Apply a Fuzzy Method to Perform Objective Allocation for Buildings Cost in Value Engineering Job Plan Process

Qi Liang, Mei-yung Leung, and Zhiyuan Zhou

Abstract Because of its benefits, value engineering (VE) has been applied in the public sector of construction industry through systematic VE job plan workshop. However, unsatisfactory VE workshop have often been reported used to the deficient in the traditional VE job plan, which has hampered the VE application for private projects. The function analysis phase plays a key role in delivering VE workshop outcomes, while how to efficiently and objectively allocate building cost to each function has long been a problem. Current study applied a fuzzy-based method to improve the traditional function cost allocation in terms of objectivity and efficiency. Triangular fuzzy numbers (TFNs), as one of fuzzy methods, is applied to transfer the VE participants' linguistic and vague evaluation of the function performance of the building elements into numerical values. A real case study was carried out to examine the proposed method. In the case study, a group of VE participants was able to establish a Function Analysis System Techniques (FAST) diagram for the case building, and give their linguistic evaluation in different degree about the function performance of specific building elements. The linguistic evaluation was then transferred to numerical value by TFNs algorithms in order to understand the function performance of building elements, which laid the ground for allocating cost of building elements to functions. The findings indicated that the function cost allocation through the TFNs are generally reasonable and reliable, which could be applied to benefit other VE projects. Current study was able to contribute to improve current VE practices by offering the way to objectively and efficiently allocate function cost.

Keywords Function cost allocation · Job plan · Triangular fuzzy numbers · Value engineering

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1 Introduction

Value Management (VE) was proposed by Lawrence Miles in 1947 who recognized that proper analysis of a product's function often led to improvement of value for products [1]. VE has been applied in the construction industry since 1980s, and it has been bringing various benefits to the construction industry in terms of saving cost, ensuring quality, controlling time, alleviating environmental impact, etc. [2, 3]. Because of its significant benefits, application of VE has been compulsory for public construction projects with certain project sum in various countries and districts (e.g., public project sum higher than 200 million in Hong Kong (HK); and public project sum exceeding RM 50 million in Malaysia) [4–6]. However, despite the strong governmental endorsement and wide application for public projects, VE is still rarely applied for construction projects in private sectors over the world. For instance, the JCP company is the major VE service provider in HK, and almost all its VE projects are public projects [7]. There may be multiple reasons contributing to the unpopularity of VE in private sectors, while the unsatisfactory VE workshop should be the key issue [8].

In fact, VE is mainly applied to construction projects through the systematic VE job plan workshop during which key project personnel work together to apply VE approach to resolve practical problems [9]. The VE job plan consists of several phases, including information phase, function analysis phase, creativity phase, evaluation phase, development phase and presentation phases [10]. Among them, the function analysis phase is the key part and makes VE approach different from other problem-solving and cost-reduction techniques [1]. In the function analysis phases for construction projects, the VE participants are often requested to analyze the functions of a building, civil or infrastructure project, identify the important functions, apply Function Analysis System Techniques (FAST) to diagram the functions in a how-why logical relationships, allocate the building cost to various functions, and finally identify the function mismatch between the function performance and function cost [11]. Most of tasks in the function analysis phases should be well performed by participants based on their logic mindset and rich practical experience. However, the function cost allocation has long been problematic, often causing unsatisfactory VE workshop.

Conventionally, the function cost is allocated by the VE participants based on their experience and knowledge of the project, which largely depends on their subjective judgement [12]. This is also a very time-consuming process; and the function cost allocation is made based on participants' subjective judgment, which make authentic and objective cost allocation impossible. In addition, the building element often perform multiple functions at different extent (e.g., the internal walls are erected to divide space, improve privacy, and decorate inner space at the same time). The vague evaluation may cause potential biases in function cost allocation and wrong identification of function mismatch, which often causes unsatisfactory VE workshop outcomes and in turn hamper the VE promotion for construction projects in private sector.

To overcome the significant shortcoming in the traditional function cost allocation process, current study aimed to apply a fuzzy-based method to allow for objective and efficient function cost allocation. Mixed research methods were applied to achieve the research purpose, including the interview with a group of VE participants, and a real case study for validating the proposed fuzzy method for function cost allocation. Despite the different characteristics of varying building projects, the functions that a building performs should be more or less the same, such as create space, accommodate people, ensure esthetic, etc. In addition, FAST diagram, which presents the functions of building in a how-why logic, should also have wide applicability for building projects. Therefore, it is expected that the proposed fuzzy-based method could be applied to other construction projects, which could generate wider effect in term of improving VE applicability.

2 Literature Review

2.1 VE Job Plan and Function Cost Allocation

VE is defined as a multiple disciplinary team decision making approach for systematic and innovative problem-solving, which aims to improve the value of products/projects [1, 13]. It has been regarded as beneficial for construction projects, as it can bring about various benefits including updating standards, promoting innovation, optimizing resources, saving time, reducing cost, improving project quality, facilitating efficient communication, etc. [6, 11]. The VE is usually applied to construction projects through the systematic job plan workshop which include several phases, from information phase, function analysis phase, creativity phase, evaluation phase, development phase and to presentation phase. In fact, the most fundamental ingredient to the VE methodology is the function analysis phase which consists of several steps, including identifying functions, examination of functions, establishment of Function Analysis System Techniques (FAST) diagram, function cost allocation, and identification of function mismatch [14].

After determining all functions and presenting the functions relationships through the establishment of FAST diagram, next step in function analysis phase is to allocate cost to functions. The cost of a building is often huge, covering the expenditure spent on materials, equipment, and facilities (e.g., doors, windows and concrete). Given that the building elements always perform similar functions despite the building types, the building cost can be calculated in building elements, such as Substructure, Superstructure (frame, upper floor, roof, staircase, external walls, windows, internal walls, and internal doors), Internal Finishes (wall finishes, floor finishes and ceiling finishes), Fitments, and so on [15]. If one building performs just one function, all of its cost should be allocated to that function; while if the element performs several functions at same time, appropriate allocation of the cost to all function is needed. Traditionally, the building cost should be allocated to the functions listed on FAST diagram based on the VE participants' experience and their knowledge of the captioned projects [16], which it is often a vague, inaccurate and subjective estimation [12]. Inappropriate cost allocation could lead to wrong identification of function cost mismatch and in turn the overall failure of the VE job plan workshop.

2.2 Building Cost

For any building projects, cost is always a significant factor, and cost management has long been implemented in the construction industry [17]. The cost of a building could be broadly divided into various building elements that are the portions of a project fulfilling a particular purpose despite the type of building [18]. There is a widely accepted list of building elements, including substructure, superstructure, finishes, fitment, services, external works, and preliminary [6, 19, 20]. Among the building elements, it is hard to assess three elements: first, the content of services varies from project to project, and thus, there is lack of items to compare; secondly, external works is heavily subject to the influence of the external environment of the site; and thirdly, preliminary is mainly determined by the main contractor's preference, which exceeds the scope of this study. In this regard, current study only considers the cost of four groups of building elements, including substructure; superstructure, such as frame, upper floor, roof, staircase, external walls, windows, internal walls, internal doors; finishes, including wall finishes, floor finishes, ceiling finishes; and fitment.

2.3 Fuzzy Set Theory and Triangular Fuzzy Numbers

A fuzzy set is a class of objects with a continuum of grades of membership ranging between 0 and 1 [21]. Fuzzy set methods can be used to transfer the linguistic/non-numerical variables whose values are expressed in words into numerical one. Studies have shown that the fuzzy set is applicable to the areas including linguistics and decision making [22]. In fuzzy set theory, the fuzzy numbers are used to represent the linguistic evaluation (e.g., Low and high) by a collection of possible numerical values between 0 and 1 [23]. One of the most widely used types of fuzzy number is Triangular fuzzy numbers (TFNs), as its representations are intuitive and easy to use [24]. In current study, the TFNs was used to transfer the VE participant's linguistic evaluation into numerical values.

3 Research Method

3.1 Overview of Research Design

The study aims to propose a fuzzy-based method for a more reliable and objective function cost allocation. Mixed research methods are needed to achieve the research purpose, including the interview with a group of construction professionals, and case study for real building project. The interview was to collect qualitative data from participants for developing FAST diagram for various functions of building and in turn the linguistic evaluation of the building elements' function performance, which was later manipulated by using TFNs. The case study was carried out to test and validate the proposed fuzzy-based method.

3.2 Qualitative Data and TFNs

In order to collect qualitative data for the linguistic evaluation of the building elements' functions performance, participants were recruited based on certain criteria: (1) participants are qualified professional in the construction industry; (2) they have direct and rich working experience in the construction industry; (3) the participants have different background (e.g., architecture, building services, quantity surveyors, etc.); and (4) have basic VE knowledge and experience (e.g., basic concept). The participants were asked to develop FAST diagram for the building, and then give linguistic evaluation of various building elements' function performance based on their experience and knowledge. The degree to which a building element performs on specific functions was rated ranging from Very Low (VL), Low (L), Medium (M), High (H) to Very High (VH). For instance, if they recognize that element A has significant contribution to function X, they can choose the linguistic option-Very High. If they think that element B has little or no contribution to function X, they can choose the option Very Low. In total, ten professionals participated in this study, including structural engineers (2), building services engineers (1), quantity surveyors (2), contractor (3), and architect (2).

TFNs, as one kind of fuzzy set theory methods, was applied into current study to transform the linguistic evaluation into a collection of numerical members [24]. A fuzzy set can be called TFNs if there exists a ≤ b ≤ c such that:

(1) $\beta(x) = \frac{x-a}{b-a}$, a ≤ × ≤ b; (2) $\beta(x) = \frac{c-x}{c-b}$, b ≤ × ≤ c; and (3) 0… for other situations (see Fig. 1).

By applying the TFNs, the linguistic evaluation can then be transformed into the TFNs weights (i.e., β(VL) = (0, 0, 0.25), β(L) = (0, 0.25, 0.50), β(M) = (0.25, 0.50, 0.75), β(H) = (0.50, 0.75, 1.00), and β(VH) = (0.75, 1.00, 1.00)) (see Fig. 2).

The final TFNs value is worked out with the consideration of the importance weighting of the linguistic evaluation providers (i.e., the participant), which involved two operations of two TFNs (e.g., A = (a1, a2, a3) and B = (b1, b2, b3)) in current

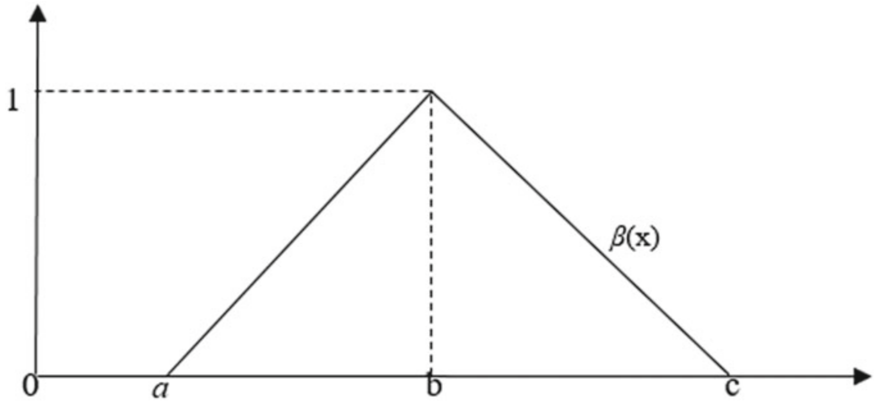

Fig. 1 A triangular fuzzy numbers. *Note* a ≤ × ≤ b, b ≤ × ≤ c

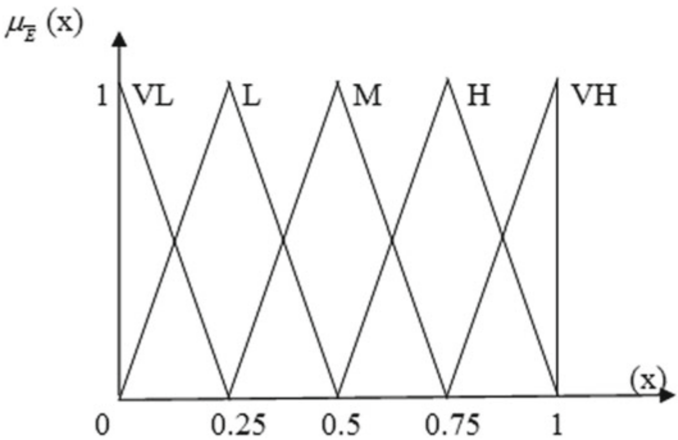

Fig. 2 Linguistic evaluation to TFNs weights

study, including the addition and multiplication of two fuzzy numbers. The two operations are expressed as below [25]: (1) for addition, A + B = (a1 + b1, a2 + b2, a3 + b3); and for multiplication, A * B = (a1 * b1, a2 * b2, a3 * b3). Based on the two operations, the final TFNs value Fqti = (Xqti, Yqti, Zqti) could be calculated by following Eq. (1):

$$\begin{aligned} \mathrm{Fqti} &= \mathrm{Dqti} \times \mathrm{Wt} \\ &= \left[(\mathrm{Dq1i} \times \mathrm{W1}) + (\mathrm{Dq2i} \times \mathrm{W2}) + \cdots (\mathrm{Dqti} \times \mathrm{Wt})\right] \end{aligned} \tag{1}$$

where Fqti = (Xqti, Yqti, Zqti) ∈ [0, 1], q = 1, 2 … n, t = 1, 2 … z, i = 1, 2 … m, be the weighted linguistic evaluation (e.g., VL, L, M, H, and VH) given to function q by participant t in accordance with building element i. Wt ∈ [0, 1], t = 1, 2 … k, be the importance weight of participant t. By Substituting Dqt and Wt with TFNs (i.e., Dqt = (Oqt, Pqt, Qqt), and Wt = (at, bt, ct)), then:

(1) $x_q = \sum_t (o_{qt} * a_n)/k;$
(2) $y_q = \sum_t (p_{qt} * b_n)/k;$
(3) $z_q = \sum_t (q_{qt} * c_n)/k.$

where q = 1, 2, … n; t = 1. 2 … z. The final integral value for TFNs (αq) can be calculated by format $a_q = \frac{X_q + Y_q + Z_q}{2}$. The integral value of function performance of each element needs to be further converted into percentage $\left(\text{i.e., } E_i F_q = \frac{a_q}{\sum a_q} * 100\right)$. After completing the above steps, an appropriate and objective way to allocate functions cost can be worked out.

4 Case Study

Case study is a powerful and reliable research method, which allows to extensively yield in-depth information for understanding specific phenomena [26]. For this study, the application of case study method is to collect actual cost data to examine the applicability of the proposed fuzzy-based method for function cost allocation in the VE job plan process. The project for the case study was selected based on certain criteria, including: (1) it should be typical residential building; (2) there is easy access to the cost data; and (3) use of cast-in-suit reinforced concrete frame and slabs with transfer plate which is one of the most commonly used types for residential building in HK. Based on these criteria, one residential building was selected. It is 42-storeys single high-rise building in HK. Its gross floor area is around 23 thousand squared meters, consisting of around four hundred unit flats, including both two bedrooms flat (around 60% of total unit flats) and three bedrooms flat (around 40% of total unit flats) with size ranging from 50 to 65 m^2.

The total construction cost of the selected residential building is around HK dollar (HK$) 290 million. Conventionally, the building cost was divided into various elements, including *substructure*, frame, upper floor, roof, stair case, external walls, windows, internal walls, internal doors, wall finishes, floor finishes, ceiling finishes, *fitment*, and so on [27]. Based on this classification, the building cost is calculated and presented in Table 1. It shows that the cost of substructure was HK$ 4098/m^2 and accounted for 32.61% of the total building cost. The second most expensive building element is the external walls (HK$ 2439/m^2; 19.4% of the total building cost), which was mainly contributed by the extensive use of glass walls, curtain walls and precast façade for the purpose of enhancing building appearance. On the contrary, the cost of staircase was the least, costing HK$ 103/m^2 (i.e., 0.82%). The cost of ceiling finishes was the second least (HK$ 164/m^2; 1.31%).

Table 1 Total elemental cost

Building elements	Total element cost *(HK$)*	%	Elemental cost/GFA
B1—Substructure	**94,265,098**	**32.61**	**HK$ 4098**/m^2
B2—Frame	15,296,439	5.29	HK$ 647/m^2
B3—Upper Floor	19,773,776	6.84	HK$ 859/m^2
B4—Roof	5,091,222	1.76	HK$ 221/m^2
B5—Staircase	*2,383,699*	*0.82*	HK$ *103*/m^2
B6—External walls	**56,113,124**	**19.41**	**HK$ 2439/m^2**
B7—Windows	14,150,726	4.90	HK$ 615/m^2
B8—Internal walls	**27,151,950**	**9.39**	**HK$ 1180**/m^2
B9—Internal doors	12,849,984	4.45	HK$ 558/m^2
B10—Wall Finishes	20,173,552	6.98	HK$ 877/m^2
B11– Floor Finishes	10,349,599	3.58	HK$ 449/m^2
B12—Ceiling Finishes	*3,787,017*	*1.31*	HK$ *164*/m^2
B13—Fitment	10,768,962	3.73	HK$ 468/m^2
Sum	292,153,588	100.00	HK$ 12,678/m^2

Note The bold items indicate the three most expensive building elements

4.1 Development of FAST Diagram for the High-Rise Building

Development of FAST diagram is the necessary step to allocate cost to functions. However, how to develop a FAST diagram is subjective, and every VE participants could develop their own FAST diagram with different styles and preferences [10]. In current study, the FAST diagram was developed through several steps for this high-rise building. Firstly, extensive review of past VE workshops for residential buildings was carried out in order to identify appropriate functions for the development of FAST Diagram. Secondly, the participants of the current study were invited to review and revise the FAST diagram. Last but not the least, the constructed FAST diagram was examined with the ground rules (e.g., basic function, supporting function, how-why logic, etc.). The developed FAST diagram is included in the Appendix, and it finally includes nineteen functions (also see Table 2).

4.2 Allocate Building Cost to Functions

Based on the established FAST diagram, the participants were invited to express their linguistic evaluation of the building elements' function performance by using ratings VL, L, M, H and VH. An example of a completed linguistic evaluation made by one participant is shown in Table 2. After gathering all the participants' linguistic

Table 2 Example of one participant's linguistic evaluation

	Building element												
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13
Functions													
Basic functions													
1.1 Divide space	1	2	5	5	5	5	3	5	5	1	1	3	4
1.2 Enclose space	1	2	5	5	5	5	5	5	5	1	1	3	4
2.1.1.1 Support load	5	5	4	1	3	3	1	3	1	1	1	1	1
2.1.1.2 Transfer load	5	5	4	1	2	3	1	3	1	1	1	1	1
Support functions													
4.1.1 Resist corrosion	1	5	3	3	2	4	5	2	2	5	4	1	3
4.1.2 Resist fire	1	5	5	3	5	3	1	5	5	3	3	3	3
5.1 Promote accessibility	1	1	4	1	5	3	2	3	5	1	1	1	4
5.2 Circulate people	1	1	2	2	5	1	1	3	3	1	2	1	3
6.1.1.1 Improve privacy	1	3	5	3	4	5	2	5	5	2	1	2	3
6.1.1.2 Protect space	1	3	5	5	5	5	3	5	5	1	2	3	3
6.1.2 Manipulate light	1	1	1	4	2	5	5	3	3	2	1	3	4
6.1.3.1 Resist weather	1	5	3	5	3	5	5	1	2	2	2	1	3
6.1.3.2 Control ventilation	1	3	2	3	2	5	5	3	3	1	1	3	3
6.2 Express Luxury	1	2	4	5	2	5	3	4	3	3	3	3	3
6.3 Beautify community	1	1	1	3	2	4	4	2	1	2	1	1	3
6.4.1 Upgrade facility	1	2	3	3	2	4	5	3	3	4	4	5	5
6.4.2 Insulate space	1	3	2	4	3	3	3	3	2	1	1	4	3
7.1.1 Enhance appearance	1	3	2	3	2	4	4	2	4	3	3	4	5
7.1.2 Decorate inner-space	1	2	2	1	2	3	4	5	4	5	2	5	5

Note B1—substructure; B2—frame; B3—upper floor; B4—roof; B5—staircase; B6—external walls; B7—windows; B8—internal walls; B9—internal doors; B10—wall finishes; B11—floor finishes; B12—ceiling finishes; B13—fitment

evaluation of the building elements' function performance, the TFNs was applied to transfer the linguistic evaluation to objective numbers $\left(\text{i.e., } a_q = \frac{X_q+Y_q+Z_q}{2}\right)$.

In VE job plan process, all the participants are regarded as equally important, and thus, the weighting of the linguistic evaluation providers (i.e., the participants) are equal to 1 in current study. The average rating on the function performance of each building element is expressed in percentage through the format $E_i F_q = \frac{a_q}{\sum a_q} * 100$, which is presented in Table 3.

Table 3 shows that building element B1 substructure performs five functions, including support load (27.3%), transfer load (26.9%) and resist corrosion (13.9%), protect space (13.8%), and enclose space (9.5%). It is understandable that the

Table 3 Percentage of function performance of each building element

	Building element												
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13
Functions													
Basic functions													
1.1	0.0	10.6	9.8	7.4	6.2	0.0	0.0	14.4	8.1	0.0	0.0	0.0	0.0
1.2	9.5	10.6	8.4	9.4	0.0	9.5	8.9	9.9	6.1	0.0	0.0	0.0	0.0
2.1.1	27.3	22.8	12.1	10.7	10.5	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.1.2	26.9	21.5	15.1	12.1	10.5	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Support functions													
4.1.1	13.9	9.3	8.0	6.9	0.0	7.3	0.0	0.0	0.0	12.1	12.1	12.1	0.0
4.1.2	0.0	8.3	0.0	0.0	6.7	0.0	0.0	9.9	7.8	0.0	0.0	0.0	0.0
5.1	0.0	0.0	0.0	0.0	15.3	7.2	0.0	0.0	10.5	0.0	0.0	0.0	0.0
5.2	0.0	0.0	7.6	0.0	18.3	0.0	0.0	6.4	11.3	0.0	0.0	0.0	0.0
6.1.1.1	0.0	0.0	9.4	8.3	5.9	0.0	7.9	13.6	11.5	8.2	8.2	8.2	0.0
6.1.1.2	13.8	9.3	11.5	12.3	6.7	10.9	6.0	12.7	10.0	0.0	0.0	0.0	0.0
6.1.2	0.0	0.0	0.0	0.0	0.0	0.0	10.5	6.5	6.1	0.0	0.0	0.0	17.3
6.1.3.1	8.7	7.6	0.0	9.6	0.0	10.9	10.6	8.0	0.0	0.0	0.0	0.0	0.0
6.1.3.2	0.0	0.0	0.0	0.0	7.3	6.9	11.1	0.0	5.3	0.0	0.0	0.0	0.0
6.2	0.0	0.0	0.0	0.0	0.0	0.0	9.8	0.0	0.0	13.9	13.9	13.9	9.5
6.3	0.0	0.0	0.0	0.0	0.0	0.0	9.2	0.0	6.3	14.3	14.3	14.3	0.0
6.4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.5	10.5	10.5	43.7
6.4.2	0.0	0.0	9.4	10.3	5.9	10.1	8.9	11.7	9.2	6.8	6.8	6.8	0.0
7.1.1	0.0	0.0	0.0	13.0	6.7	21.3	17.0	0.0	0.0	9.0	9.0	9.0	0.0
7.1.2	0.0	0.0	8.7	0.0	0.0	0.0	0.0	6.8	7.9	25.2	25.2	25.2	29.6
Total	100	100	100	100	100	100	100	100	100	100	100	100	100

Note B1—substructure; B2—frame; B3—upper floor; B4—roof; B5—staircase; B6—external walls; B7—windows; B8—internal walls; B9—internal doors; B10—wall finishes; B11—floor finishes; B12—ceiling finishes; B13—fitment

Note 1.1—divide space; 1.2—enclose space; 2.1.1—support load; 2.1.2—transfer load; 4.1.1—resist corrosion; 4.1.2—resist fire; 5.1—promote accessibility; 5.2—circulate people; 6.1.1.1—improve privacy; 6.1.1.2—protect space; 6.1.2—manipulate light; 6.1.3.1—resist weather; 6.1.3.2—control ventilation; 6.2—express luxury; 6.3—beautify community; 6.4.1—upgrade facilities; 6.4.2—insulate space; 7.1.1—enhance appearance; 7.1.2—decorate inner-space

substructure serves the function to support load and transfer load, while it was interesting to find that it also makes contributions to resist corrosion, and space. The building element B6 external walls are commonly considered to enhance appearance (21.3%), protect space (10.9%), resist weather (10.9%), and insulate space (10.1%), which is also fit for the conventional understanding of the external's functions. The building element B12 ceiling finishes mainly perform five functions, such as decorate inner-space (25.2%), beautify community (14.3%), express luxury

(13.9%), resist corrosion (12.1%) and upgrade facilities (10.5%). The least expensive building element B5 staircases mainly performed four functions, including circulate people (18.3%), promote accessibility (15.3%), support load (10.5%) and transfer load (10.5%).

Based on the identified function performance of building elements through TFNs method, the function cost can be easily allocated. For instance, the function cost for *divide space* (1.1) should be the result of summing up the contributions from building element B8 internal walls (HK$ 1180/m^2 * 14.4%), B2 frame (HK$ 657/m^2 * 10.6%), B3 upper floor (HK$ 859/m^2 * 9.8%), B9 internal doors (HK$ 558/m^2 * 8.1%), B4 roof (HK$ 221/m^2 * 7.4%), and B5 staircases (HK$ 103/m^2 * 6.2%). By calculation, the function cost for divide space is HK$ 391/m^2. The full function cost is presented in Table 4. This table revealed that function cost of support load (HK$ 1607/m^2), transfer load (HK$ 1587/m^2), and protect space (HK$ 1267/m^2) are among the highest for a residential building, which together contribute to around 35% of the total building cost. The three lowest function cost are for resist fire (HK$ 221/m^2), promote accessibility (HK$ 250/m^2), and circulate people (HK$ 223/m^2), which only contribute to a total of around 5% of the building cost. This finding is also understandable.

5 Discussion

Through the application of the TFNs, current study was able to transfer the VE participants' vague evaluation of the building elements' function performance into numerical values. A case study for a residential building was carried to validate the proposed fuzzy-based method for function cost allocation, and the case study findings have indicated its applicability. As revealed in the case study results, the participants were able to firstly give a value to indicate the degree to which building elements perform on specific functions (i.e., the linguistic evaluations like very low, low and medium) (see Table 2). This prevents the wrongdoings that evaluate the function performance of building elements based on binary value of high and low, which could not reflect the specific performance of the building elements. Secondly, the application of the TFNs was able to transfer the VE team members' linguistic evaluation (e.g., very high) of the building elements' function performance to numerical values (i.e., percentage) (see Table 3). Through this numerical transmission, it was allowed to understand the participants' authentic evaluation of the building elements' function performance in higher degree of precise (e.g., 27.3% and 26.9% performance of substructure on function support load and transfer load, respectively). This laid the ground for the realistic and precise function cost allocation from building elements to functions.

The results of the TFNs function cost allocation generally make sense (see Table 4), which also demonstrated the reliability of the proposed fuzzy-based method as well. It shown in Table 4 that allocated function cost of support load was the highest among all functions, followed by transfer load. In fact, the load of the building is

Table 4 Function cost of building

Function	Calculation (refer to Tables 1 and 3)	Function cost	%
Basic functions			
1.1 Divide space	= B2 * 10.6% + B3 * 9.8% ··· + B9 * 8.1%	HK$ 391/m^2	3.08
1.2 Enclose space	= B1 * 9.5% + B2 * 10.6% ··· + B9 * 6.1%	HK$ 988/m^2	7.80
2.1.1 Support load	= B1 * 27.3% + B2 * 22.8% ··· + B6 * 8.3%	HK$ **1,607**/m^2	**12.68**
2.1.2 Transfer load	= B1 * 26.9% + B2 * 21.5% ··· + B6 * 7.3%	HK$ **1587**/m^2	**12.52**
Sub-total	HK$ 4573/m^2		
4.1.1 Resist corrosion	= B1 * 13.9% + B2 * 9.3% ··· + B9 * 7.8%	HK$ 1072/m^2	8.46
4.1.2 Resist fire	= B2 * 15.3% + B5 * 7.2% ··· + B9 * 10.51%	HK$ *221*/m^2	*1.74*
5.1 Promote accessibility	= B5 * 10.6% + B6 * 9.8% ··· + B9 * 8.1%	HK$ *250*/m^2	*1.97*
5.2 Circulate people	= B3 * 7.6% + B5 * 18.3% ··· + B9 *11.3%	HK$ *223*/m^2	*1.76*
6.1.1.1 Improve privacy	= B3 * 9.4% + B4 * 8.3% ··· + B12 * 8.2%	HK$ 501/m^2	3.95
6.1.1.2 Protect space	= B1 * 13.8% + B2 * 9.3% ··· + B9 * 10.0%	HK$ **1267**/m^2	**10.00**
6.1.2 Manipulate light	= B7 * 10.5% + B8 * 6.5% ··· + B13 * 17.3%	HK$ 256/m^2	2.02
6.1.3.1 Resist weather	= B1 * 8.7% + B2 * 7.6% ··· + B8 * 8.0%	HK$ 852/m^2	6.73
6.1.3.2 Control ventilation	= B5 * 7.3% + B6 * 6.9% ··· + B9 * 5.3%	HK$ 274/m^2	2.16
6.2 Express Luxury	= B7 * 9.8% + B10 * 13.9% ··· + B13 * 9.5%	HK$ 312/m^2	2.46
6.3 Beautify community	= B7 * 9.2% + B9 * 6.3% ··· + B12 * 14.3%	HK$ 305/m^2	2.40
6.4.1 Upgrade facility	= B10 * 10.5% + B11 * 10.5% ··· + B13 * 43.7%	HK$ 361/m^2	2.85
6.4.2 Insulate space	= B3 * 9.4% + B4 * 10.3% ··· + B12 * 6.8%	HK$ 701/m^2	5.53
7.1.1 Enhance appearance	= B4 * 13.0% + B5 * 6.7% ··· + B12 * 9.0%	HK$ 794/m^2	6.26
7.1.2 Decorate inner-space	= B3 * 8.7% + B8 * 6.8% ··· + B13 * 29.6%a	HK$ 713/m^2	5.63
Sub-total	HK$ 8101/m^2		

(continued)

Table 4 (continued)

Function	Calculation (refer to Tables 1 and 3)	Function cost	%
Total		HK$ 12,678/m^2	100.00

Note B1—substructure; B2—frame; B3—upper floor; B4—roof; B5—staircase; B6—external walls; B7—windows; B8—internal walls; B9—internal doors; B10—wall finishes; B11—floor finishes; B12—ceiling finishes; B13—fitment

Note The bold items indicate the three highest building function cost often bore, transferred and supported by various structural components in building, including foundation, structural walls, beams, and columns, while the cost of these components is often high because of the use of a lot of high-level concrete (C40 or above) and steel bars with high quality and big diameter [28]. As found in current study, the least function cost in building is rendered to resist fire. In most residential buildings, the ways to resist fire include the use of the fireproof doors, fire-proof paint and various fire-fighting equipment, and so on [29], all of which are not expensive in comparison to the cost spent in the building structure.

By applying the VE methodological approach, the building cost was able to be transferred to the function cost which was based on the evaluation of experienced construction professionals, an established FAST diagram and the TFNs method. In fact, the function cost set a standard benchmark (i.e., the functions) to facilitate the comparison of building cost for projects with different building types and characteristics. It is also reasonable to claim that this proposed fuzzy-based approach could greatly improve the function cost allocation process in terms of objectivity and efficiency.

6 Conclusion

VE is often applied to construction projects through systematic VE job plan workshop. The cost allocation to function plays a key role in identifying the value mismatch, while current study aimed to improve existing practices in function cost allocation through the application of the TFNs method. The proposed TFNs for cost allocation was examined through a real case study. After establishing a FAST diagram for the case study residential building, professionals were invited to give their linguistic evaluation of the building elements' function performance, which was further transferred into numerical values by TFNs. The building cost, which was spent in 13 building elements, was then allocated to the functions based on the authentic TFNs value. The case study confirmed that the TFNs is applicable and reliable, as the TFNs-based function cost allocation is generally reasonable. Current study contributed to provide an objective and efficient way for function cost allocation in the VE job plan process. Given the similarity of functions of building, this proposed method could have a wider applicability, which is expected to improve the VE practices.

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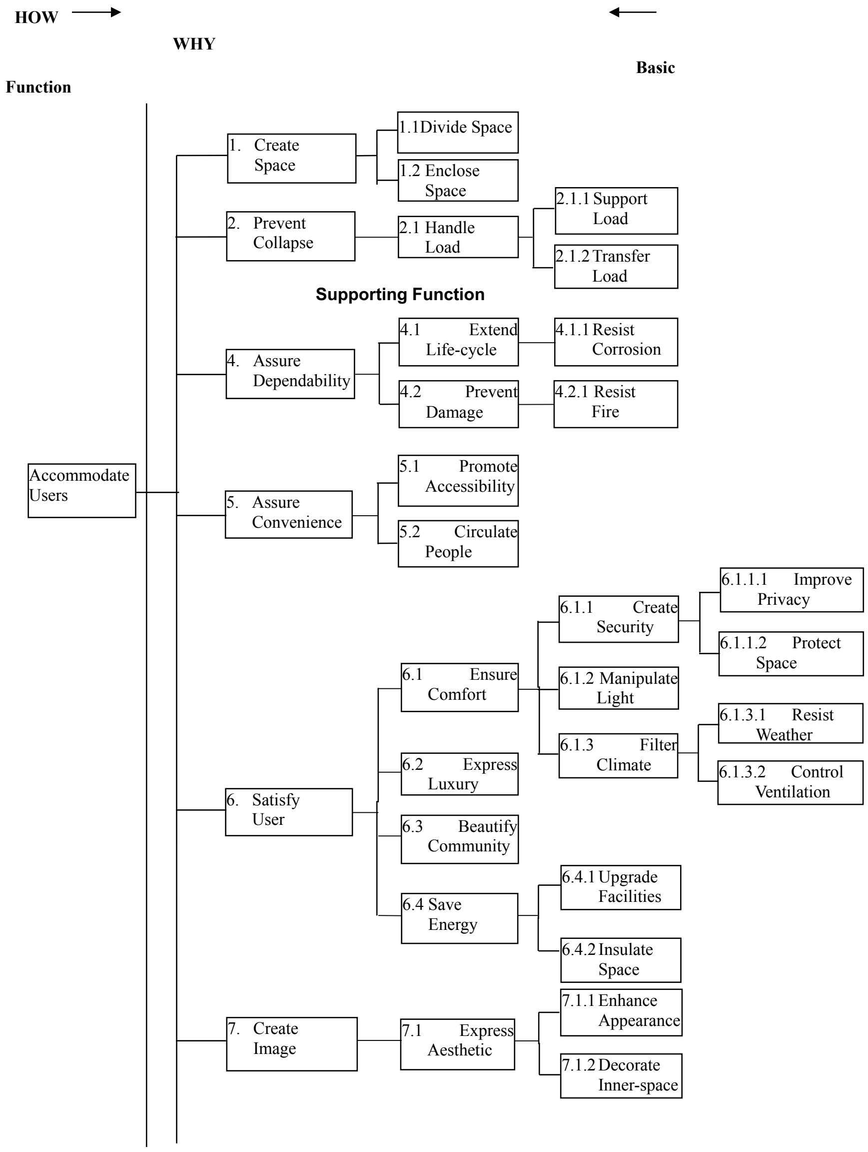
Appendix


HOW
WHY
Basic
Function
Accommodate Users
1. Create Space
1.1Divide Space
1.2 Enclose Space
2. Prevent Collapse
2.1 Handle Load
2.1.1 Support Load
2.1.2 Transfer Load
Supporting Function
4. Assure Dependability
4.1 Extend Life-cycle
4.1.1 Resist Corrosion
4.2 Prevent Damage
4.2.1 Resist Fire
5. Assure Convenience
5.1 Promote Accessibility
5.2 Circulate People
6. Satisfy User
6.1 Ensure Comfort
6.1.1 Create Security
6.1.1.1 Improve Privacy
6.1.1.2 Protect Space
6.1.2 Manipulate Light
6.1.3 Filter Climate
6.1.3.1 Resist Weather
6.1.3.2 Control Ventilation
6.2 Express Luxury
6.3 Beautify Community
6.4 Save Energy
6.4.1 Upgrade Facilities
6.4.2 Insulate Space
7. Create Image
7.1 Express Aesthetic
7.1.1 Enhance Appearance
7.1.2 Decorate Inner-space

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