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Hidden Fuzzy Information:

Requirement specification and measurement of project provider performance

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Abstract:

The requirement specification process is an important part of a project and has the potential to prevent problems that may last for years after a project is delivered. Previous studies on the requirement specification process have focused on clarifying stated fuzzy terms in software requirement engineering. However, in many projects there is information that is not stated, but it is implied and can be inferred. This hidden information is usually ignored due to the assumption that 'the provider understands what they mean/need'. This assumption is not always true. Such information, if extracted, may include fuzzy terms, namely hidden fuzzy terms (HFTs), which need specification. Therefore, these fuzzy terms have to be identified and then specified to avoid potential future consequences. This study proposes an algorithm to extract the hidden fuzzy terms, utilises a fuzzy inference system (FIS) to specify them, and apply the best worst multi criteria decision making method (BWM) to evaluate the delivered product and measure the performance of the provider. The model is then examined on a case from defence housing Australia. Such evaluation and measurement enable the project owner/manager to have a transparent basis to support decisions later in different phases of the project, and ultimately reduce the likelihood of conflict and receiving an unsatisfactory product.

Keywords: Hidden Fuzzy; Requirement specification; BWM; MCDM; Fuzzy inference system

1. Introduction

The requirement specification process is an important part of projects and is mostly concerned with the process of specifying buyer's requirements and expectations [1]. Such a process should be performed early in a project to reduce the likelihood of future conflicts or disagreements on product specifications and provider's obligations [2]. Determining a clear set of requirements by the buyer also provides a clear basis for measuring the provider's performance [3]. Given this, a transparent basis for buyer's future decisions in the project is built.

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Requirement specification is a phase of the procurement process which has hitherto attracted insufficient studies to address this significant problem of large procurement projects [2]. Admitting there are studies which deal with the requirement specification process, most of the current relevant literature has been focused on the specification process in the context of software engineering [4-7]. This is a challenging part of the procurement process which needs proper investigation in managing the procurement process of projects. More explicitly, the requirement specification process can be considered as the first stage of the four stages of the procurement; specifying the requirements, identifying potential suppliers, selecting the best supplier, and managing the contract [8]. This is to say that requirement specification is a key and fundamental stage of the procurement process, and we believe that it has not yet received proper attention as will be discussed in Section 2. Given this, requirement definitions in Australian Defence projects were investigated. Processing the information exposed fuzzy words written in documents that could be well specified using fuzzy sets, which was attractive. More interesting than that was the missing or implied information; there is sometimes implied information about the product specifications, which is not stated but can be implied. To investigate further, we decided to add the information. In doing so, we noticed that the added statements may occasionally be in the form of fuzzy information, which drew our attention again to the use of fuzzy graphs. Thus, an algorithm to process the information was designed with the aim of reducing the fuzziness of the defined requirements. The proposed algorithm increases the clarity of the requirements through the application of fuzzy graphs.

This study, unlike the previous studies in software engineering, discusses the problem in the domain of procurement projects. Moreover, it introduces the concept of hidden fuzzy terms (HFTs) which is concerned with hidden information in defining project owner/manager's requirements and expectations in projects and exposes the importance of taking into consideration such implied information in the specification process. The immediate gain of identifying and specifying implied information is that the buyer has to evaluate the specification of the future product more accurately and therefore become knowledgeable enough to specify what product or deliverables really fits the needs for which the project is being developed. Further, this paper explicitly shows how the specified requirements can benefit the buyer in the evaluation phase of managing the project. To do this, Mamdani's fuzzy inference system (FIS) [9-11] is employed to find the relationship between fuzzy requirements and the satisfaction level of the buyer. Finally, the best worst multi criteria decision making (BWM) method is utilised in order to measure how satisfactory the performance of the provider is with respect to the specification of a delivered product. This measurement can be referred to for future decisions in the project, for example, to consider extra payments as bonus or reduced payments as punishment. Therefore, the contribution of this study is to introduce the concept of HFTs, identify and specify HFTs, and utilise specified requirements to evaluate the performance of the provider. Further, it shows how at least a part of the payment can be tied to how well the provider meet the specified requirements. This paper encourages future studies to apply tools and techniques to improve the identification, specification and utilisation of HFTs. Establishing such a specification process in projects, especially in large projects, reduces the fuzziness of requirements, and so the likelihood of conflicts and receiving unsatisfactory products.

The remainder of this paper is organised as follows. After this, the related literature is reviewed which is followed by the methodology. To show how the methodology works a case of Defence Housing in Australia (DHA) is examined. The results are then discussed.

2. Literature review

The literature review has two sections. The first section includes related studies on requirement specification which are mostly in the domain of software engineering. The second section reviews previous studies on procurement projects in order to expose the importance of the requirement specification process in the domain of logistics and supply chain and more specifically in procurement processes.

2.1 Requirement specification

The requirement specification process deals with examination of different methods and techniques to evaluate and improve the quality of requirements. Studies on requirement specification are concerned with a variety of issues, such as traceability [12], incompleteness [13], internal conflicts [14], requirement fuzziness [2] among others. A few studies advocate improving the quality of requirement presentations through employing templates [15, 16] and grammatical formats, such as avoiding for example passive voice or negative sentences [17].

Most of the current studies on requirement specification investigate and examine the process in the software engineering domain. The approaches that have been used are quite diverse. Vilpola and Kouri [18] deal with requirement specification in enterprise resource planning (ERP) systems for small and medium size enterprises. Their discussed case is quite complicated as an ERP implementation project is a challenging software development project. They propose a method for ERP requirement specification that includes operational, contextual and risk analysis. In doing so, they specify the requirements for the new ERP system in a case study, and identify the restrictions and risks related to the ERP project. Similarly, Mallek et al. [19] discuss the problem and consequences of requirement ambiguity. They, however, focus on improving the verifiability aspect of the requirements. The suggested approach includes the use of conceptual graphs, a model checking approach, and a heuristic technique. They conduct a survey in order to consolidate and enrich the list of requirements of different partners. Through this, requirements such as the one presented below were extracted.

"*Keep the performance as good as possible in terms of cost, quality (product and service) and time spent, after the partnership is over, as before it was started.*"

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They argue that this ambiguity, imprecision and incoherence must be removed, and relate these mainly to the expressiveness of natural language. Their proposed approach to tackle this issue relies on using consistent language in order to have these requirements clarified, structured, and formulated. Given this, they develop a repository of interoperability requirements that is as comprehensive and generic as possible. Here, in this paper, the ambiguity of requirements, such as the above highlighted requirement are addressed differently. The ambiguity is observable with regard to the question of what *'cost'*, *'quality'*, and *'time'* is good enough to guarantee that the system works with a *'good performance'*. This is to say that there are hidden fuzzy terms such as (low) cost, (high) quality and (short) time, which are in need of clarification. Later, it is shown such fuzzy terms can be first identified and then clarified.

There are other studies focusing on the software requirement specification process. Lutters and Klooster [20] explain the role of functional requirements in product life cycles and investigate ways of specifying requirements. Astesiano and Reggio [21] argue that a refined structure of information can significantly improve the process of specifying the requirements. Therefore, they suggest a case driven unified modelling language for presenting information in the requirement specification process. Zuo [22] proposes a framework for requirement specification and representation processes in critical information systems. The framework is illustrated using a military command and control system. Aligned with the proposal of Zuo (2010), Ljung and Engström [23] propose a conceptual framework for specifying requirements and apply it in driving simulator and test track experiments. Bang [24] discusses approaches to increase the speed of the requirement specification process through face to face communication, and relies on a software requirement specification case. Rashid et al. [25] discuss the requirement specification process when performed by end users. They argue that in such situations, since the end users are not expert in the area of requirement specification, the previously proposed methods are not useful and hence they propose a visual requirement specification process which is designed to be user friendly. These studies among others examine applications of tools and techniques to improve the specification of the requirements.

There are studies working on processes that need to be done before performing the requirement specification process. One of the processes is finding ambiguous words. However, in some cases, it might be time consuming with regard to the volume of the documents in which ambiguous words need to be identified. This is usually the case in government projects [26]. To deal with such situations, text mining tools, such as natural language processing (NLP), can be used to structure a semi-automated approach to identify ambiguous words in a written text [26-28]. Femmer [27] provides categories of ambiguity types for requirements, namely requirement smells. This categorisation is followed with a study by Femmer et al. [26] which identifies the smells in some documents written in German utilising dictionaries and POS tagging in a data analysis platform, referred to as ConQAT[1]. The accuracy of the smell detection model is later investigated by Femmer et al. [28] and the defects that can be detected with the method are exposed. Although these studies discuss the importance of the pre-specification processes, they focus on existing ambiguity and fuzziness (which are already written). Moreover, their scope does not go beyond the identification phase. The term ‘pre-specification’ has also been mentioned earlier in a study by Ravichandar, Arthur, and Pérez-Quinones [29] that is focused on the traceability aspect of requirements which captures the relationship between requirements and their sources.

There are also examples of applications of fuzzy logic in areas close to requirement specification. Yen et al. [30] utilise fuzzy logic to deal with requirements which have internal conflict: where multiple members of a team define the requirements from their own perspectives. Liu et al. [31] classify the relationship between the requirements into four groups: conflicting, cooperative, mutually exclusive and irrelevant. Then, they discuss how satisfying one requirement affects satisfaction of another. The only application of fuzzy logic in specifying requirements is limited to a study by Yen and Lee [32]. They propose a software specification methodology to formulate imprecise requirements. Reviewing papers discussed in this section, it becomes clear that that the current literature does not discuss the requirement specification process in procurement processes.

2.2 Specifying requirements in procurement projects

Projects in most cases are to procure products or services. On a larger scale, such processes are referred to as procurement projects in the literature [33]. Typically, the procurement process involves four critical stages: requirement specification, supplier identification, supplier selection, and contract management [8]. From the four stages of the procurement process, both supplier identification and supplier selection are completely beyond the scope of this paper and there is already a considerable amount of literature dealing with these two areas that can be referred to in the case of further interest [34]. The remaining two stages, requirement specification and contract management, are closely related to this study, and they have key roles in receiving satisfactory products.

In the procurement process, it may happen that the product that the buyer receives is unsatisfactory and differs from what they expected [35]. An example could be the procurement process of Collins Class Submarines. Early in the 1980s, a contract was signed for AUD 3.9 bn between the Commonwealth and Australian Submarines Corporation (ASC) to procure six customised submarines, namely the Collins-Class submarines. This was the most expensive Australian Department of Defence project at the time. The program received criticism from its initial contract until several years after the delivery of the products. There were many drawbacks with the Collins submarines such as issues relevant to the propeller, fuel system, noise, diesel engine, periscope, combat system, and

[1] https://www.cqse.eu/en/

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communications, where the requirements were considerably underattained [36, 37]. A report to the Minister for Defence states that the submarines were demonstrably unable to meet the required performance due to design deficiencies and operational limitations [37]. The ambiguity of requirements definitions was acknowledged by Schank and his colleagues [38]: *"The Collins program had poorly defined specifications. ASC had no motivation to provide more than what it interpreted as its obligations*....". Finally, in 2003, the six submarines which cost about AUD 5 bn were delivered (more than a billion dollars over the budget with more than two years delay) (ANAO report, 1997[2]). They will be in service until 2020s and will be replaced with 12 Shortfin Barracuda Submarines a contract signed with the French. It might seem too soon to claim, but we believe that not all the lessons learnt from Collins Class Submarines were utilised in negotiations between the Naval Group of France and the Australian government (see [39]). There may be ambiguously defined requirements in the project (the attempt to obtain access to data was denied at this stage due to the sensitivity of the case). This contract valued at AUD 50 bn over the next three decades and is one of the largest naval contracts in the world.

Another example, of a smaller scale, is the ship as warehouses in military logistics information system, referred to as the SWIM Project. This was a software project in Australian Defence Force initiated in 2012 in order to address the concerns of the Australian National Audit Office[3] (ANAO) regarding the visibility of data between Army and Navy logistics systems. It also aimed to improve Navy's inventory management processes and governance. The project that was supposed to deliver business transformation, organisational change, and logistics information system enhancement to Navy's information systems was not able to make a noticeable progress beyond the requirement specification phase[4]. There are many examples of ambiguity in defining its critical requirements such as:

"Procedural guidance shall be updated to reflect new/amended business processes."

While it is wrong to claim that all errors in the delivered products are related to the ambiguity of requirements, we believe that one of the key reasons for receiving such unsatisfactory products is due to the buyer's inability to clarify, specifically and explicitly, what they want [40, 41]. The consequences of unspecified requirements become even more critical when a product is delivered after several years, such as the above mentioned cases (the Collins Class Submarines project took about two decades to be delivered and the SWIM project took several years and was never delivered). This is because in such projects the cost of resolving errors and discordances would be considerably high [42]. To reduce the

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[2] https://www.anao.gov.au/sites/g/files/net616/f/anao_report_1997-98_34.pdf
[3] https://www.anao.gov.au/
[4] Miko, Michael "Analysing the Ships as Warehouses (SWIM) in MILIS", Project Assignment for UNSW@ADFA, June 2014

likelihood of receiving unsatisfactory products, it is crucial that the buyer make sure that the requirements are well specified at initial phases of a project [2].

The ambiguity of requirements can cause misinterpretation, which may cause the delivery of an imperfect product. This misinterpretation can either be intentional or unintentional, the first one fairly simple, the other subtler. The unintentional misinterpretation of requirements is quite straightforward. The provider misunderstands the requirements and unintentionally considers or disregards some redundant or essential capabilities, respectively, and delivers an item that sometimes has some useless capabilities (wasted resources) or is unable to meet the purchaser's expectation. By contrast, the intentional misinterpretation happens when the provider purposely misinterprets the requirements in order to deliver 'easy to accomplish' jobs. This creates a game-like situation, which has been investigated in a recent study by Asadabadi and Keiran [43].

In the contract management phase of the procurement process, key performance indicators (KPIs) [44] are utilised. KPIs are developed to measure the performance of providers and facilitate provider evaluations and relevant decisions in procurement processes/projects. KPIs are indicators to measure different dimensions of the performance, e.g., quality, cost efficiency, safety, etc. [45]. They can be used to define the targets and validate the actual performance [46]. The requirement specification process is prerequisite for accurate determination of KPIs and contributes to facilitating such measurements and validations. In some cases, it would almost be impossible to set effective and accurate KPIs when requirements are not clearly defined [47, 48]. With ambiguous and fuzzy requirements, setting KPIs can even be harmful as this would leave room for providers finding shortcuts to increase the indicators, e.g., cream skimming [49].

In summary, without the first stage of the procurement process, namely requirement specification, being properly done, other stages of the process, especially contract management, may become quite problematical. This study works on strengthening the link between the first and last stages of the procurement process. To do so, a clear set of requirements with a high level of specification is defined. Then, the performance of the provider is measured based on how successful they are at meeting the precisely defined requirements. The algorithm to do so is explained in the next section.

3. Methodology

The specification process is performed through the utilisation of fuzzy graphs. Fuzzy graphs are a replacement of specification using crisp numbers which makes the defined specification more realistic. Here, one may argue "why not use crisp numbers instead of fuzzy sets?" To answer this, assume that a person wants to ask somebody to find a house for them and sets out some required dimensions for different partitions of the house. While the sizes and dimensions can be specified using crisp numbers, this would really be limiting to the provider, and moreover, it would not reveal the real preference of the buyer. It does not seem to be reasonable that the buyer claims to be fully satisfied with specific dimensions of a room and completely unsatisfied with any other sizes. In reality, the satisfaction level is a fuzzy concept and can be defined to be within an interval, for example [0, 1], where *zero* stands for complete dissatisfaction, *one* for complete satisfaction, and the values between for different levels of satisfaction. In this section, the method is explained which includes the processes of identifying HFTs, specifying them, and utilising of the specified HFTs in measuring the performance of the provider.

3.1 Identification of HFTs

The concept of 'hidden fuzzy terms' or HFTs, is referred to the information that is implied and includes fuzzy words. There are occasions that a person (the purchaser, here) assumes that the other person (the provider, in this study) knows what he means, and therefore, skips explaining specifically, or does not state explicitly some information. The skipped information, however, may sometimes include fuzzy words and the purchaser's assumption may turn out to be incorrect. This information can be identified and specified in order to avoid misinterpretations and confusion in the procurement process. Here, an example is provided to show how HFTs are identified. The following text does not include a fuzzy word.

> Buildings may have up to three bedrooms. Each bedroom needs to have a wardrobe. All bedrooms should fit at least a single bed and a table.

However, this text has the following hidden information, which is exposed by the HFTs, which have been added in parenthesis.

> Buildings may have up to three bedrooms. Each bedroom needs to have a (an appropriate (size)) wardrobe. All bedrooms should (be large enough to) fit at least a single bed and a table.

HFTs: large bedrooms, an appropriate (size) wardrobe

For each component of the product, such as bedroom and wardrobe in the above example, the following algorithm needs to be followed in order to identify HFTs.

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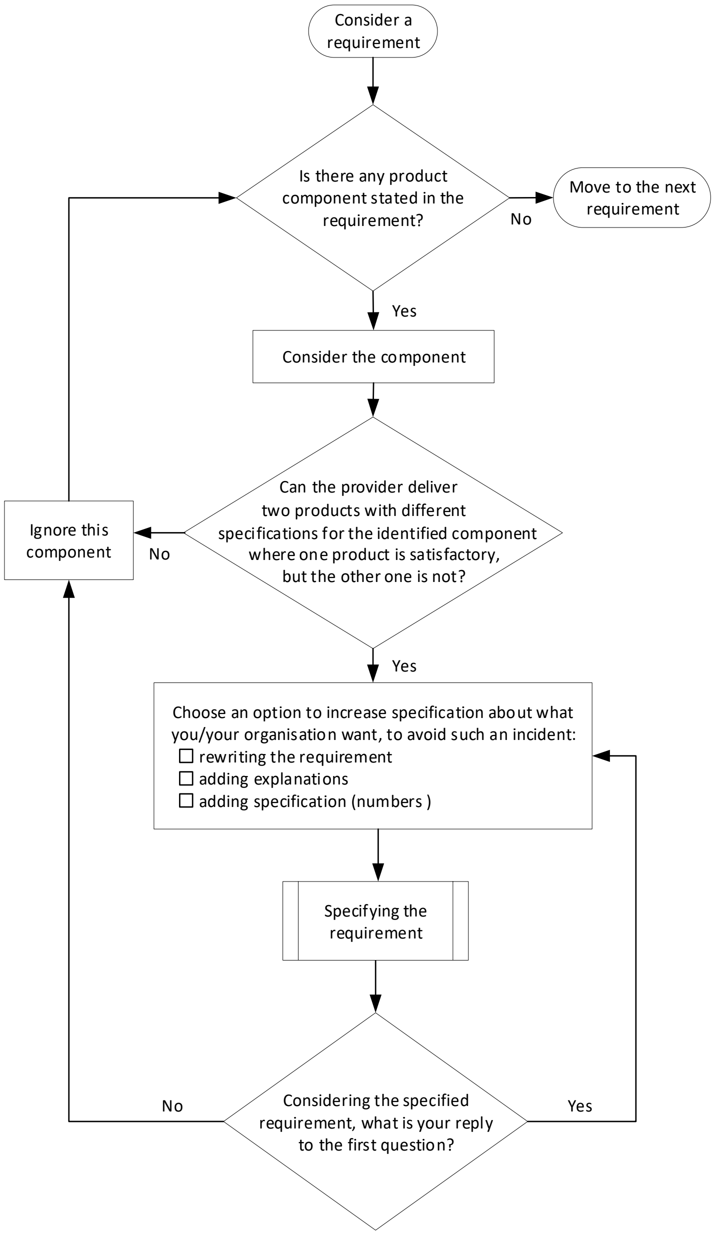

Figure 1. Identification algorithm for hidden fuzzy information

Through this algorithm, fuzzy requirements are highlighted, and HFTs are identified and then specified. In the next phase, the specification process is explained.

3.2 Specifying the identified HFTs

In this section, the identified fuzzy terms are clarified. First step is to ask: “does the identified term have elements/aspects/dimensions/subcomponents/etc. to be specified’. If yes, then the term should be broken down to such mentioned elements to enable a more accurate specification of the fuzzy term.

For example in the case of the bedroom, the term ‘large’ is a fuzzy word and for the specification purpose, it can be considered as a combination of two dimensions length and width. Then a question is that ‘what length/width in a bedroom can be considered large enough’. Here, straight line fuzzy graphs are used (triangle and trapezius) to visualise fuzzy terms and present the dimensions in graphs. In doing so, the fuzzy bounds (a,b,c,d) need to be determined for each fuzzy dimension. The domain expert is asked two simple questions to obtain the bounds. The first question is presented below.

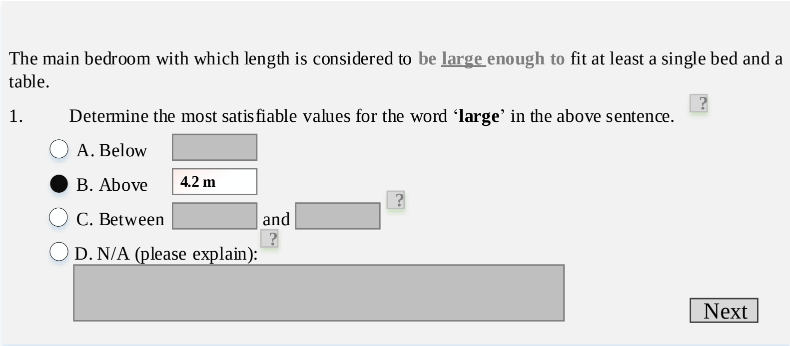

Figure 2. The first question of the specification process

Note that option C can have the same number in its two blank spaces (triangle fuzzy graph), and option D usually is answered with the suggestion of adding some verbal explanations to the requirement.

After this, the second question is asked in which only one option, based on the expert’s answer to the first question, is active to fill, as presented below.

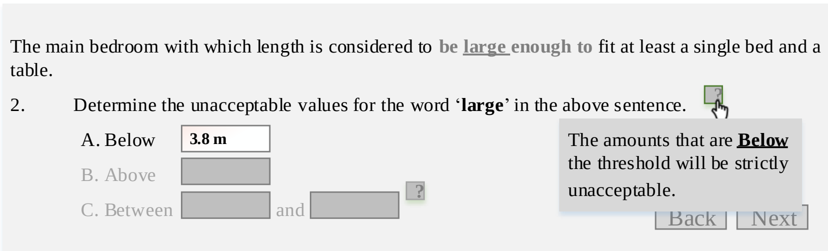

Figure 3. The second question of the specification process

If the expert’s answer to the first question is A, for the second one options B and C become inactive and the amount for option A should be determined. Similarly, if the expert, answering the first question, selects B (or C), the next question should activate only B (or C).

The above two questions are enough to draw the fuzzy graph and find the membership functions. The sequence of these two questions creates four possible states which are presented in Figure 4.

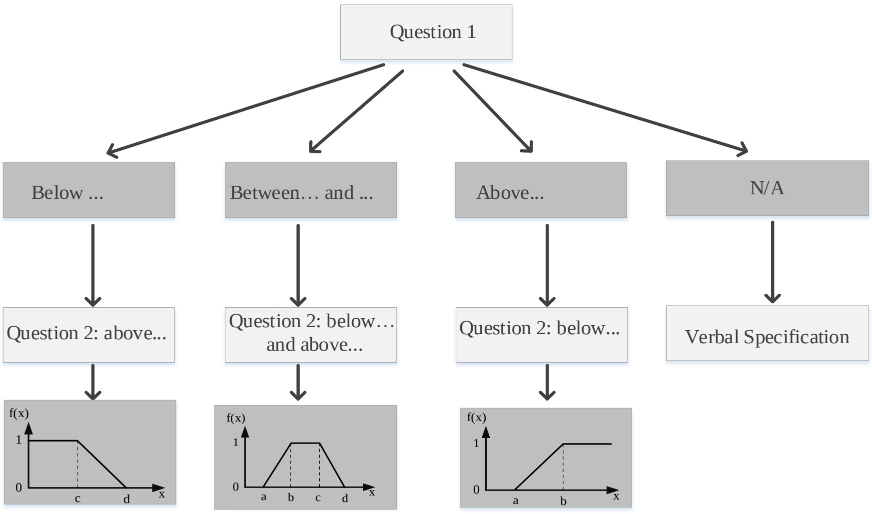

Figure 4. Possible graph types

Note that if the expert selects option C and fills both blanks with the same number, the trapezius graph changes to a triangle. In the next section, the merit of specified HFTs and how such information can be utilised are explained.

3.3 The utilisation of the specified HFTs

The specified HFTs enable the buyer to measure the performance of the provider. Assume that a provider delivers a product. If it is completely satisfactory or unsatisfactory with regard to all of its components, the performance of the provider receives *one* (perfect) or *zero* (not acceptable). However, it is often the case that the purchaser provides a product which is not either completely satisfactory or unsatisfactory with regard to its different components.

As mentioned previously, some components are a combination of a number of elements/aspects/dimensions/subcomponents/etc. In the previous section, fuzzy graphs were used to specify such mentioned elements, for example dimensions of a component. These dimensions can be combined in order to represent the satisfaction level of the buyer with regard to each delivered component. For example, the satisfaction level for length of the bedroom is *zero* for any length below 3800 cm, *one* for any length above 4200 cm and a number between *zero* and *one* for any value between 3800 and 4200 cm. The satisfaction level is similar with regard to the width of the bedroom. Now, a building (or a number of buildings) has (have) been delivered. How can the general satisfaction level of the buyer be measured?

To do such measurement, first linguistic variables are added to the dimensions. For example, the length below 3800 cm is referred to as small, above 4200 as large and between these two as medium. A similar approach is used for the width (questions similar to those designed in the previous section can be asked to obtain the bounds). Now, fuzzy rules can be employed to combine the dimensions. Such rules state that for example, if the width is small and the length is medium, the satisfaction level is low. Using such rule and Mamdani's FIS [50] the satisfaction level of the components for different values of the dimensions is computable.

Then, the question is: 'assuming that the satisfaction levels of all components have been measured, how can the overall satisfaction level of the main product be determined?' This can be taken into consideration as a multi criteria decision making problem, where the quality of the delivered components are the criteria. The delivered product receives scores with respect to each component and the scores are considered as inputs to an MCDM method in order to compute the overall satisfaction level. In doing so, components can be weighted using MCDM methods, such as analytical hierarchy process (AHP) [51], analytic network process (ANP) [52, 53], elimination and choice expressing reality (ELECTRE) [54], preference ranking organization method for enrichment of evaluations (PROMETHEE) [55], BWM [56], technique for order of preference by similarity to ideal solution (TOPSIS), multi criteria optimization and compromise solution (VIKOR) [11], and decision making trial and evaluation laboratory (DEMATEL) [57]. Here, BWM which is a relatively new MCDM approach is applied to compute the weightings of importance of the components (consider components as the criteria of an MCDM problem). Then based on the scores that the deliverable receives with respect to the components (using FIS in MATLAB), the overall level of satisfaction is computed.

BWM can compute the weightings of importance for alternatives with respect to different criteria (with various weightings of importance) relying on pairwise comparisons. In comparison with methods such as AHP and ANP, this method reduces the number of pairwise comparisons between the alternatives, and therefore has lower inconsistency. Note that zero inconsistency refers to a situation where the comparisons are perfect and there are no conflicting judgements. This is to say that the pairwise comparison matrix A=$(a_{ij})_{n\times n}$ is considered to be perfectly consistent, if and only if for each i and j, $a_{ik} \times a_{kj} = a_{ij}$. However, for various reasons, such as the loss of concentration, limitation of the ranking scale, and the number of comparisons that the decision maker has to make, there are recurring inconsistencies in pairwise comparison matrices [56, 58, 59]. In particular, where the order of a matrix increases to more than three, the inconsistency is very likely to happen. This is due to human's memory limitation in making consistent judgments when the number of the elements being compared increases [60].

According to BWM, first, the best and the worst criteria are identified by decision makers. Then, with respect to each criterion, best and worst alternatives are selected. After that, the other alternatives are compared with these two options separately with respect to the criterion. The final scores of the alternatives are derived by collecting these weightings. To check the reliability of the comparisons, a consistency ratio has been developed by Rezaei [56]. The consistency ratio presents the level of the reliability of the results. The final weights derived from BWM are relatively more reliable than other

MCDM method such as AHP [56] as it involves fewer pairwise comparisons that may sometimes be confusing. Employing BWM, components are compared, ranked, and their weightings of importance are computed. The steps are set out below.

1. Determine the best (highest priority) and the worst (lowest priority) components among the total of *n* existing components. For example, the *dining room* may be the best and the *wardrobe of the bedroom* may be the worst component.
2. Determine the preference of the best component over all other components using a 1 to 9 scale, where 1 is the best preference and 9 is the least preference. This results a vector $A_B = (a_{B1}, a_{B2}..., a_{Bn})$ where the preference of the *best component, B,* over component j is shown by a_{Bj}. For this example, the preference of the *dining room* over all the components is represented in A_B.
3. Determine the preference of all the component over the *worst component* using the same scale. This results a vector, $A_W = (a_{1W}, a_{2W}..., a_{nW})^T$, where the preference of the component j over the worst component, *W*, is shown by a_{jW}. For this example, the preferences of all the components over *wardrobe of the bedroom* are represented in A_w.
4. Compute the optimal weightings ($w_1, w_2, \ldots, w_n$). The perfect comparisons, which result in the perfect weightings for the components, happen where for each pair of w_B/w_j and w_j/w_W, the following equations are true: $w_B/w_j = a_{Bj}$ and $w_j/w_W = a_{jW}$. However, a perfect comparison is unlikely when the number of components goes beyond 4 or 5. The weightings of the components can be computed where the maximum absolute differences: $\left|\frac{w_B}{w_j} - a_{Bj}\right|$ and $\left|\frac{w_j}{w_w} - a_{jw}\right|$ for all *j*, are minimized.

$$\left.\begin{array}{c} \left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi, for\ all\ j \\ \left|\frac{w_j}{w_w} - a_{jw}\right| \leq \xi, for\ all\ j \\ \sum_j w_j = 1 \\ W_j \geq 0, \text{for all } j \end{array}\right\} \quad (1)$$

The letter ξ denotes the inconsistency of comparisons. If it is above the maximum values of ξ represented in Table 1, the comparisons are inconsistent and should be repeated to improve.

Table 1. Consistency Index (CI) [56]

a_{BW}	1	2	3	4	5	6	7	8	9
maxξ	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

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Following the steps of BWM, the weightings of the components are computed through following the following Algorithm.

1. **BWM Algorithm**
2. BWM (components)
3. CI = Consistency Index table;
4. Select the best component
5. Select the worst component
6. j = 1;
7. set $a_{BW} = x$ where $x \in [1,9]$
8. **while (**j ≤ count(components)
9. do
10. set $a_{Bj} = x$ where $x \in [1,9]$;
11. set $a_{jW} = x$ where $x \in [1,9]$;
12. while($a_{BW} = a_{Bj}$ and $a_{BW} = a_{jW}$);
13. A_B.add(a_{Bj});
14. A_W.add(a_{jW});
15. end while
16. **for** all j in Q
17. Form equation of the form $|w_B - w_j * a_{Bj}| = \xi$ where $a_{Bj} \in A_B$;
18. Form equation of the form $|w_j - w_W * a_{jW}| = \xi$ where $a_{jW} \in A_W$;
19. end for
20. Form equation $\sum_j w_j = 1$;
21. Compute w_j by solving system of linear equations;
22. return w of the components;

Considering the above algorithm a_{BW} is set and represents the outperformance of the best over worst components with the highest possible value of 9 (line 4). A while loop in the algorithm is used to perform the comparisons (line 5-12). In the case of inconsistency, the loop requires re-adjusting of the comparisons. The comparisons are utilised to structure equations, such as Eq. (1): the weightings as the variables and the comparisons as the co-efficient (line 13-17). The equation can be solved using Gaussian Elimination (Gauss-Jordan Elimination) and the weightings are computed (line 18).
After the computation of the weightings of the components, the scores coming from FIS are multiplied by the relevant weightings and the sum represents the overall satisfaction level of the buyer. In the next section, the method is explained using data from “Defence Housing Australia (DHA)”.

4. Case study

The information used in this case study is available online on the DHA’s website[5]. The document provides guidelines and requirements for the construction of dwellings in low and medium density development.

4.1 Identification of fuzzy terms

The requirements are categorised in four groups and presented below.

- **Bedrooms**

[5] https://www.dha.gov.au/

Buildings may have up to three bedrooms. Each bedroom needs to have a wardrobe. All bedrooms should fit at least a single bed and a table.

- **Kitchen and Living**

  Kitchen needs to have designated space for a refrigerator clear of all obstructions, e.g., skirting. Dining must fit a table with seating space for at least 6 people. Lounge should comfortably accommodate 6 people.

- **Car Park and Storage**

  Each building needs to have a carpark plus a storage space, if achievable. The storage could alternatively be sourced internally under the main roof. If neither can be achieved, then a shed can be installed in the yard next to the carpark.

- **Outdoors**

  Covered outdoor area must fit table and chairs for 4 to 6 people plus a space for BBQ. Storage needs to be shed or fully secured.

Following the steps presented in Figure 1, the HFTs presented below were identified and added for the purpose of specification.

- **Bedrooms**

  Buildings may have up to three bedrooms. All bedrooms should (be large enough to) fit at least a single bed and a table. Each bedroom needs to have a (~~a~~ an appropriate (size)) wardrobe.

HFTs: large enough; appropriate (size)

More detail: The term 'large enough' needs to be specified both for the main bedroom and other bedrooms. This can be through specifying the preferred length and width of the bedrooms. Note that the word 'large enough' has different meanings for the main bedroom and the other bedrooms as the common perception is that the size of the main bedroom is greater than the others. The bedrooms also need to have appropriate wardrobe, which is not clear.

- **Kitchen and Living**

  Kitchen needs to have designated (large, but not too large) space for a refrigerator clear of all obstructions, e.g., skirting.

  Dining must (be large enough to) fit a table with seating space for at least 6 people. Lounge should (be spacious to) comfortably accommodate 6 people.

HFTs: large enough, but not too large; large; spacious

More detail: The fridge space is expected to be *large enough* to accommodate most types of the fridges available in market. However, a *too large* space is not preferred. The sizes of dining and lounge need to be specified. The graphs are presented in Figure 7.

- **Car Park and Storage**

  Each building needs to have a (roomy) carpark plus a (~~a~~ an ample) storage space, if achievable. The storage could alternatively be sourced internally under the main roof. If neither can be achieved, then a shed can be installed in the yard next to the carpark.

HFTs: roomy; ample

More detail: a carpark needs to have appropriate dimensions to fit different sizes of cars. The storage is also preferred to be large: the larger, the better. The graphs are presented in Figure 7.

- **Outdoors**

  Covered outdoor area must (have enough space to) fit table and chairs for 4 to 6 people plus a (reasonable) space for BBQ.

HFTs: Enough space; reasonable space

More detail: again here, the size of the covered outdoor area is based on two sizes which have no specific dimensions, and therefore can be interpreted differently by different people. The specifying graphs are presented in Figure 7.

In the next section, fuzzy graphs are used to specify the identified HFTs.

4.2 Specification of fuzzy terms

Now that the fuzzy terms are identified, they can to be specified using fuzzy graphs and with regard to how satisfactory different specifications can be to the buyer. The satisfaction level is considered within the interval of [0, 1] where *zero* stands for complete dissatisfaction, *one* for complete satisfaction, and the values in between, for different levels of satisfaction. For example, the buyer can say that for the main bedroom, the length and width over *4200 m* and *3800 m* are completely satisfying, below *3800 m* and *3500 m*, completely unsatisfying, and where it is between these numbers, it is somewhat satisfying. These numbers, fuzzy bounds, can be obtained through asking two straight forward questions, explained previously in the methodology, from the decision maker or domain expert. For the sake of simplicity, assuming that the satisfaction level is linear, the above information about the length and width of the first bedroom information can be visually represented (Figure 5).

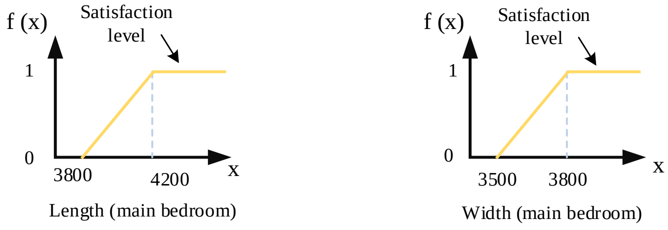

Figure 5. Dimensions of the main bedroom

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The above graphs specify the meaning of ‘being large enough’ for the main bedroom.

Following a similar approach, the buyer preference regarding the hidden information can be visualised. The graphs presented below specify the preferred sizes in order to resolve the fuzziness of the terms ‘large enough’ *for the sizes of other bedrooms* and ‘appropriate’ *for the sizes of wardrobes* (the dimensions of the main bedroom above are presented in Figure 5).

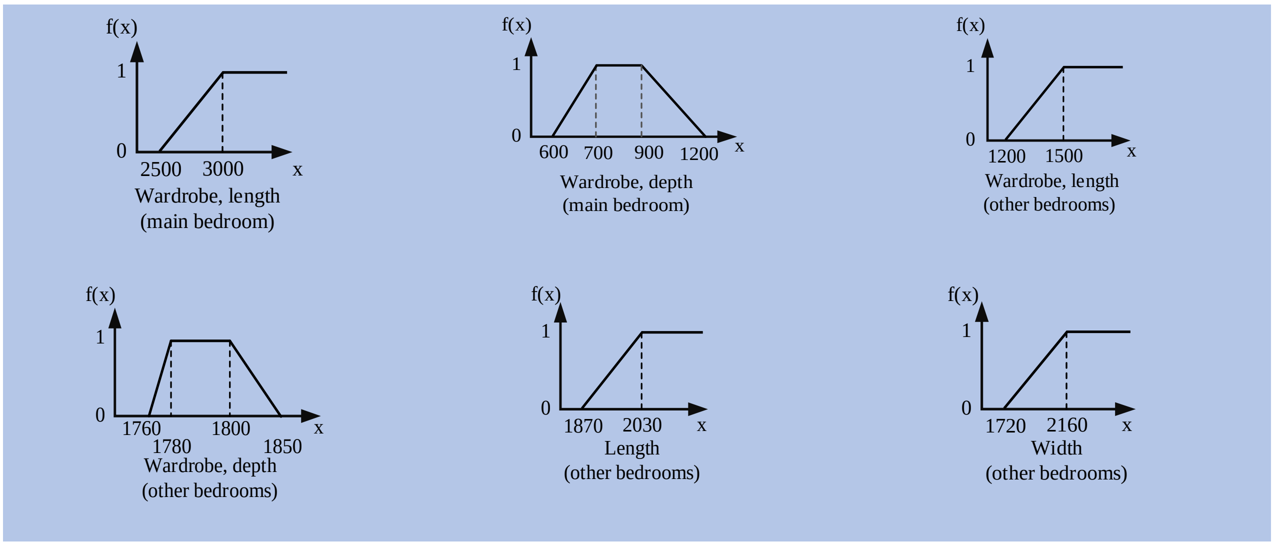
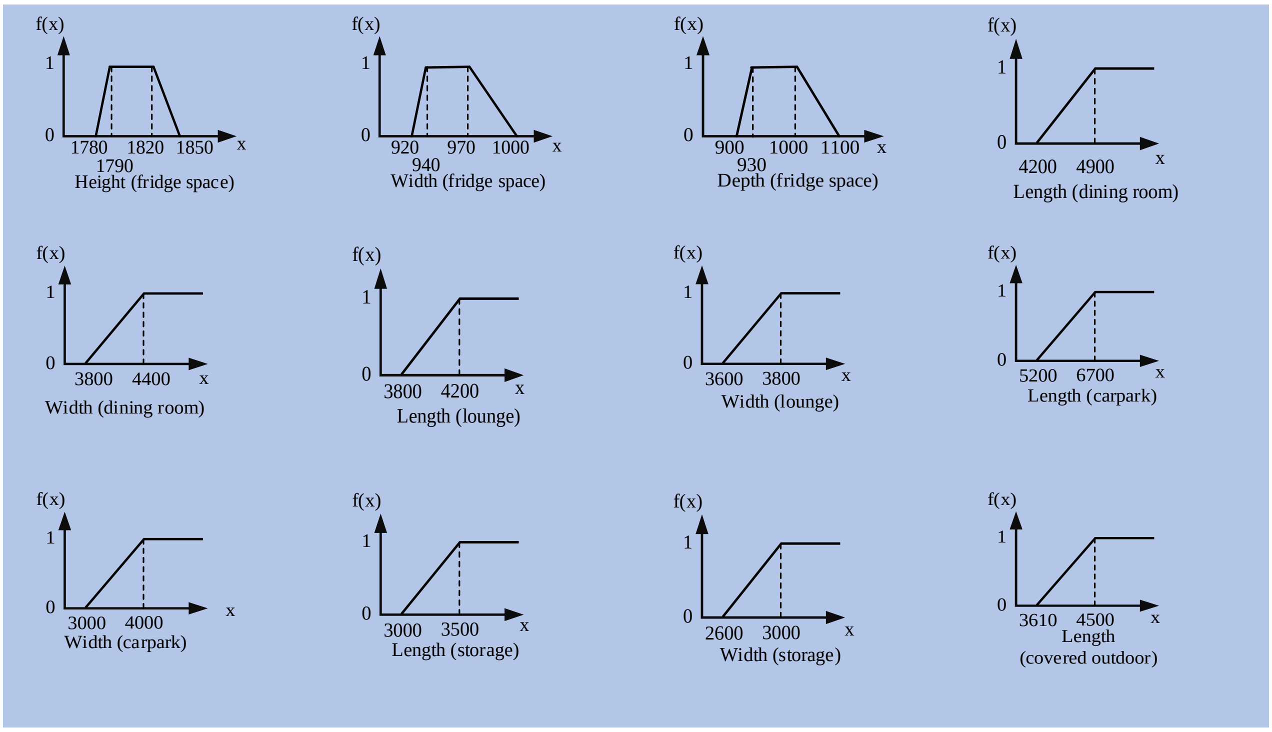


Figure 6. Dimensions of other bedrooms and wardrobes

The hidden information in the rest of the text is specified using the following fuzzy graphs. Note that the bounds need to be confirmed by the project manager/owner.



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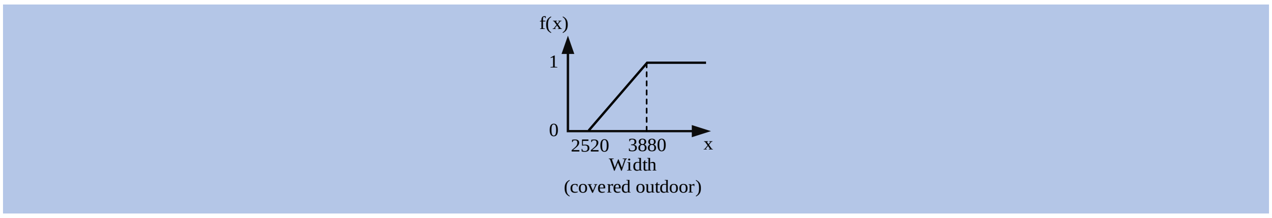

Figure 7. Dimensions of the other components of a typical building

In the next sections, the specified requirement presented in Figure 5, 6, and 7 are used to find the satisfaction level of the buyer with regards to each of the components of the buildings (products).

4.3 Utilisation of specified terms

Consider a two bedroom building. There are nine components associated with the building, namely the main bedroom, main wardrobe, second bedroom, second wardrobe, fridge space, dining room, lounge, carpark, storage, and covered outdoor. Each of the components has different dimensions and can affect the buyer's satisfaction level. For instance, the satisfaction level of the buyer about the quality of the main bedroom's wardrobe depends on two dimensions: length, and depth. Finding the satisfaction level requires examining the combination of the two fuzzy numbers which can be performed using FIS. Therefore, Mamdani's FIS which requires defining linguistic variables [50] is used. Fuzzy linguistic variables are involved as follows (the bounds are determined by the domain experts):

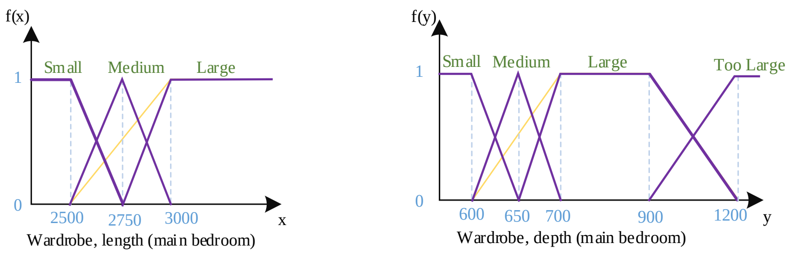

Figure 8. Linguistic variables

To show how the satisfaction level changes, the 12 possible combinations are presented in the figure presented below:

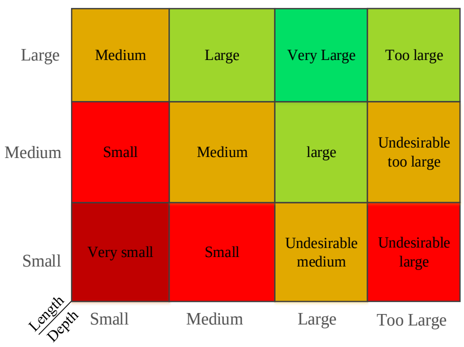

Figure 9. Combined dimensions

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These two variables are combined using fuzzy rules on MATLAB as follows:

1. If (Length is Small) and (Depth is Small) then (Sat,_Wardrobe,_BR1 is Very_low) (1)
2. If (Length is Small) and (Depth is Medium) then (Sat,_Wardrobe,_BR1 is Low) (1)
3. If (Length is Medium) and (Depth is Small) then (Sat,_Wardrobe,_BR1 is Low) (1)
4. If (Length is Small) and (Depth is Too_large) then (Sat,_Wardrobe,_BR1 is Low) (1)
5. If (Length is Large) and (Depth is Small) then (Sat,_Wardrobe,_BR1 is Medium) (1)
6. If (Length is Medium) and (Depth is Medium) then (Sat,_Wardrobe,_BR1 is Medium) (1)
7. If (Length is Small) and (Depth is Large) then (Sat,_Wardrobe,_BR1 is Medium) (1)
8. If (Length is Medium) and (Depth is Too_large) then (Sat,_Wardrobe,_BR1 is Medium) (1)
9. If (Length is Large) and (Depth is Medium) then (Sat,_Wardrobe,_BR1 is High) (1)
10. If (Length is Medium) and (Depth is Large) then (Sat,_Wardrobe,_BR1 is High) (1)
11. If (Length is Large) and (Depth is Too_large) then (Sat,_Wardrobe,_BR1 is High) (1)
12. If (Length is Large) and (Depth is Large) then (Sat,_Wardrobe,_BR1 is Very_high) (1)

Figure 10. The satisfaction rules

Using the rules, the satisfaction graph is as below:

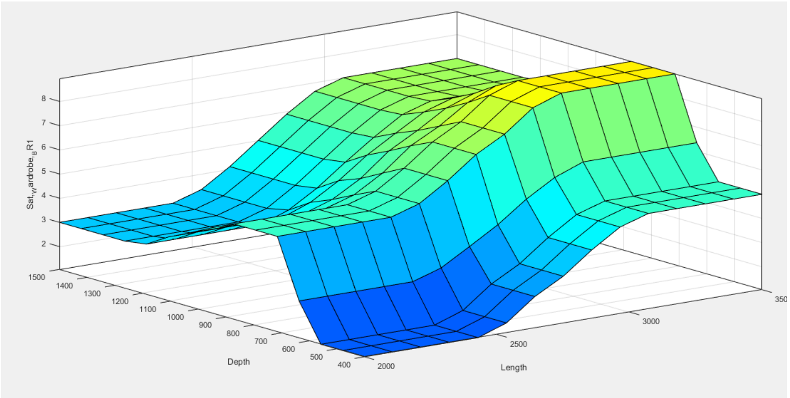

Figure 11. The satisfaction graph

While admitting that this part of the methodology may take time to apply (e.g., for fridge the number of fuzzy rules increase to 64), in return the requirements become quite clear and can be well utilised in measuring the performance of the provider.

For example, assume that the provider finishes a two bedroom building with the dimensions presented in the second column of Table 3. In order to measure the performance, the weightings of importance of the components from the buyer's perspective should be involved (note that this part can be performed in the beginning of a project by the buyer and shared with the provider).

As explained in the methodology, BWM is applied to compute the weightings of the components and the results are presented in Table 2. Note that the following abbreviations are used in the tables. The dining room (DR), lounge (LG), first bedroom (FB), carpark (CP), second bedroom (SB), fridge space (FS), storage (ST), wardrobe of the first bedroom (WFB), wardrobe of the second bedroom (WSB). covered outdoor space (CS).

Table 2. The weightings of the components using BWM

	DR	**LG**	**FB**	**CP**	**SB**	**FS**	**ST**	**WFB**	**WSB**	**CS**
Best (DR)	1	1.2	1.5	2	2.6	7.6	7.7	7.9	8.9	9
Worst (Cs)	9	8.3	6.7	5.1	3.9	1.6	1.3	1.3	1.1	1
Optimal Weightings	0.246	0.202	0.162	0.126	0.094	0.039	0.032	0.031	0.026	0.024

CI (ξ) = 0.093 CR = 0.018

Having weightings of importance of the components (last row of Table 2), if the satisfaction levels of the buyer with respect to the components are found, the overall satisfaction level is easy to compute.

Inserting the information in the second column of Table 3 into MATLAB, the satisfaction levels are found as presented in the third column of the same table.

Table 3. The specifications of a delivered building

Component	Dimensions	Satisfaction level	Optimal weightings	Weighted satisfaction
DR	height 1800, width 938, depth 950	8.47	0.246	2.084
LG	length 5000, width 3700	7	0.202	1.414
FB	length 4200, width 3770	8.39	0.162	1.359
CP	length 5000, width 3800	8.94	0.126	1.126
SB	length 3350, width 2850	7.59	0.094	0.713
FS	depth 1750, length 1550	8.37	0.039	0.326
ST	length 7000, width 4000	5	0.032	0.257
WFB	depth 1750, length 1550	8.370	0.031	0.277
WSB	depth 750, length 3000	8.94	0.026	0.220
CS	length 3000, width 3400	8.04	0.024	0.120

The sum of the weighted satisfaction, namely overall satisfaction is equal to 7.898. This means that from the scores ranged from 1.06 to 8.94, the building has been 77% satisfactory. Note that another application of fuzzy variables might be preferred by the decision maker in which scores from zero to ten can belong to different intervals such as not satisfactory, somewhat satisfactory, satisfactory, fully satisfactory. However, specific numbers in this paper were used in order to explain more accurately how the evaluation results can be used to determine the amount of payment. The use of the results is discussed in the next section.

5. Discussion

The requirement specification process increases the clarity of buyers' expectations and therefore can hinder misinterpretation of requirements. This process, if performed properly, positively influences the final output of a project and increases the quality of deliverables. In particular, it facilitates the contract management phase of the procurement process by increasing transparency in the process of evaluating the performance of the provider and the related payments and decisions. There are many examples of government projects in which the specifications of the delivered items were somehow different from the government's required specifications. Clarity in measuring the performance of the provider on the basis of well specified requirements and then structuring a transparent payment system with consideration of the entitlements for bonuses and penalties may considerably benefit a large project. There are many cases when a provider has some inability to meet the specified requirements. However, because the payment system is not structured on the basis of clearly defined requirements, the provider intentionally postpones the declaration of the issues, hides the limitations, and finally provides the deliverable with some excuses to justify the shortcomings. This creates a game like situation, tackled recenlty by Asadabadi and Keiran [43]. If the provider knows that there is a predetermined model that will be used to determine the payment, instead of hiding the issues, sharing them with the buyer in order to find reasonable solutions would be the more reasonable option.

In the case illustrated in the previous section, the hidden fuzzy terms of each requirement were identified, broken down to the components, and used to structure the measure of the satisfaction level of the required components of the deliverables. The satisfaction levels were then combined to compute the buyer's overall satisfaction level with regard to a delivered product. Satisfaction levels can be considered with thresholds for different amounts of payment. For example, the medium satisfaction level of *five* can be considered as the point where the provider is entitled to the pre-agreed amount of the payment (note that it does not have to be always *five*). A performance resulting satisfaction levels above this can be considered for receiving a part of the maximum considered/allowed bonus (for example the performance of the provider in the illustrated case can be rewarded with 54 percent of the maximum bonus), and satisfaction levels below *five* can be compensated with penalties or lower payments. Through this process, the specified requirements can contribute to structuring a transparent payment system in a large/government project and this is expected to reduce conflicts about the performance of the provider and relevant decisions, such as the amount of the payments [61]. Such clarity in measuring the performance and payments reduces the likelihood of intentional misinterpretation of requirements by providers; usually for the sake of doing easier tasks, or possible future earnings in the product improvement and issues resolution processes. Note that specified requirements using HFTs facilitate measuring processes in a project's performance measurement [62], but to comprehensively design a measurement system (which can be used to determine the payment), other aspects of the quality and output, usually measured using KPIs, should be taken into consideration [63, 64]. KPIs are typically used to measure how well some requirements have been met [65]. Aligned with that, HFTs algorithm, proposed in Figure 1, could be helpful to specify requirements that can then be used, quite explicitly, to formulate KPIs. In that case, the consideration of satisfaction level of KPIs with regard to the specified requirements can also be taken into account as other inputs to BWM in order to provide a more comprehensive and accurate evaluation of the performance of the provider.

The immediate benefit of this approach is that the buyer has to start thinking and identifying the specification of what they really '*need'*, rather than what they believe that they '*want'* which is a common problem, especially in government projects [66, 67]. An example can be the real situation that was confronted and resolved in the case discussed in the previous section. Some requirements were stated in a way that could be the sum of two fuzzy numbers, for example: *"Covered outdoor area must (have enough space to) fit table and chairs for 4 to 6 people plus a (reasonable) space for BBQ)."*

In this example, the size of the covered area depends on 'the size of a table and 4 to 6 chairs' and 'the size of the BBQ' which both have fuzzy dimensions. The minimum and maximum dimensions for such mentioned table and an ordinary BBQ were considered as presented in Figure 12.

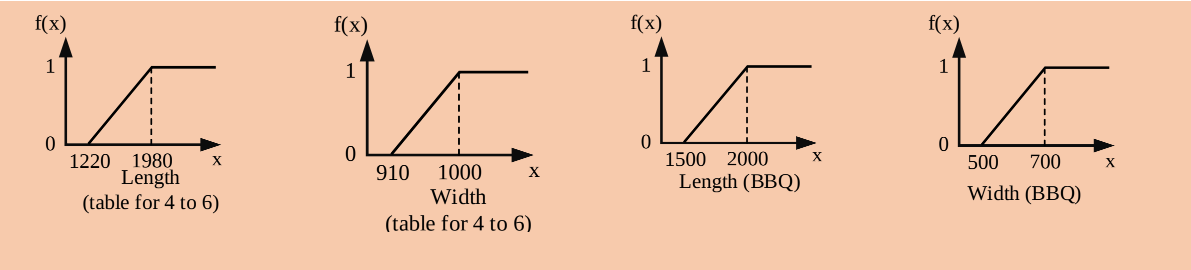

Figure 12. The fuzzy graphs for the dimensions of a table and BBQ

Adding these numbers (width + length), the fuzzy bounds for the covered area were as presented in the first two graphs in Figure 13. Thinking about the computed bounds, they were not reasonable and seemed to be too small for a covered outdoor area. But, why? Was the area not based on the specified sizes of the table and BBQ?

The answer is that 'it was small' because no buffer space was considered neither between the table and BBQ nor between them and the uncovered areas. DHA *want*s the outdoor area to fit a table and BBQ, but this needs to be specified through clarifying what dimensions they *need* in order to accommodate a table and BBQ. Therefore, some extra hidden information was identified: 'the buffer space'. Some buffers to the length and width of the first two graphs (presented in the second two graphs of Figure 13) were added.

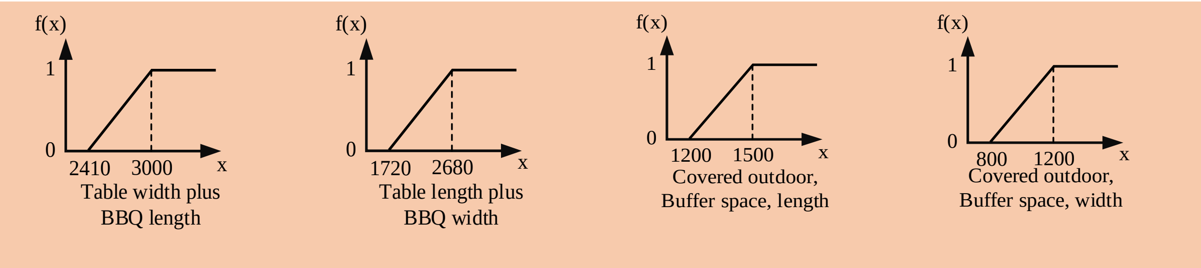

Figure 13. Adding the dimensions of the table and BBQ

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Adding the buffers, the length and width of uncovered areas were computed and were presented in Figure 7. This modification in specifications is an example of the inherent positive effect of the specification process on buyers themselves to obtain a better understanding of what they need. This will also help the provider to clearly understand the requirements of what they need, does not make any unintentional misinterpretations of the requirements, and makes the product more accurate.

A concern with the proposed method might be that it may take time to perform such a specification process. For example, in the explained case the number of fuzzy rules increase to 64 when the word 'large' is being specified. This can be seen as a time-consuming process. While the time-consuming criticism to the proposed method is admitted, the benefits of applying such an approach can be significant. In addition to the immediate benefits of this approach (explained above), the time and resources that are consumed in this phase may save considerable effort and further resources because it may prevent future conflicts, decision difficulties, and ambiguity which can create barriers to the progress of a project. Furthermore, the amount of consumed time and resources is expected to be insignificant when compared to other expenditures in a large project.

The requirement specification process is a phase of the procurement process and, if performed properly, facilitates managing the process. The fuzziness of requirements can be reduced by adding verbal explanations, but the suggestion of this paper is to use soft computing techniques, such as fuzzy sets, where applicable. This is for two reasons. First, the added verbal explanations may again include fuzzy terms and need further specification. Second, the fuzzy sets/graphs include a level of precision that cannot be usually achieved using verbal explanations. Studies dealing with the fuzziness of requirements are quite limited, and furthermore, mostly have been undertaken in the area of software engineering [4-7]. Prior to this study, the concept of hidden fuzzy terms and the importance of identifying and specifying them have not been studied. In addition, a methodological approach utilising the specified fuzzy requirements to measure the performance of the provider has not been proposed. This study contributes to the current literature by discussing the concept of HFTs and the importance of extracting and resolving requirement fuzziness in large projects. This study has illustrated how requirements should be well specified, then utilised to measure the performance of the provider, and finally contribute to facilitating projects' decisions. Future studies are encouraged to employ tools and techniques to improve the identification, specification and utilisation of HFTs. In particular, the problem of confliction between the requirements was not covered in this paper. In practical cases it may happen that the provider confronts conflicting criteria, due to the limitation of resources such as time, budget, human labour among others. There is a previous study on conflicting imprecise requirements in software engineering [68] that may be referred to in order to make the proposed model of this paper more advanced.

6. Conclusion

Setting clear requirements contributes to creating a transparent basis for future decisions and also facilitates management of the procurement process/project. The immediate benefit of such a process is to help the buyer realise and state 'what they *need'* rather than state 'what they *want'*. This process also helps the provider to clearly understand what they are required to do and reduces the likelihood of occurrence of unintentional misinterpretation of the requirements. Moreover, this process increases clarity in measuring the performance of the provider which can be used in determining the payments. Therefore, the likelihood of a provider's intentional misinterpretations of requirements has been decreased (explained in Section 5). This study, unlike the previous studies that deal with the requirement specification process in software engineering, has discussed the process in procurement projects. The concept of HFTs and the importance of identifying and specifying them were explained and a methodological approach utilising the specified fuzzy requirements to measure the performance of the provider was proposed. For such a utilisation, an MCDM method, namely BWM, was employed. Establishing such a specification process in projects, especially in government projects, increases the transparency of the processes and decisions while reducing the chance of conflict and misinterpretation of requirements. Therefore, the likelihood of receiving unsatisfactory products would considerably decrease.

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