, then $(s_n, \alpha_1)$ is bigger than $(s_m, \alpha_2)$

To aggregate 2-tuples, the arithmetic mean can be adapted to be applied to the 2-tuple representation. Let $x = [(s_1, \alpha_1), \ldots, (s_n, \alpha_n)] = [(\beta_1, \ldots, \beta_n)]$ be a set of linguistic values represented as 2-tuple, $W$ a weighting vector $(|w_i| = 1, \ldots, n)$, and $W^*$ its normalised version $(|w^*_i| = 1, \ldots, n)$, i.e. $\sum_{i=1}^{n} w^*_i = 1$. The arithmetic weighed extended mean $\tilde{x}^D$ is defined as:

$$\tilde{x}^D(x) = \sum_{i=1}^{n} (\frac{\Delta^{-1}(s_i, \alpha_i) \cdot w^*_i}{\sum_{i=1}^{n} w^*_i}) = \Delta \left( \frac{\sum_{i=1}^{n} \Delta^{-1}(s_i, \alpha_i) \cdot w^*_i}{\sum_{i=1}^{n} w^*_i} \right). \quad (2)$$

**Example 1.** A linguistic term set with five linguistic terms can be as: $S = \{\text{nothing, little, middle, high, very high}\}$. A linguistic variable $\vartheta$ representing the ambient noise of a neighbourhood could be valued at midnight as little. So $\vartheta = s_1$, but in operations the 2-tuple $(s_1, 0)$, or $\beta = 1$, will be used.

2.2. Hesitant fuzzy linguistic term set

In situations where is usual to handle imprecise information, it is needed a solution to model hesitation in the elicitation of linguistic information. In a quantitative setting, the concept of hesitant fuzzy set (HFS) was introduced in [22] to allow decision makers the consideration of several values to determine the membership of an element to a set. The concept of HFS have proved to be applicable to DM, evaluation and clustering techniques [20]. To be used in linguistic fuzzy decision making situations, its extension known as HFLTS was presented in [18]. Afterwards, many researchers have apply the concept of HFLTS [21,22–15,17,19,25,26,31,32].

**Definition 2.** [18] Let $S = \{s_0, \ldots, s_g\}$ be a fixed set of linguistic term set. A hesitant fuzzy linguistic term set (HFLTS) $H$ is an ordered finite subset of the consecutive linguistic terms of $S$. 
The HFLTS is a new and flexible tool in representing hesitant qualitative information that can be used to elicit several linguistic values for a linguistic variable. The use of a context-free grammar increase the flexibility of the model by including the possibility of eliciting comparative linguistics expressions.

**Definition 3.** [18] Let $G_H$ be a context-free grammar. The elements of $G_H = (V_H, V_T, I, P)$ are defined as follows:

$$
V_H = \{ \text{primary term}, \text{composite term}, \text{unary relation} \},
V_T = \{ \text{lower than}, \text{greater than}, \text{at least}, \text{most} \},
I \in V_H;
$$

$$
P = \{ I \Rightarrow \text{primary term} | \text{composite term} \Rightarrow \text{unary relation} \Rightarrow \text{primary term} \}).
$$

Expressions in this grammar would need to be transformed into something useful to carry out the CW processes. The following transformation functions $E_{G_H}$ [18] are used to generate a HFLTS from a comparative linguistic expression.

$$
E_{G_H}(\text{greater than } s_j) = \{ s_k | s_k \in S \text{ and } s_k > s_j \}
$$

$$
E_{G_H}(\text{lower than } s_j) = \{ s_k | s_k \in S \text{ and } s_k < s_j \}
$$

$$
E_{G_H}(\text{at least } s_j) = \{ s_k | s_k \in S \text{ and } s_k \geq s_j \}
$$

$$
E_{G_H}(\text{most } s_j) = \{ s_k | s_k \in S \text{ and } s_k \leq s_j \}
$$

$$
E_{G_H}(\text{between } s_j \text{ and } s_j) = \{ s_k | s_k \in S \text{ and } s_j \leq s_k \leq s_j \}
$$

**Example 2.** Following the previous example of $S$ and $\vartheta$, let us give a valuation using the following grammatical expression: the ambient noise of a neighbourhood $x$ is at least little and is lower than very high. The resulting HFLTS is:

$$
E_{G_H}(\text{at least } s_1) = \{ s_1, s_2, s_3, s_4 \}
$$

$$
E_{G_H}(\text{lower than } s_4) = \{ s_0, s_1, s_2, s_3 \}
$$

$$
\{ s_1, s_2, s_3, s_4 \} \text{ and } \{ s_0, s_1, s_2, s_3 \} = \{ s_1, s_2, s_3 \}
$$

$$
H(\vartheta) = \{ \text{little, middle, high} \}
$$

The previous grammatical expression is equivalent to $\text{between little and high}$. 

**Definition 4.** [18] The envelope of a HFLTS, $\text{env}(H)$, is a linguistic interval whose limits are obtained by means of its upper bound $H^+$ and lower bound $H^-$:

$$
H^+ = \max(s_i) = s_j, s_j \leq s_i \text{ and } s_i \in H, \forall i,
$$

$$
H^- = \min(s_i) = s_j, s_j \geq s_i \text{ and } s_i \in H, \forall i.
$$

The envelope is computed as:

$$
\text{env}(H) = [H^-, H^+], H^_s \leq H^+.
$$

**Example 3.** Following the previous example of $H(\vartheta)$, the envelope is:

$$
\text{env}(H(\vartheta)) = [\text{little, high}]
$$

Note that when experts give their preferences with grammatical expressions (as in Example 2), the resulting valuation need to be transformed into some computable form. We have considered to operate with linguistic intervals, that allows to propagate the hesitation intrinsic in the assessment. For that reason, our CW processes are carried out using the envelope of a HFLTS. Though we use the original envelope calculation (given in Definition 4), it is possible to compute such linguistic intervals by means of a fuzzy envelope of HFLTS [13].

### 3. Linguistic multiple-expert multi-criteria decision using the hesitant 2-tuple fuzzy linguistic representation for the housing market

Decision Making problems are common in real life situations, when people have to choose the most desirable alternative under multiple influential attributes and opinions. Since the concepts of fuzzy sets and linguistic variable was introduced by Zadeh [29] many research lines have evolve in the application of linguistic computational models to DM [21,7,16,31]. In this section we describe a fuzzy linguistic multiple-expert multi-criteria decision making (MEMCDM) problem for the housing market and the considerations that should be taken to integrate a fuzzy linguistic DM model with HFLTS in our web tool.

#### 3.1. Problem description

In the housing market, online web sites are commonly used by people met online to buy, for sale or to rent properties. The Real Estate agencies put in their web sites a complete catalogue of house rental and sale offers that can be consulted by web clients around the world. Each house has a record with detailed information about its characteristics, where some of them are private to the realtors and some are public at the website. Basically each property is defined by a set of quantitative values (number of bedrooms, square feet, price, etc.) and a free text field used for an additional description. The description tends to be rich but unstructured and informal. It means that its format does not suit the filters that can be used to search for a property by tags or keywords. This is inherently a situation of having information with a strong qualitative definition.

Linguistic information attracts new possibilities of developments that could benefit from the techniques and proposals of the fuzzy linguistic approach. What we propose in this paper is a new service for a Real Estate agencies. The business model is supported by offering new services to the users under a fee (e.g. free account, pro account, V.I.P. account). This type of web sites could offer a new service that would rely in a fuzzy linguistic decision making model built in. Firstly, we need to provide a method to store houses of interest in the own user space in the website. The key point is to include qualitative information to describe the property to be used internally in the model. These extra information would come by the realtors. It is a reality that the housing market changes continuously, therefore the experts that better describe new acquisitions are the agents of the Real Estate and not the property owners desirable for a good sale. The output of the decision making model are the client’s houses of interest sorted in a way that it better reflects the client’s preferences.

In our system, to catalogue a new property it is necessary to include qualitative information additionally to the usual fields (number of baths, type of floors, pool yes-no, garage yes-no, etc.). The qualitative description comes in the form of eight criteria (shown in Table 1) assessed by the agent that takes in first place the order of sale or rent. In our case, these set of characteristics were selected by the experts themselves because they have the knowledge of what customers want to know about. For us it is mandatory that at least one agent assess the property, but the main idea of the model proposed is that many other agents (from the same Real Estate agency or from an alliance of agencies) include as well their
Table 1
Criteria used by the experts to assess the benefits of a property.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1 Quality / Price</td>
<td>Quality with respect to Price. It represents the sale price of the property as a conditional value to the benefit that would be achieved with the arrangement (rent or purchase) of the property.</td>
</tr>
<tr>
<td>C2 Property Condition</td>
<td>Review the need for housing reform. It represents the time and economic effort invested before you can enjoy the property.</td>
</tr>
<tr>
<td>C3 Luminosity</td>
<td>Combined evaluation of number of exterior rooms, altitude and number of floors, orientation with respect to sun and proximity of other buildings.</td>
</tr>
<tr>
<td>C4 Soundproofing</td>
<td>Evaluates the absence of acoustic discomfort observing the existence of factories or services (such as a fire house) that may increase the recommended threshold for external acoustic noise.</td>
</tr>
<tr>
<td>C5 Public Services</td>
<td>Provision of public services (schools, hospitals, post office, etc.) in the area, accessible within walking distance.</td>
</tr>
<tr>
<td>C6 Shopping &amp; Leisure</td>
<td>Offer related to leisure (cinema, restaurants, gymnasium, shops (hairdresser, hardware, repair, etc.) and other services within walking distance.</td>
</tr>
<tr>
<td>C7 Transportation</td>
<td>Quality of public transport provision in the area (taxi, bus, metro, etc.).</td>
</tr>
<tr>
<td>C8 Communications</td>
<td>Indicates the proximity to highway access points and roads of the national road network.</td>
</tr>
</tbody>
</table>

Besides aggregation and exploitation our scheme imply other processes. **Fig. 2** shows our DM scheme, which combines the two representations.

- **Unification phase.** Valuation matrices are provided by experts by using linguistic expressions for each criterion constructed with the grammar $G_l$. Some experts would give single term valuations, and others, due to hesitation, would need to elicit comparative preferences values. So, a unification phase is needed to homogenise all the assessments. Transformation functions $E_{C_l}$ (Eq. (3)) are applied to the preference relations getting HFLTS.
- **Interval calculation phase.** Each alternative is valued over a set of criteria by each expert. To operate with linguistic intervals we calculate the envelope of the HFLTS (as in Definition 4). In this stage every single valuation is noted as $[s_i, r_i]$.
- **2-tuple transformation phases.** The linguistic intervals are represented using the 2-tuple fuzzy linguistic computational approach, and are translated to $[(s_i, 0), (r_i, 0)]$. Following an standard scheme of CW processes [27], the translation would also imply the re-translation phase (using Eq. (1)). This backward operation converts 2-tuples results into something understandable by the user, as it is expressed in the original term set $S$. Other benefits can be derived from the use of the 2-tuple representation as stated in [9].

3.3. **Elicitation of linguistic information with HFLTS**

To illustrate our MEMCDM problem, let $S = \{\text{nothing, very low, low, medium, high, very high, perfect} \}$ be a linguistic term set, $A = \{A_i| i = 1, \ldots, N \}$ a set of $N$ alternatives or candidates. Each candidate has a common number of $M$ attributes or criteria, $C = \{C_j| j = 1, \ldots, M \}$, that are assessed by experts. The model use the combination of $P$ experts in the subject, $E = \{E_k| k = 1, \ldots, P \}$. Generally, this type of multi-criteria problem is described with an evaluation matrix as the one shown in **Table 2** where $y_{i}^{E_k}$ is the assessment given by $E_k$ over the alternative $A_i$ with respect to criterion $C_j$. Additionally, an input to the computational model is the relevance of each criteria given in percentage $W = \{W_1, \ldots, W_M\}$.

assessments in the system. Therefore the problem of suggest a visiting order is transformed into a MEMCDM problem with the houses as the alternatives $A (\{A_i| i = 1, \ldots, N\})$, the realtors as the experts $E (\{E_k| k = 1, \ldots, P\})$, the criteria $C (\{C_j| j = 1, \ldots, M\})$ as the information that is qualified linguistically by realtors. In our proposal, the clients express their preferences over each criterion by means of a percentage value, used as weights $W (\{w_j| j = 1, \ldots, M\})$.  

**3.2. A hesitant fuzzy linguistic decision making model**

The computational linguistic model described in this work allows to elicit evaluations by means of a context-free grammar, that would be managed with HFLTS [18] and the 2-tuple representation. Our general CW scheme is shown in **Fig. 1**.
Later on, the system would use the normalised version of weights $W = \{w'_1, \ldots, w'_M\}$ with $\sum_{i=0}^M w'_i = 1$.

Considering our Real Estate web site problem, for any alternative $A_i$ (a flat, a house, etc.), all the criteria have been mandatory evaluated and at least one expert $E_k$ (a realtor) has reviewed the candidate by means of grammar-free expressions over S. Under this premise, $y_{jk}^{i}$ is a hesitant expression that is transformed after the application of the function $E_{C_{ij}}$ (see Eq. (3)). Thus we get a HFLTS for each valuation made by the expert.

$$E_{C_{ij}}(y_{jk}^{i}) = H_{i}^{jk}$$

**Definition 5.** A HFLTS fuzzy evaluation matrix $F_{H}$ is the overall evaluation of experts $E$, when each criteria $C_j$ is considered as a linguistic variable, and $H$ results after the interpretation of the grammar $G_{ij}$ over $S$. The matrix $F_{H}$ collects the opinion of experts over candidates and is given by:

$$F_{H}(A_{i}) = \begin{pmatrix} H_{i}^{11} & H_{i}^{12} & \cdots & H_{i}^{1M} \\ H_{i}^{21} & H_{i}^{22} & \cdots & H_{i}^{2M} \\ \vdots & \vdots & \ddots & \vdots \\ H_{i}^{p1} & H_{i}^{p2} & \cdots & H_{i}^{pM} \end{pmatrix}$$

where $0 < p \leq P$. (5)

The condition of which $0 < p \leq P$ is going to give us a degree of flexibility in the implementation of the DM model as it would not impose the same number of experts valuations over each alternative, and thus is closer to reality.

**Example 4.** Let be $N = 3$ the number of alternatives, $M = 3$ the criteria, and $P = 3$ the number of experts. Instead of having an $P \times M$ evaluation matrix we have a situation in which expert $E_1$ has evaluated all the criteria, $E_2$ has evaluated $A_1$ and $A_2$, and $E_3$ only gives its opinion about $A_3$. The three evaluation matrices would be:

$$F_{H}(A_1) = \begin{pmatrix} H_{1}^{11} & H_{1}^{21} & H_{1}^{31} \\ H_{1}^{12} & H_{1}^{22} & H_{1}^{32} \\ H_{1}^{13} & H_{1}^{23} & H_{1}^{33} \end{pmatrix}$$

3.4. **Choice of an aggregation operator**

The aggregation phase works with HFLTS fuzzy evaluation matrices $F_{H}$, of size $N \times M \times P$, that are transformed into matrices of HFLTS envelopes $F_{env}$. As we stated before, each envelope $env(H)$ could be consider as linguistic interval $[s_i, s_j]$ and internally as 2-tuple fuzzy linguistic intervals. According to [19], $s_i$ and $s_j$ represent the pessimistic and optimistic perception of the assessments, respectively. When needed, we use in the notation the super index $−$ or $⋆$ to refer to operations performed only with $s_i$ or $s_j$ respectively. Complete operation, shown in Fig. 3, is described in this section.

The aim of the aggregation process is to compute a collective value for each alternative aggregating the experts assessments, and latter to compute a single valuation for each alternative according to the weights of each criterion stated by the customer. In the literature we find that, originally to aggregate HFLTS, Rodriguez et al. [18] defined two symbolic operators: the $\min$ upper and $\max$ lower, but according to [26] these operators cannot deal with the situation where the importance weights of criteria are considered. In our MEMCDM problem, weights are considered but the fact that each linguistic interval could be converted into a interval of 2-tuples $[(s_i, 0), (s_j, 0)]$ (translation step of Fig. 2) resolves this situation as we could use any 2-tuple weighted aggregation operator. Furthermore, from now on we could use any fuzzy linguistic aggregation operation ($\phi$) and depending of the problem each aggregation operator could be different on each round [31]. Such operator $\phi$ should be used separately over the two values of the linguistic interval.

We operate with $\min$ upper operator $\phi^{−}$ in two steps [18]: (i) apply the upper bound for each HFLTS envelope, (ii) obtain the minimum linguistic term for each alternative. For some given $A_i$ and $C_j$ we have:

$$env(H(A_i)) = \{env(H_{i1}^{11})^{+}, \ldots, env(H_{i1}^{1M})^{+}\}$$

$$\phi^{−}(H_{ij}) = \min\{env(H_{ij}^{k})^{+} / k \in \{1, \ldots, p\}\}$$

![Fig. 2. Computing with Words scheme using 2-tuples and HFLTS.](image)

![Fig. 3. From F to FC and FV by using aggregation operators φ and θ.](image)
The max_lower operator, \( \varphi^* \), also operates in two steps [18]: (i) apply the lower bound for each HFLTS envelope, (ii) obtain the maximum linguistic term for each alternative.

\[
\text{env}(H(A_i)) = \{ \text{env}(H_{1i}^l), \ldots, \text{env}(H_{pi}^l) \} \text{ with } p \leq P, \\
\varphi^+(H_i^l) = \max\{\text{env}(H_{ki}^l) / k \in \{1, \ldots, p\}\}
\]

**Example 5.** Consider a DM problem with \( C = 5 \) and \( P = 3 \), and that we have to aggregate the valuations given by experts for \( A_1 \) with HFLTS.

\[
F_{\text{env}}(A_1) = \begin{pmatrix}
[s_3, s_3] & [s_4, s_4] & [s_5, s_5] & [s_5, s_5] & [s_5, s_1] \\
[s_3, s_3] & [s_2, s_2] & [s_3, s_3] & [s_3, s_4] & [s_3, s_4] \\
[s_4, s_3] & [s_5, s_5] & [s_5, s_6] & [s_5, s_6] & [s_0, s_4]
\end{pmatrix}
\]

We combine \( \varphi^- \) and \( \varphi^+ \) for each criterion to obtain a collective valuation. When \( C_1, \varphi^- (1/2\{[s_3, s_3], [s_3, s_3], [s_4, s_5]\}) = s_3 \) because \( 3 = \min(3, 3, 5) \) and because \( 4 = \max(3, 3, 4) \), \( \varphi^+(1/2\{[s_3, s_3], [s_3, s_3], [s_4, s_3], [s_4, s_3]\}) = s_4 \). To complete the example:

\[
F_{C}(A_1) = \{ [s_3, s_4], [s_2, s_2], [s_3, s_3], [s_4, s_4], [s_1, s_1] \}
\]

The following represents the transformation step on the collective pessimistic evaluation matrix after the first aggregation:

\[
(s_i, \alpha_i^j)^+ = \Delta(\varphi(\Delta^{-1}(\text{env}(H_{ki}^l)))) \forall k \in \{1, \ldots, p\} \text{ with } p \leq P.
\]

\[
F_{C}^+(A_1) = \begin{pmatrix}
(s_3, \alpha_1^1) & \cdots & (s_3, \alpha_1^p) \\
(s_2, \alpha_1^1) & \cdots & (s_2, \alpha_1^p) \\
\vdots & \ddots & \vdots \\
(s_3, \alpha_1^1) & \cdots & (s_3, \alpha_1^p)
\end{pmatrix}
\]

The resulting \( F_{C}^+ \) and \( F_{C}^- \) are two \( N \times M \) matrices of collective pessimistic and optimistic valuations respectively. In our MCMMEDM problem not every criterion has the same importance, as we allow the web clients to express their criteria preferences with weights. The next aggregation phase represents a weighted combination of collective valuations that is carried out using the 2-tuple linguistic intervals separately. We choose the aggregation operator \( \theta \) as the arithmetic weighted extended mean (see Eq. (2)).

We aggregate the valuation for each criterion but under the consideration that not every criterion has equal importance. The result of this aggregation (given in Eq. (7)) is a vector of \( N \) collective weighted values one for each alternative, \( F_V = (v_1, \ldots, v_N) \). It is applied to the pessimistic and optimistic valuations respectively as follows:

\[
v_i = \Delta(\theta(\Delta^{-1}(s_i, \alpha_i^j))) \forall j \in \{1, \ldots, M\}
\]

**3.5. Ranking of alternatives**

The ranking of alternatives is the last phase to the solution of a MCMMEDM problem. With the resulting vector \( F_V \) of linguistic 2-tuples for each candidate, we just have to sort it from the best (the greater value) to the worst (the smaller value). It is part of the exploitation phase and it could be performed according several criteria.

So far there are few methods attending specifically the use of HFLTS into decision making problems. In our proposed model we have used five different methods. From the fact that information it is represented by 2-tuple fuzzy linguistic intervals, we could use comparison rule on 2-tuples (see Section 2.1), so the first three cases are straightforward:

1. **Pessimistic case.** We consider only the lower values of the given intervals to arrange elements of the evaluation vector \( F_V \), that is \( F_V^- \). The higher value is the better option.
2. **Optimistic case.** We apply the comparison rule on 2-tuple values to sort \( F_V^+ \). As well, the higher value is the better option.
3. **Average value.** Intervals values of \( F_V \) are averaged into single 2-tuple values. The comparison rule is applied to obtain a final rank.
4. **Choice degree.** Is the original procedure for comparison of HFLTS given in [18]. It employs the theory of interval values to rank HFLTS. We have followed the same operations with the 2-tuples linguistic intervals.
5. **Possibility degree.** In [26] a comparison of HFLTS procedure is given based on the probability theory. It calculates the possibility degree matrix \( P \) and a preference relation matrix \( U \) in an iterative algorithm. We have followed the same operations with the 2-tuples linguistic intervals.

**4. A web tool for fuzzy decision making**

The model presented in the previous section is applicable to real life decision making problems. We have found a practical application in the housing market and related to it, we have developed a web tool to support the model and the elicitation of linguistic information based on HFLTS. This section gives the details of the web tool and also presents an example.

**4.1. Solution with the hesitant 2-tuple fuzzy linguistic representation**

The evaluation process in a MEMCDM problem of describe rental housing or for sale opportunities poses some difficulties because valuations could be uncertain or fuzzy, mostly due to the subjectivity of reales. This could be overcome by the use of a context-free grammar, given by the use of HFLTS, and it is an added value of the website, as it is a flexible procedure for electing linguistic information.

We have implement a linguistic model for decision making applied to offer a recommendation service on a housing market website. The input to the model correspond to a general MEMCDM problem. The web clients are able to browse the catalogue of opportunities for sale or for rent, and include them in a list of favourites (illustrated in Fig. 4). In this way they select a set of alternatives or candidates, which are already assessed by experts. In this case the experts are the reales and their valuations are internally stored with a combination of HFLTS and 2-tuples representation. In the same client profile area, a customization of the importance of each criteria (a percentage weight used in the aggregation phase) it is permitted.

When the client is ready, he or she will consult the decision making model built in the portal to get a recommendation of the ideal visitation order for those candidates according to the given preferences. The user could modify the list or his/her preferences at any time. Fig. 5 illustrates how this is done in the web site.

**4.2. Case use: three customers with same candidates**

An unlimited number of users, \( U \), could get logged in our site to store their preferences over the given criteria, and to use our decision making implementation. As a result, they are going to be advised about what candidates are closer to their preferences according to the internal reviews of the reales. Let consider an example that three customers are interested on the same zone of one city. Suppose that they have selected the same three flats \( A_1, A_2 \) and \( A_3 \), after a search is done. What makes the difference in the output of the DM for the three customers is the preferences over the criteria. Their weights are different as could be noted in Table 3.
The internal linguistic description, which is private, can only be consulted and modified by realtors under identified access in an administrative area. Fig. 6 shows the subarea of the new record form where realtors are allowed to use single linguistic terms or hesitant expressions.

In this case of use, four different realtors has assessed the candidates. We give in Table 4 the original review of one realtor and in Table 5 the complete internal linguistic information retrieved from the database after the unification phase.

After a request for decision making, the portal shows a table that ranks the candidates according five methods of comparison:

---

**Fig. 4.** Candidate selection after a search in the catalogue. Clients add their items of interest into a list called My favourites.

**Fig. 5.** When the user is logged in, the My favourites section includes the sliders used to assign preferences to criteria.

**Table 3**

Weights W in percentage given by clients $U_1$, $U_2$, and $U_3$. The normalised version $W'$ will be used in the computations.

<table>
<thead>
<tr>
<th>Client</th>
<th>$W_1$</th>
<th>$W_2$</th>
<th>$W_3$</th>
<th>$W_4$</th>
<th>$W_5$</th>
<th>$W_6$</th>
<th>$W_7$</th>
<th>$W_8$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_1$</td>
<td>80</td>
<td>80</td>
<td>100</td>
<td>100</td>
<td>20</td>
<td>12</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>$U_2$</td>
<td>80</td>
<td>100</td>
<td>53</td>
<td>81</td>
<td>0</td>
<td>100</td>
<td>71</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$W'_1$</th>
<th>$W'_2$</th>
<th>$W'_3$</th>
<th>$W'_4$</th>
<th>$W'_5$</th>
<th>$W'_6$</th>
<th>$W'_7$</th>
<th>$W'_8$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_1$</td>
<td>0.1694</td>
<td>0.1694</td>
<td>0.2118</td>
<td>0.2118</td>
<td>0.0423</td>
<td>0.0254</td>
<td>0.0635</td>
</tr>
<tr>
<td>$U_2$</td>
<td>0.1652</td>
<td>0.1404</td>
<td>0.1239</td>
<td>0.1239</td>
<td>0.1322</td>
<td>0.1239</td>
<td>0.1074</td>
</tr>
<tr>
<td>$U_3$</td>
<td>0.1666</td>
<td>0.2057</td>
<td>0.1090</td>
<td>0.1666</td>
<td>0.0</td>
<td>0.0057</td>
<td>0.1460</td>
</tr>
</tbody>
</table>

**Table 4**

The realtor $E_2$ reviews candidate $A_1$ with hesitant expressions or single terms.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$</td>
<td>At least $s_4$</td>
</tr>
<tr>
<td>$C_2$</td>
<td>Between $s_4$ and $s_5$</td>
</tr>
<tr>
<td>$C_3$</td>
<td>At least $s_5$</td>
</tr>
<tr>
<td>$C_4$</td>
<td>Between $s_3$ and $s_4$</td>
</tr>
<tr>
<td>$C_5$</td>
<td>$s_3$</td>
</tr>
<tr>
<td>$C_6$</td>
<td>Between $s_2$ and $s_4$</td>
</tr>
<tr>
<td>$C_7$</td>
<td>Between $s_3$ and $s_4$</td>
</tr>
<tr>
<td>$C_8$</td>
<td>Between $s_4$ and $s_5$</td>
</tr>
</tbody>
</table>
A pessimistic case, optimistic case, average value, choice degree and possibility degree. Detailed output for this case use is given in Table 6 as labels followed by internal values (2-tuples or a degree value between 0 and 1, depending on the method of comparison). The visiting order suggested vary between web clients:

- Client $U_1$ is suggested with $A_2 > A_3 > A_1$ with the pessimistic and possibility degree methods, and $A_2 > A_1 > A_3$ with the optimistic, average and choice degree methods. Note that because criterion $C_5$ and $C_6$ in benefit of criterion $C_4$ which confirms the selection of candidate $A_2$ as the best choice, the other two candidates are rated quite similarly.

- Client $U_2$ is suggested with $A_2 > A_1 > A_3$ in the three method which ranks 2-tuples. $A_2 > A_3 > A_1$ it is suggested on the choice and possibility degrees methods. This client cancelled with his/her weights criterion $C_5$ and $C_6$ in benefit of criterion $C_4$ which confirms the selection of candidate $A_2$ as the best choice, the other two candidates are rated quite similarly.

In summary the candidate $A_2$ is arguably the best in all ranking methods and for every client. In the second and third positions $A_3$ and $A_1$ are rated similarly, but according the client’s preferences. The perspective of the ranking method (e.g. optimistic vs. pessimistic) is also affecting the final output.

### Table 5

<table>
<thead>
<tr>
<th>Candidate</th>
<th>Expert</th>
<th>$C_1$</th>
<th>$C_2$</th>
<th>$C_3$</th>
<th>$C_4$</th>
<th>$C_5$</th>
<th>$C_6$</th>
<th>$C_7$</th>
<th>$C_8$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_1$</td>
<td>$E_1$</td>
<td>[4, 4]</td>
<td>[5, 5]</td>
<td>[6, 6]</td>
<td>[2, 2]</td>
<td>[3, 3]</td>
<td>[2, 3]</td>
<td>[3, 3]</td>
<td>[4, 4]</td>
</tr>
<tr>
<td>$A_2$</td>
<td>$E_2$</td>
<td>[4, 4]</td>
<td>[5, 5]</td>
<td>[6, 6]</td>
<td>[2, 2]</td>
<td>[3, 3]</td>
<td>[2, 3]</td>
<td>[3, 3]</td>
<td>[4, 4]</td>
</tr>
<tr>
<td>$A_3$</td>
<td>$E_3$</td>
<td>[4, 4]</td>
<td>[5, 5]</td>
<td>[6, 6]</td>
<td>[2, 2]</td>
<td>[3, 3]</td>
<td>[2, 3]</td>
<td>[3, 3]</td>
<td>[4, 4]</td>
</tr>
</tbody>
</table>

### Table 6

<table>
<thead>
<tr>
<th>Client</th>
<th>Ranking</th>
<th>Pessimistic</th>
<th>Optimistic</th>
<th>Average value</th>
<th>Choice degree</th>
<th>Possibility degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_1$</td>
<td>1</td>
<td>$A_2$ High</td>
<td>$A_2$ Very high</td>
<td>$A_2$ High</td>
<td>$A_2$ 1</td>
<td>$A_2$ 0.694</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4, 0.13)</td>
<td>(5, 0.25)</td>
<td>(4, 0.44)</td>
<td>$A_2$ 0.405</td>
<td>$A_2$ 0.5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>$A_1$ High</td>
<td>$A_1$ High</td>
<td>$A_1$ High</td>
<td>$A_1$ 0.053</td>
<td>$A_1$ 0.305</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4, 0.46)</td>
<td>(4, 0.05)</td>
<td>(4, 0.08)</td>
<td>$A_1$ 0</td>
<td>$A_1$ 0.722</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>$A_1$ Middle</td>
<td>$A_1$ High</td>
<td>$A_1$ Middle</td>
<td>$A_1$ 0</td>
<td>$A_1$ 0.388</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4, 0.16)</td>
<td>(5, 0.28)</td>
<td>(4, 0.45)</td>
<td>$A_1$ 0</td>
<td>$A_1$ 0.388</td>
</tr>
<tr>
<td>$U_2$</td>
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<td>$A_2$ High</td>
<td>$A_2$ Very high</td>
<td>$A_2$ High</td>
<td>$A_2$ 1</td>
<td>$A_2$ 0.722</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4, 0.18)</td>
<td>(5, 0.28)</td>
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</tr>
<tr>
<td></td>
<td>2</td>
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<td>$A_1$ High</td>
<td>$A_1$ Middle</td>
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<td>$A_1$ 0.388</td>
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<td>$A_1$ 0.388</td>
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<tr>
<td>$U_3$</td>
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<td>$A_2$ Very high</td>
<td>$A_2$ Very high</td>
<td>$A_2$ 1</td>
<td>$A_2$ 0.722</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4, 0.19)</td>
<td>(5, 0.13)</td>
<td>(5, 0.47)</td>
<td>$A_2$ 0</td>
<td>$A_2$ 0.388</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>$A_1$ Middle</td>
<td>$A_1$ High</td>
<td>$A_1$ Middle</td>
<td>$A_1$ 0</td>
<td>$A_1$ 0.388</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3, 0.31)</td>
<td>(4, 0.07)</td>
<td>(4, 0.31)</td>
<td>$A_1$ 0</td>
<td>$A_1$ 0.388</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>$A_1$ Middle</td>
<td>$A_1$ High</td>
<td>$A_1$ Middle</td>
<td>$A_1$ 0</td>
<td>$A_1$ 0.388</td>
</tr>
</tbody>
</table>

5. Conclusions

In this paper we have presented a web tool to support decision making in the housing market. It is a real application of a multi-expert multi-criteria decision
making problem. It benefits from the use of the fuzzy linguistic approach and the
techniques available for Computing with Words. We apply the 2-tuple linguistic
representation model to keep accuracy in the processes of Computing with Words
and the hesitant fuzzy linguistic term sets to qualify for situations of uncertainty
and hesitation in the assessments. The housing market valuations are inherently
complex because they are under multiple influential attributes and opinions, but
with the use of a context-free grammar that concede complex expressions these
experts are granted to evaluate each house under hesitation.

The portal has a private area in which agents qualify each property according to
the proposed fuzzy linguistic approach with 2-tuples and HFLTs. In our scheme, the
first stage comes from the unification and translation of assessments to HFLTs. Then,
information is internally managed as linguistic intervals so we apply the envelope of
a HFLTs before translation to the 2-tuple linguistic representation. Aggregation
comes as two rounds of computations with the application of the user’s weights.
In the exploitation phase, five different criteria are applied to rank the candidates.
Finally, the Real Estate web clients select their alternatives list and their preferences
about the characteristics considered (criteria under valuation). The portal is able to
rank a candidate list according to the client’s preferences and the internal knowledge
associated to the properties. Thus, this helps to the web clients in the decision of
visiting a property.

We are committed to further improve the online tool on the base of using hesi-
tant context free grammar expressions. Following the line of extensions of the
2-tuple linguistic computational model, we foresee the application of unbalanced
linguistic linguistic term sets. In our context, experts of the housing market could
be specialised in a particular city zone. Assessments could be more precise in the
zone where he and she develops more intensely their work, and thus the possibility
of choice between a larger or an smaller term set is more convenient. The use of
a linguistic hierarchy and hence to deal with unbalanced linguistic information,
is one of our future lines of work, as well as the inclusion of weights over experts,
to consider some opinions over others depending on the zone that is been evaluated.
Another improvement to the online tool is in the line to obtain agreement among
the decision makers. We know that consensus reaching is a transverse topic in the
decision making field, and for this particular application, the customers of a Real
Estate agency are the ones that could obtain a benefit. Think in a standard family
of four members with two teenage offspring, much in the mood of make their opin-
ion count. The web site should extends the user profile to include not only a single
preference set over criteria but a family profile set of preferences, weights over the
family roles and the possibility of counting with hesitant information to represent the
uncertainty, and to adjust suggestions which help decision makers reach the
desired level of consensus [5].

This application is available at the URL: http://sci2s.ugr.es/flicticia for demonstra-
tive purposes with the user demo / demo and agent expert / expert.

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