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PRIORITISING SUSTAINABILITY FACTORS FOR AUSTRALIAN COMMUNITY BUILDINGS' MANAGEMENT USING ANALYTICAL HIERARCHY PROCESS (AHP)

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Abstract. The essence of Australian community buildings' sustainable management drives through a previously established decision-making structure with four sustainability aspects and accompanying 18 criteria. Informed decisions are supported with a decision-making model that generates sustainability impacts of building components based on this decision-making structure. Building components' individual impacts can be assigned using a numbering scale incorporated with linguistic terms. However, similar importance given to each aspect or criterion is arguable when the combined effect is considered. Hence, they should be given different weightings and their combination with individual impacts will produce final sustainability impacts. For calculating weightings, the study uses Analytical Hierarchy Process (AHP), widely used technique in Multi Attribute Decision-Making (MADM). The study also conducted an industry-wide questionnaire across Australian local councils because pair-wise comparison data is essential for weighting calculation. This paper presents the survey data and analysis results that captured weightings of sustainability aspects and criteria.

Keywords: sustainable management, sustainability impacts, decision-making structure, decision-making model, AHP, MADM.

Introduction

Varying levels of service and the huge built up costs (replacement costs, maintenance and operation costs) have attracted much attention on the sustainable management of Australian community buildings (GHD, 2015), perhaps recently during the past two decades. Community buildings in Australia provide essential services to community under different roofs such as aged care centres, childcare centres, community centres and sports pavilions. Consequently, governments of Australia have invested a large sum of money for them over decades – the result is to make them the second largest infrastructure asset class upon financial value (Edirisinghe, Setunge, Zhang, & Wakefield, 2012). Sustainable development is defined as "meeting the needs of the present without compromising the ability of future generations to meet theirs" (Brundtland, 1987) while sustainability interprets the ability to continue something over a long period of time (Cambridge Advanced Learner's Dictionary, 2005).

There are several studies in research literature to incorporate sustainability concerns into buildings management (Benoît et al., 2010; Boonstra & Pettersen, 2003; Häkkinen, Vesikari, & Pulakka, 2007; Junghans, 2013; McShane, 2006). However, this research focus is relatively new due to the increased focus on climate impact, Cooperate Social Responsibility (CSR) and sustainability as important goals for companies and public institutions, and has become a contributor in the branding of companies (Nielsen, Møller, Jäschke, & Alexander, 2012). It has been identified as one particular challenge for continuous research is to integrate sustainability into the local FM culture and work processes (Elmualim, Shockley, Valle, Ludlow, & Shah, 2010).

While the integrated sustainability is the biggest concern of Sinou and Kyvelou (2006) there are only very few studies (Cuadrado, Zubizarreta, Rojí, García, & Larrauri, 2015; Cuadrado, Zubizarreta, Rojí, Larrauri, & Álvarez, 2016) including the current study given a major focus on it. In comparison, the current study can be applied to

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building elements and later on to the whole building by aggregating the elements; however, few other studies can mostly be applied to whole buildings. This is not the only difference: the current study has given a major focus on to only community buildings whereas the other studies have given a broader focus on to industrial buildings. Another distinguishable difference can be seen upon the application purpose where the other studies can only be applied for buildings' design and assessment towards sustainability; however, the current study provides an additional ability which is for maintenance and operation of buildings. In similar to the main purpose of the current study, there are other models developed for sustainable management of buildings focusing a particular building and providing strategies to improve building performance (Häkkinen et al., 2007). However, lack of consideration on budget constraints in maintenance and refurbishment practices is predominant in these studies. With these models, it can also be difficult for a facilities manager to make decisions on a daily basis in accordance with a vision of sustainability because the vision is unclear (K. R. Galamba, K. R. Galamba, S. B. Nielsen, & Nielsen, 2016).

In particular to the current practice of Australian local councils, it shows lack of robustness for an approach by which they can make informed decisions towards the sustainable management of community buildings. With the growing interest of such a practice including the solutions given to the concerns explained in the former paragraph, main focus of this paper is to prioritise previously captured sustainability aspects and criteria in the same research project as part of decision-making model's development for the sustainable management of community buildings. Previous work of this research project captured the sustainable management of community buildings with four sustainability aspects (environmental, economic, social and functional aspects) and accompanying 18 influencing criteria (Kalutara, Zhang, Setunge, & Wakefield, 2017). The decision-making model is designed such that the sustainability impact caused by a given building component can be calculated using these sustainability aspects and criteria. Individual impact of a building component through criteria and aspects can be obtained according to a numbering scale incorporated with linguistic terms (Campbell, 1955). However, sustainability aspects and criteria do not generally exhibit the same importance in situations where the combined sustainability effect is considered; hence, different weightings should be assigned to them. Then, they can be combined with individual impacts to calculate final impacts. Presently in Australian local councils, panels are engaged in such decision-makings to assign weightings based on the opinions of individual members, which may reduce some subjectivity. However, there remains a need for an efficient and objective method to capture weightings of aspects and criteria.

In finding such a method, the definition given for decision-making by Harris (2012) is valuable. According to him, decision-making should be involved in identifying and choosing alternatives mapped with decision-maker's values and preferences. The nature of decisions of the present problem deals with multiple criteria; hence, the best approach is to follow multiple attribute decision-making (MADM) method (Fülöp, 2005). According to AHP method, first step is to capture pair-wise importance data for criteria and aspects in the developed decision-making structure. Responses from an industry-wide questionnaire across Australian local councils are the prime mode for collecting these data. Analysis of the data determined the significance of each criterion and aspect towards the sustainable management of community buildings: the significance is reflected by their weighting values. This paper presents default weighting values for sustainability aspects and criteria and suggests using in standard community buildings management applications for Australian local councils.

1. Decision-making methods

> *Decision-making is the study of identifying and choosing alternatives based on the values and preferences of the decision maker. Making a decision implies that there are alternative choices to be considered, and in such a case we want not only to identify as many of these alternatives as possible but to choose the one that (1) has the highest probability of success or effectiveness and (2) best fits with our goals, desires, lifestyle, values, and so on (Harris, 2012).*

While Harris (2012) defines decision-making as above, Baker et al. (2002) identifies the general decision-making process comprised of eight major steps; (1) define the problem, (2) determine requirements, (3) establish goals, (4) identify alternatives, (5) define criteria, (6) select a decision-making tool, (7) evaluate alternatives against criteria, (8) validate solutions against problem statement. According to this process, identifying alternatives and defining criteria depends on the goals and alternatives of the case of the decision problem. Those cases can be different and be equipped with single criteria or multiple criteria. The problem focused in this study deals with multiple criteria. Hence, the selection of decision-making methods for the problem is designed considering the techniques which can be dealt with multiple criteria. Multiple attribute decision-making (MADM) is a widely used system of methods for this purpose (Fülöp, 2005).

Attributes can be regarded as part of the criterion (Fülöp, 2005) and MADM can be regarded as a branch of the field of multiple criteria decision-making (MCDM) (Yoon & Hwang, 1995). Additional to MADM, MCDM includes multiple objective decision-making (MODM), which is used for problems exposed to a set of conflicting objectives for designing the best alternative (Hwang, Lai, & Liu, 1993). The present study, that incorporates sustainability aspects and criteria into sustainable management of community buildings, lacks situations leading to MODM. Its attributes and criteria can also be considered as synonymous for the problem. Problems involving a number of finite criteria and alternatives which can be expressed explicitly are said to require MADM (Fülöp, 2005). Apart from these two characteristics, Yoon and Hwang (1995) identified three more characteristics in such problems regardless of their diversity: (1) each attribute has different units of measurement (incommensurable units); (2) incorporation of attribute weights; and (3) concise representation of the problem with a decision matrix.

Distilled to the essence of problem-solving, the generation of attributes is the initial task and the key role in the process. Keeney and Raïffa (1976) prefaced attribute generation with the need to include the following properties: (1) completeness, (2) operational, (3) decomposable, (4) non-redundancy, (5) minimum size. In general, the whole conceptual process of MADM can be summarised as follows (Dubois & Prade, 1980; Tzeng & Huang 2011): (1) define the nature of the problem, (2) construct a hierarchy system for its evaluation, (3) select the appropriate evaluation model, (4) obtain the relative weights and performance score of each attribute with respect to each alternative, (5) determine the best alternative according to the synthetic utility values, which are the aggregation value of relative weights, and performance scores corresponding to alternatives. Among the several MADM methods in practice (e.g. TOPSIS, ELECTRE, Maxmin, Maximax), analytical hierarchy process (AHP) was selected for the present problem considering its close alignment to the problem's nature.

2. Analytical hierarchy process (AHP)

2.1. Concept of AHP

AHP is a widely-used MADM method which can be used in problems involving qualitative data. Saaty (1980) invented the method for complex problems by understanding the problem through a hierarchical view. Furthermore, he introduced a table which enables decision-makers to make the choice between two elements (normally attributes) by comparing pairs both qualitatively and quantitatively. Table 1 shows Saaty's table of which a nine point intensity scale is used to express important classifications of linguistic terms.

The application of AHP can be identified in three stages according to the layout of the process: hierarchic design, capture of pair-wise comparison data and performance aggregation through analysis. Problem identification through a multi-level structure is very important in the hierarchic design. The first level of the structure is the focus or objective of the application whereas the last level is the alternatives. The objective can be captured by different aspects and succeeding levels can be formed by the required criteria to fulfil aspects. Similarly the structure forms sub-criteria for criteria and follows the same to other levels. The remaining level after this whole process is connected to alternatives, which is the last level.

Table 1. Saaty's pair-wise comparison table (source: Saaty, 1980, 1990)

Scale	Linguistic definition
1	Equally importance of both elements
3	Moderate importance of one element over another
5	Strong importance of one element over another
7	Very strong importance of one element over another
9	Absolute importance of one element over another
2,4,6,8	Intermediate values

Pair-wise comparison basically starts from the last level of the structure; hence, it is applied to alternatives. The pair-wise comparison of alternatives will be acquired with respect to the immediate component (commonly sub-criteria) connected with alternatives. The components of any bottom level will be compared pair-wise with the immediate component at their top level. This will continue until the second level, which reflects on the objective through their pair-wise comparison. Saaty (1980) developed a method to calculate priority levels or weightings of the relevant elements based on their pair-wise comparison data. Tzeng and Huang (2011) call this method the "Eigen value method" whereas Yoon and Hwang (1995) call it the "Hierarchical SAW method". An example is provided to explain the calculation process applied in AHP. For the example, n number of criteria and their pair-wise comparison is considered. Hence, a matrix (say P) can be formed using the pair-wise comparison data shown in Equation 1. Reciprocal values are used when the direction of the comparison is changed in the elements.

$$P = \begin{bmatrix} 1 & P_{12} & P_{13} & \cdots & \cdots & P_{1n} \\ 1/P_{12} & 1 & P_{23} & \cdots & \cdots & P_{2n} \\ 1/P_{13} & 1/P_{23} & 1 & \cdots & \cdots & P_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \cdots & 1 & \vdots \\ 1/P_{1n} & 1/P_{2n} & 1/P_{3n} & \cdots & \cdots & 1 \end{bmatrix}. \quad (1)$$

Afterwards, normalisation is applied to the above matrix and its normalised matrix is derived. Let W_r be the weighting of the criterion r, then W_r is given by the following equation (Eq. (2)):

$$W_r = \frac{X_r}{\sum_{r=1}^{r=n} X_r} \text{ where } X_r = \sum_{j=1}^{n} \frac{P_{rj}}{\sum_{i=1}^{i=n} P_{rj}}, \quad (2)$$

where: $r = 1, 2, 3\ldots n$; $j = 1, 2, 3\ldots n$; $i = 1, 2, 3\ldots n$

Hence, weighting values for all criteria can be calculated and a weighting matrix, W, is formed accordingly (Eq. (3)):

$$W = \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ \vdots \\ \vdots \\ W_n \end{bmatrix}. \quad (3)$$

The final stage of AHP is the aggregation of these weightings or priority levels to obtain the priority level of alternatives for the objective of the problem. An example is considered to explain the phenomenon clearly. The problem has a three-level hierarchical flow which starts from the goal and follows through "n" number of criteria (C) to acquire "m" number of alternatives (A). The way the aggregation occurs can be shown as a multiplication of two matrices as follows (Eq. (4)):

$$\begin{bmatrix} W_{A1C1} & W_{A1C2} & \cdots & \cdots & W_{A1Cn} \\ W_{A2C1} & W_{A2C2} & \cdots & \cdots & W_{A2Cn} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \vdots & \vdots & \cdots & \ddots & \vdots \\ W_{AmC1} & W_{AmC2} & \cdots & \cdots & W_{AmCn} \end{bmatrix} \times \begin{bmatrix} W_{C1} \\ W_{C2} \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ W_{Cn} \end{bmatrix} = \begin{bmatrix} W_{A1} \\ W_{A2} \\ \vdots \\ \vdots \\ W_{Am} \end{bmatrix}. \quad (4)$$

> *In decision-making problems it may be important to know how good our consistency is, because we may not want the decision to be based on judgements that have such low consistency that they appear to be random (Saaty, 1990).*

In this regard, a certain degree of consistency is vital in pair-wise comparison data as it reflects on the validity of the final decision. AHP addresses the issue by introducing a consistency ratio (CR) to measure the overall consistency of judgements. The CR (Eq. (5)) is derived by dividing the consistency index (CI) by a random consistency value (R). The value of the consistency ratio should be below or equal to 10 percent (0.1) in order to keep the judgements consistent (Saaty, 1990):

$$CR = \frac{CI}{R} \le 0.1 . \quad (5)$$

R values vary according to the matrix size, which can be obtained according to Table 2. Maximum Eigen value or Lamda max (λ_{max}) is used to find the CI, which can be calculated from Eq. (6) as follows:

$$CI = \frac{\lambda_{max} - n}{n-1}, \quad (6)$$

where: n is the size of matrix.

The calculation of λ_{max} for the previous example can be explained in the following steps:

– Let R matrix be the multiplication of P matrix (Eq. (1)) and W matrix (Eq. (3)), then R can be obtained from Eq. (7):

$$[R] = \begin{bmatrix} 1 & P_{12} & P_{13} & \cdots & \cdots & P_{1n} \\ 1/P_{12} & 1 & P_{23} & \cdots & \cdots & P_{2n} \\ 1/P_{13} & 1/P_{23} & 1 & \cdots & \cdots & P_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \cdots & 1 & \vdots \\ 1/P_{1n} & 1/P_{2n} & 1/P_{3n} & \cdots & \cdots & 1 \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \\ W_3 \\ \vdots \\ \vdots \\ W_n \end{bmatrix} = \begin{bmatrix} R_{11} \\ R_{21} \\ R_{31} \\ \vdots \\ \vdots \\ R_{n1} \end{bmatrix}; \quad (7)$$

– Then λ_{max} is given by Eq. (8) as follows:

$$\lambda_{max} = \frac{\sum_{i=1}^{n} R_{i1} / W_i}{n} . \quad (8)$$

In contrast to Saaty (1980)'s threshold of CR for being consistent with data, Pedrycz and Gomide (2007) proposed a threshold by manipulating CI. They maintained a superimposed value of 0.1 for CI index and stated that the experiment may need to be repeated if its CI index exceeds 0.1.

2.2. AHP by application

The wide utilisation of AHP in numerous problem applications can be seen in a large number of related research reports. The applications are not limited to one area but cover diverse areas. According to Zahedi (1986), the number of areas exceeds 25 broad and specific areas. This highlights the power of AHP in problem-solving and decision-making. Saaty (1990) showcases how AHP has been involved in problem-solving, providing a great range of cases of applications. His first example comes from politics, when US president Carter had to make a decision whether to send troops on a mission to rescue 53 American hostages from Teheran, where they had been held since early November 1979. Different levels of hierarchy were used in the problem, in which the first represented the likelihood of success of the project. Then it followed through different intermediate levels up to the last level which indicated the options whether to or not

Table 2. Random consistency values according to the size of matrix (source: Saaty, 1990)

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random consistency	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

to send the troops. Seven people participated in giving pair-wise comparison data. Some other examples he uses to showcase the importance of AHP are: for determining consumer preference, estimating the economy's impact on sales, selecting a portfolio.

The AHP-based approach was used by Al Khalil (2002) to select the most appropriate method for project delivery. The goal of the study was to allow project owners to decide the best project delivery method out of three different alternatives. He introduced a mathematical approach to evaluate the best method by using available specialized software or a spread sheet program. Wei, Chien, and Wang (2005) used AHP in a systematic review of enterprise resource planning (ERP) to find the most suitable ERP system. Firstly, the authors developed a fundamental objective hierarchy system based on the fundamental idea of how to select the most suitable ERP system, and secondly, the means-objective network according to the established hierarchy. They carried out a factor analysis of the means-objective network and found major factors in different levels which ultimately influence the selection of the ERP system. The addition of alternative systems to the established hierarchy was the last task for the evaluation process. Depending on the highest value obtained for alternative systems, the most suitable system can be selected from Wei et al. (2005)'s approach.

Zhang and Zou (2007) applied AHP in order to assess the risks in joint venture (JV) projects in China with the use of expert knowledge. Their method with AHP was not primarily based on identifying the best alternative and then to make the decision, which was originally proposed by Saaty (1980) though. In contrast, they kept their objective to measure the risk condition of JV projects, which was at the first level of their hierarchy. For the next levels, they identified three major risk groups affecting the risk condition and each risk group depended on several risk factors. Hence, their evaluation started with risk factors and finished with the risk condition of the project. In their evaluation, weighting represented the priority level or significance of the attribute in the context of any project, whereas the performance or impact of an attribute was calculated according to a specific project. Pair-wise comparison data of five experts was used to calculate weightings individually and the average was kept as the weighting in terms of the group's decision. The SAW method was adopted to evaluate the aggregate value out of the values of weighting and performance. They exploited fuzzy logic in order to minimise subjectivity by measuring the performance with assigned numbers for linguistic expressions of impact levels.

Kahraman, Ruan, and Doğan (2003) used the fuzzy AHP approach to select the best facility for a new factory for a Turkish motor company out of three alternative locations. The best facility was selected on the basis of four criteria: environmental regulation (ER); host community (HC); competitive advantage (CA); and political risk (PR). The criteria with themselves and also with alternatives (Istanbul, Ankara, and Izmir) were compared using compromised decisive data of three members of the decision-making group. The method applied in the problem was an extended analysis of fuzzy AHP, which found Izmir to be the best selection. The authors continued their interest in the method of extent analysis of AHP by incorporating the method in another application (Kahraman, Cebeci, & Ruan, 2004). This time it was to find the best catering service while providing the most customer satisfaction. In this case, three catering firms, namely Durusu, Mertol and Afiyetle, were considered and the problem was identified using a four-level hierarchy. Five experts from the Turkish Chamber of Food Engineers provided pair-wise comparison preferences for all attributes pertaining to the evaluation of the best catering company. Afiyette scored a very high priority level of 0.69 out of 1, and hence it was the recommended catering firm for the large textile company.

3. Methodology: industry-wide questionnaire

In order to find the importance and relative importance of the derived criteria and their related aspects, a questionnaire survey was conducted across Australian local councils. Table 3 shows those aspects and criteria: all abbreviations to denote aspects and criteria will be followed to represent any aspect or criterion henceforth.

Multi-criteria decision-making refers to selecting or ranking alternative(s) from available alternatives with respect to multiple but usually conflicting criteria. In practical situations, subjectivity and imprecision are always pre-

Table 3. Sustainability aspects and criteria

Aspect	Criterion
Environmental aspect (En)	Water management (En_1)
	Material sustainability (En_2)
	Energy efficiency (En_3)
	Waste management (En_4)
	Air and noise pollution (En_5)
	User comfort (En_6)
	Usage of hazardous goods and materials (En_7)
Economic aspect (Ec)	Life cycle cost (Ec_1)
	Land value (Ec_2)
	Local economy (Ec_3)
	Additional capital investment (Ec_4)
Social aspect (Sc)	Local community engagement (Sc_1)
	Community benefits and equity (Sc_2)
	Neighbourhood character (Sc_3)
	Employee well-being (Sc_4)
Functional aspect (Fn)	Impact of failure and response (Fn_1)
	Level of service (Fn_2)
	Compliance to building standards and regulations (Fn_3)

Table 4. Pair-wise comparison of linguistic variables using fuzzy numbers (source: Buckley, 1985)

Intensity of Fuzzy scale	Definition of linguistic variables	Fuzzy number	User defined
$\tilde{1}$	Similar importance	(L, M, U)	(_, 1, _)
$\tilde{3}$	Moderate importance	(L, M, U)	(_, 3, _)
$\tilde{5}$	Intense importance	(L, M, U)	(_, 5, _)
$\tilde{7}$	Demonstrated importance	(L, M, U)	(_, 7, _)
$\tilde{9}$	Extreme importance	(L, M, U)	(_, 9, _)
$\tilde{2}$, $\tilde{4}$, $\tilde{6}$, $\tilde{8}$	Intermediate values	(L, M, U)	(_, _, _)

sent in the multi-criteria decision-making process (Chen, Hwang, Beckmann, & Krelle, 1992). However, fuzzy AHP has the ability to minimise subjectivity and imprecision compared with general AHP (Buckley, 1985). Rather than using single numbers for pair-wise comparison, Buckley (1985) utilised fuzzy logic to create a different preference table for fuzzy AHP methods as shown in Table 4.

Moving from a single decision-maker's setting to a group decision-makers' setting increases the complexity in the decision-making process. The pilot survey among the research group suggested the practical impossibility of obtaining opinions via a questionnaire using a fuzzy AHP preference table rather than the general AHP preference table. This could have done if the objective was only to develop a model for one particular council; so pair-wise comparison opinions can easily be collected according to the opinions of one person or group in the council. However, the objective here is different and the proposed model is to widely apply within Australia. Therefore, the questionnaire was developed and opinions were sought from local councils in Australia using the general Satty's preference table.

As recommended by Fellows and Liu (2008), a pilot survey was conducted among the research team and research partners when designing the questionnaire. The final questionnaire was formulated in Survey Monkey web-based software using the pilot survey. Data collection through the questionnaire followed key informant approach (Knodel, Saengtienchai, Im-Em, & Vanlandingham, 2001; Morrissey, Ridgely, Goldman, & Bartko, 1994; Yadrick et al., 2001). Hence, the target respondents to the final questionnaire were key informants who occupy roles that make them knowledgeable about the core research issues addressed by the questionnaire (Campbell, 1955). It was obvious for the current research that key informants are building professionals from local councils in Australia (such as building managers, building engineers, infrastructure asset managers, infrastructure engineers) because they are responsible for and greatly engage in community building management.

The questionnaire was designed in two sections: Section 1 was to capture demographic details of the respondents and Section 2 to capture relative importance data for aspects and criteria. The purpose of Section 1 with demographic data was to confirm that key informants possess sufficient knowledge on community building management in order to proceed with Section 2 of the questionnaire. Following demographic questions were asked in Section 1:

1.0 Respondent current position;
2.0 How long have you been working in the current position;
3.0 Number of buildings under management of the council;
4.0 Please insert the state in Australia where your organisation is located;
5.0 Total years of work experience in building management.

It is noted that the participation of experts in giving opinions have been mostly limited to ten in similar AHP applications in the literature. However, the higher the number of experts involved, the greater the appropriateness of the solution. Hence, this study tried to capture as many responses as possible from the questionnaire. Finally responses obtained to the questionnaire fluctuated between a minimum of 46 responses and a maximum of 48 responses within five themes including sustainability aspects and four sustainability criteria, which was an excellent outcome for problems of such nature. Table 5 shows the responses received to all demographic questions mentioned above which will give a clear picture of respondents and their profile.

According to Table 5, respondent profiles are greatly aligned with the study proposed ones. It seems that duration of the current position of majority of them is within 1–5 years range (44% of all the responses); however, responses to question 5 proves that their total working experience in building management is greatly higher; only 19% of all respondents have experience less than 5 years in building management. Data also confirms that most councils responded to the questionnaire have at least 50 buildings under their management (only 5 councils had less than 50). All councils responded to the questionnaire represent all five states and two territories of Australia and majority came from Victoria where the researchers

Table 5. Responses to demographic questions

Question 1 Respondent current position:			Question 2 How long have you been working in the current position:			Question 3 Number of buildings under management of the council:			Question 4 Please insert the state in Australia where your organisation is located:			Question 5 Total years of work experience in building management:		
Response	Number of responses	As a percentage of all responses	Response	Number of responses	As a percentage of all responses	Response	Number of responses	As a percentage of all responses	Response	Number of responses	As a percentage of all responses	Response	Number of responses	As a percentage of all responses
Asset engineer	9	19%	1–5 years	21	44%	<50 buildings	5	10%	NSW	7	15%	1–5 years	9	19%
Asset coordinator	5	10%	5–10 years	17	35%	50–100 buildings	4	8%	NT	1	2%	5–10 years	11	23%
Asset manager	16	33%	10–15 years	7	15%	100–150 buildings	10	21%	QLD	7	15%	10–15 years	13	27%
Building engineer	2	4%	15–20 years	1	2%	150–200 buildings	8	17%	SA	5	10%	15–20 years	3	6%
Building coordinator	6	13%	20–25 years	1	2%	200–250 buildings	9	19%	TAS	2	4%	20–25 years	3	6%
Building manager	10	21%	>25 years	1	2%	250–300 buildings	3	6%	VIC	23	48%	>25 years	9	19%
						300–350 buildings	4	8%	WA	3	6%			
						350–400 buildings	1	2%						
						400–450 buildings	1	2%						
						>500 buildings	3	6%						

and partners were located. The reason to higher responses was due to the leading role of Municipal Association of Victoria who was one of our greatly contributed industry partner. In summary, all captured data validates that all the respondents referred for our study possess sufficient knowledge level to act as key informants and represent Australia.

4. Data analysis

Obtaining data for section 2 of this Questionnaire is quite complex compared to the previous questionnaire conducted by the same research project. The nature of giving responses is completely different because the respondent needed to be aware of each item of the set prior to giving the pair-wise opinion. In this case, consistency of data is essential in terms of the reliability of the result. Fortunately, (Saaty)'s AHP has an inbuilt consistency check of data, which is reflected by the consistency ratio. This has been discussed in Eq. (5).

As shown in Figure 1, an AHP hierarchy can be constructed for the proposed decision-making structure. For decision making, it needs individual weighting and impact values of four sustainability aspects and their related criteria. The figure interprets the idea with the symbols of 'W' and 'I' which represent individual weighting and impact values respectively. The designed questionnaire survey is only targeted to compute weighting values of aspects and criteria; hence, a detailed analysis will be given in this section. As the decision-making structure consists of four aspects and their criteria, weighting calculation is done in the following order:

- Weighting calculation of sustainability aspects;
- Weighting calculation of environmental criteria;
- Weighting calculation of economic criteria;
- Weighting calculation of social criteria;
- Weighting calculation of functional criteria.

For each calculation, relative importance scores in pairwise comparison of aspects and criteria were captured with linguistic terms and their associated scales according to Table 1.

4.1. Weighting calculation of sustainability aspects

Each respondent had given different scales for the same pairwise comparison of sustainability aspects; hence, the mean value of all responses was considered to be used in the final matrix of comparison data. If A_{ij} is the final relative importance value of Aspects A_i and A_j; where, i = 1, 2, 3, 4 and j = 1, 2, 3, 4 for the present situation. Say r^{th} respondent's score is denoted by $U_{r(i,j)}$; hence, the mean value i.e. A_{ij} can be computed with the following equation:

$$A_{ij} = \frac{\sum_{r=1}^{r=n} U_{r(i,j)}}{n}, \quad (9)$$

where: n is the number of respondents.

The total number of responses received was 48 to compare the aspects against the significance to corporate (total) sustainability impact; hence, n equals to 48 for the present problem. Moreover, A_1, A_2, A_3 and A_4 represent Environmental (En), Economic (Ec), Social (Sc) and Functional aspects (Fn) and it is obvious that all A_1A_1, A_2A_2, A_3A_3 and A_4A_4 values equal to 1. A_{ji} equals to the reciprocal value of Aij is another obvious fact when forming the comparison data matrix. As a result, only A_1A_2, A_1A_3, A_1A_4, A_2A_3, A_2A_4 and A_3A_4 are mainly to be calculated for the computation purpose. Based on individual results of respondents for the six comparisons mentioned above, final values were calculated using Eq. (9). The final results suggested that A_{12} = 1.965; A_{13} = 2.000; A_{14} = 1.526; A_{23} = 2.142; A_{24} = 1.558 and A_{34} = 1.467. Upon these values, final comparison data matrix was formed and it is shown in Table 6.

Table 6. Matrix of comparison data for sustainability aspects

Aspects	$A_1(En)$	$A_2(Ec)$	$A_3(Sc)$	$A_4(Fn)$
$A_1(En)$	1	1.9651	2.0002	1.5264
$A_2(Ec)$	0.5089	1	2.1421	1.5581
$A_3(Sc)$	0.4999	0.4668	1	1.4668
$A_4(Fn)$	0.6551	0.6418	0.6818	1
Σ	2.6639	4.0737	5.8242	5.5513

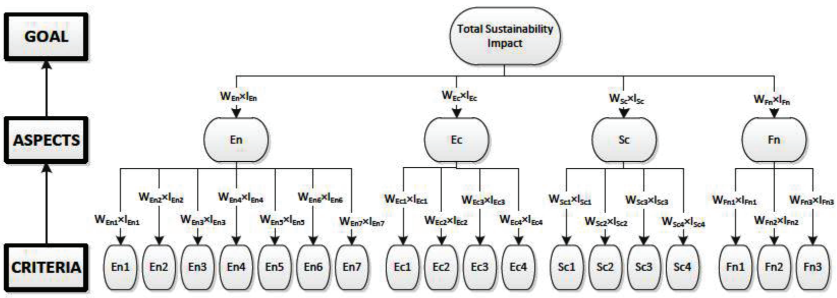

Figure 1. AHP hierarchical decision-making structure

Based on the values of comparison matrix, weighting values of A_1, A_2, A_3 and A_4 can be calculated using Eq. (2). As the first step of the calculation process, normalised matrix will be produced and weighting values can be calculated based on these values. Table 7 shows the normalised matrix for original comparison data previously obtained for aspects.

Table 7. Normalized matrix for sustainability aspects

Aspects	*En*	*Ec*	*Sc*	*Fn*
En	0.3753	0.4824	0.3435	0.2750
Ec	0.1910	0.2455	0.3678	0.2807
Sc	0.1876	0.1146	0.1717	0.2642
Fn	0.2459	0.1576	0.1171	0.1801
Σ	1	1	1	1

Therefore, weighting values of each aspect can be calculated and those values are shown below:

$W_{A1} = W_{En} = 0.3691$; $W_{A2} = W_{Ec} = 0.2712$;
$W_{A3} = W_{Sc} = 0.1845$; $W_{A4} = W_{Fn} = 0.1752$.

Weighting values are not confirmed yet until the reliability of the data used in the calculation process is proved. Hence, the very next step after obtaining the weighting values was to check the reliability of the input values by carrying out the consistency check. The main task of the reliability-check process was to calculate the consistency ratio, which first requires maximum Eigen value (λ_{max}) to be calculated. As its first step, R matrix can be produced according to Eq. (7) and it is shown below:

$$[R] = \begin{bmatrix} 1 & 1.965 & 2.000 & 1.526 \\ 0.509 & 1 & 2.142 & 1.558 \\ 0.500 & 0.467 & 1 & 1.467 \\ 0.655 & 0.642 & 0.682 & 1 \end{bmatrix} \begin{bmatrix} 0.3691 \\ 0.2712 \\ 0.1845 \\ 0.1752 \end{bmatrix} = \begin{bmatrix} 1.539 \\ 1.127 \\ 0.753 \\ 0.717 \end{bmatrix}.$$

Once R is known, overall λ_{max} can be calculated using Eq. (8); therefore,

$$\lambda_{max} = \frac{\sum_{i=1}^{n} R_{i1} / W_i}{n} = 4.1239.$$

The consistency ratio (CR) is depicted by the consistency index (CI) and random consistency value (R) (see Eq. (5)). Since the size of matrix ($n = 4$) is known and λ_{max} is already calculated, CI can be calculated by Equation 6:

$$CI = \frac{\lambda_{max-n}}{n-1} = 0.0413.$$

R varies according to the size of matrix; however, no calculation is required because those values are already known and shown in Table 2. The R value related to the current problem is 0.90 due to the size of matrix being equal to 4. Hence, CR value can be obtained applying CI and R values in Equation 5 as shown below:

$$CR = \frac{CI}{R} = \frac{0.0413}{0.90} = 0.0459.$$

Pedrycz and Gomide (2007) reported that consistency of results can be assured if the analysis can obtain a CI value less than 0.1. Since their recommendation was mainly relied on fuzzy AHP data, making the decision based on CR value (CR is less than 0.1) is beyond doubt for any situation. Hence, the consistency of pair-wise data used for the sustainability aspects in this study satisfies both methods of check. As a result, weighting results can be confirmed and used for practice.

4.2. Weighting calculation of sustainability criteria

Similar process was followed to calculate weightings of sustainability criteria of four sustainability aspects. The total number of responses was similar (46) to all four sustainability aspects to compare their criteria. Basic representation for criteria is given by letter C and they are further denoted by number of criteria for a given aspect; for an example, criteria of environmental aspect has been represented as $C_1(En_1)$, $C_2(En_2)$, $C_3(En_3)$, $C_4(En_4)$, $C_5(En_5)$, $C_6(En_6)$ and $C_7(En_7)$. Similar method has been followed to other aspects' criteria: $C_1(Ec_1)$, $C_2(Ec_2)$, $C_3(Ec_3)$ and $C_4(Ec_4)$ for criteria of economic aspect; $C_1(Sc_1)$, $C_2(Sc_2)$, $C_3(Sc_3)$ and $C_4(Sc_4)$ for criteria of social aspect; $C_1(Fn_1)$, $C_2(Fn_2)$ and $C_3(Fn_3)$ for criteria of functional aspect. Average values of pairwise comparison data are computed by Equation 10 below, modifying Equation 9 for criteria.

$$C_{ij} = \frac{\sum_{r=1}^{r=n} U_{r(i,j)}}{n}, \quad (10)$$

where: n is the number of respondents. Based on all the average values of respondents' data, matrix of comparison data for criteria of each aspect is developed and they are shown in Table 8.

Weighting values can then be easily calculated following Equation 2 and with the production of normalised matrix of comparison data for criteria of each aspect. Table 9 shows those normalised values for different matrices.

Therefore, weighting values for environmental criteria can be obtained and presented below:

$W_{En1} = 0.2304$; $W_{En2} = 0.2111$; $W_{En3} = 0.2148$; $W_{En4} = 0.1177$; $W_{En5} = 0.0829$; $W_{En6} = 0.0793$; $W_{En7} = 0.0637$.

Similarly, weighting values for economic, social and functional criteria were obtained and presented below:

$W_{Ec1} = 0.0.5553$; $W_{Ec2} = 0.1212$; $W_{Ec3} = 0.1722$; $W_{Ec4} = 0.1513$.

$W_{Sc1} = 0.0.4216$; $W_{Sc2} = 0.3276$; $W_{Sc3} = 0.1430$; $W_{Sc4} = 0.1078$.

$W_{Fn1} = 0.0.4660$; $W_{Fn2} = 0.2782$; $W_{Fn3} = 0.2558$.

To confirm weighting values, consistency check was undertaken for each data set of environmental, economic, social and functional criteria. Their maximum Eigen values (λ_{max}) eventually affect the consistency ratio of sets of data upon which data reliability is generally checked. R matrix is required for each dataset in order to find λ_{max} and it can be produced by multiplying original pairwise

Table 8. Matrix of comparison data for sustainability criteria

En	En_1	En_2	En_3	En_4	En_5	En_6	En_7	Ec	Ec_1	Ec_2	Ec_3	Ec_4	Sc	Sc_1	Sc_2	$Sc3$	$Sc4$	Fn	Fn_1	Fn_2	Fn_3
En_1	1	1.7031	1.2450	2.3391	2.4464	2.3367	2.5002	Ec_1	1	5.2609	3.6232	2.9420	Sc_1	1	1.7739	3.0580	2.9217	Fn_1	1	1.9620	1.5695
En_2	0.5872	1	1.4074	2.4306	2.9640	2.4712	2.7424	Ec_2	0.1901	1	0.8455	0.7890	Sc_2	0.5637	1	3.3188	3.0406	Fn_2	0.5097	1	1.2693
En_3	0.8058	0.7105	1	2.7536	3.3884	2.8783	2.9826	Ec_3	0.276	1.1827	1	1.4741	Sc_3	0.3270	0.3013	1	1.8594	Fn_3	0.6371	0.7878	1
En_4	0.4275	0.4114	0.3631	1	2.0944	2.0108	2.1538	Ec_4	0.3399	1.2675	0.6784	1	Sc_4	0.3423	0.3289	0.5378	1				
En_5	0.4088	0.3374	0.2951	0.4775	1	1.5367	1.5917														
En_6	0.4280	0.4047	0.3474	0.4973	0.6508	1	1.7797														
En_7	0.4000	0.3646	0.3352	0.4643	0.6282	0.5619	1														
Σ	4.0573	4.9317	4.9892	9.9624	13.1722	12.7956	14.7504	Σ	1.8060	8.7110	6.1471	6.2051	Σ	2.2330	3.4041	7.9146	8.8217	Σ	2.1468	3.7499	3.8388

Table 9. Normalised matrix for sustainability criteria

En	En_1	En_2	En_3	En_4	En_5	En_6	En_7	Ec	Ec_1	Ec_2	Ec_3	Ec_4	Sc	Sc_1	Sc_2	Sc_3	Sc_4	Fn	Fn_1	Fn_2	Fn_3
En_1	0.246	0.345	0.249	0.235	0.186	0.183	0.170	Ec_1	0.5537	0.6039	0.5894	0.4741	Sc_1	0.4478	0.5211	0.3864	0.3312	Fn_1	0.4658	0.5232	0.4088
En_2	0.145	0.203	0.282	0.244	0.225	0.193	0.186	Ec_2	0.1052	0.1148	0.1376	0.1271	Sc_2	0.2524	0.2938	0.4193	0.3447	Fn_2	0.2374	0.2667	0.3306
En_3	0.199	0.144	0.200	0.276	0.257	0.224	0.202	Ec_3	0.1528	0.1358	0.1627	0.2376	Sc_3	0.1464	0.0885	0.1263	0.2108	Fn_3	0.2968	0.2101	0.2605
En_4	0.105	0.083	0.072	0.100	0.159	0.157	0.146	Ec_4	0.1882	0.1455	0.1104	0.1612	Sc_4	0.1533	0.0966	0.0680	0.1134				
En_5	0.101	0.068	0.059	0.048	0.076	0.120	0.108														
En_6	0.105	0.082	0.070	0.050	0.049	0.078	0.121														
En_7	0.099	0.074	0.067	0.047	0.048	0.044	0.068														
Σ	1	1	1	1	1	1	1	Σ	1	1	1	1	Σ	1	1	1	1	Σ	1	1	1

comparison matrix (P) and weighting matrix (W) as depicted in Eq. (7). Produced R matrices are shown below:

$$[R]^{En} = \begin{bmatrix} 1.718 \\ 1.594 \\ 1.620 \\ 0.885 \\ 0.616 \\ 0.592 \\ 0.472 \end{bmatrix} \quad [R]^{Ec} = \begin{bmatrix} 2.262 \\ 0.492 \\ 0.692 \\ 0.610 \end{bmatrix};$$

$$[R]^{Sc} = \begin{bmatrix} 1.755 \\ 1.368 \\ 0.580 \\ 0.437 \end{bmatrix} \quad [R]^{Fn} = \begin{bmatrix} 1.413 \\ 0.840 \\ 0.772 \end{bmatrix}.$$

Once R is known, overall λ_{max} can be calculated using Equation 8; therefore,

$$\lambda_{max}^{(En)} = \frac{\sum_{i=1}^{n} R_{i1} / W_i}{n} = 7.4816;$$

$$\lambda_{max}^{(Ec)} = \frac{\sum_{i=1}^{n} R_{i1} / W_i}{n} = 4.0458;$$

$$\lambda_{max}^{(Sc)} = \frac{\sum_{i=1}^{n} R_{i1} / W_i}{n} = 4.1112;$$

$$\lambda_{max}^{(Fn)} = \frac{\sum_{i=1}^{n} R_{i1} / W_i}{n} = 3.0237.$$

According to Eq. (5), consistency ratio (CR) values can be obtained for each dataset when CI and R values are known. λ_{max} values are already calculated and size of matrix values are also known; hence, captured CI values using Eq. (6) are given below:

$$CI^{(En)} = 0.0803; CI^{(Ec)} = 0.0153;$$

$$CI^{(Sc)} = 0.0371; CI^{(Fn)} = 0.0119.$$

Different R values depending on the size of the matrix were used for the calculations above and they were directly obtained from Table 2. Hence, R value related to the environmental criteria is 1.32 due to the size of matrix being equal to 7. That value for economic and social criteria is 0.90 because the size of both matrices equals to 4. For financial criteria, that value is even a lesser value equals to 0.58 because there exists only 3 functional criteria. The application of these CI and R values in Equation 5 will eventually compute CR values for each dataset as shown below:

$$CR^{(En)} = \frac{CI}{R} = 0.0608; CR^{(Ec)} = 0.017;$$

$$CR^{(Sc)} = 0.0041; CR^{(Fn)} = 0.0205.$$

In Fuzzy AHP situations, Pedrycz and Gomide (2007) identified that the data reliability can be assured if CI value is less than 0.1. As Saaty (1980) pointed out, CR is less than 0.1 can be applied to any situation for data consistency check. The results of CI and CR values for all criteria data sets show they all are less than 0.1; hence, the consistency of pairwise data sets is highly satisfactory. Consequently, weighting results of criteria can be confirmed and used for practice.

5. Results and discussion

Following data analysis, Figure 2 clearly distinguishes weighting value differences between aspects. It suggests that the environmental aspect (En) is the most significant aspect in terms of sustainable management of community buildings whereas the functional aspect (Fn) is the least significant aspect. Economic (Fc) and social (Sc) aspects have taken the second and third places in the list in terms of significance to sustainable management of community buildings. On the other hand, Figure 3 captures weightings of criteria of different aspects and the results showcase more and less significant criteria within the same aspect. Out of seven environmental criteria, En_1 (water management) is the most significant criterion while En_7 (usage of hazardous goods and materials) is the least significant criterion. In contrast, Ec_1 (life cycle cost) and Ec_2 (land value) are the most and least significant criteria respectively for economic aspect. In social terms, respondents have given the highest priority to Sc_1 (local community engagement) while Sc_4 (employee well-being) is given the lowest priority. Functionally, Fn_1 (impact of failure and response) is recorded as the most significant criterion whereas, Fn_3 (compliance to building standards and regulations) is the least significant criterion.

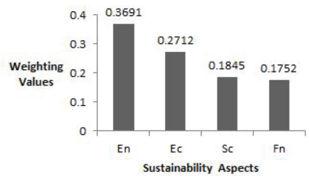

Figure 2. Weighting values of sustainability aspects

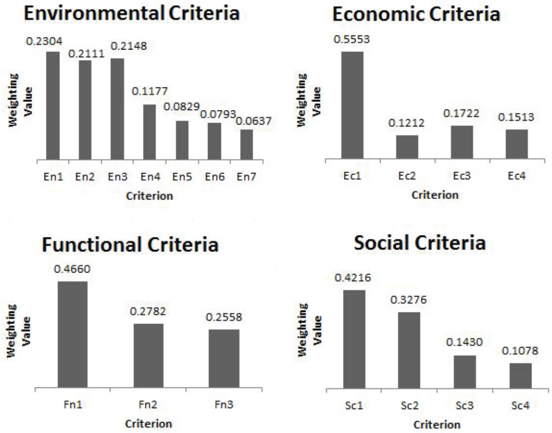

Figure 3. Weighting values of sustainability criteria

In situations where the combined impact is considered, the evaluations will always be relied on two major parameters: weighting and individual impact (refer Figure 1). Weighting provides the extent of significance of each variable to the combined effect. In relevant to the present study, sustainability criteria and aspects have a combined effect to the total sustainability impact of a given building component; hence, weighting values of each criterion and aspect have been calculated in data analysis section. While weighting is computed comparing all variables, individual impacts of variables are only assigned based on the particular variable. This study focuses on building management; hence, individual impacts of different building components are required for the final impact value. In contrast, weighting values are fixed for different building components because the significance is considered in terms of the whole context of building management. Following the procedure shown in Figure 1, local councils are in a great position not only to find total sustainability impact (may also refer to an index) but also other impact values such as environmental impact, economic impact, social impact and financial impact. Based on these values, they can classify building components as highly or less influential to the sustainable management of community buildings. Consequently, they can prioritise building components for their maintenance activities.

The whole study followed two case studies to demonstrate the decision-making model. The first case study is selected for this paper and it was undertaken with a partner council of the research in Victoria. Its results are only used to give a brief idea of the practical approach that local councils may apply for effective and sustainable decision-making using the given model. The case followed the same element hierarchy as the council (Element group and Element) and the sheet of impact values was created against the element hierarchy. The researchers consulted the building manager and his team who are involved in the management of community buildings to seek the impact values of all 18 criteria for the selected building components. In addition, the study used the weighting values obtained here as the defaults to be used for those building components. Weighted impact values were considered for sustainability indices and they were generally obtained aggregating weighting values and impact values. Detailed explanation of the weighted impact values calculation process will be given in future publications. The study selected one of the council's community halls for the case study.

Table 10 provides sustainable indices values obtained from the case study for only 23 selected building elements.

Based on Table 10 data, that local council can determine the extent to which any particular building element

Table 10. Sustainability index values

Element group	Element	Environmental index	Economic index	Social index	Functional index	Sustainability index
Essential services	Cabinets	1	1	1.07	2.72	1.31
	Exit doors	1	1	1.14	2.86	1.35
	Fire hydrants/fire mains	1.46	1.83	1.14	2.86	1.75
	Mechanical & air conditioning	2.06	2.67	1.14	2.86	2.19
	Valves	1.46	1	1.14	2.86	1.52
Finishes	Floors	1.24	1	1.6	2.02	1.38
	Wall	1.24	1	1.6	2.02	1.38
	kitchen	1.11	1	1.6	2.02	1.33
Fittings	Door furniture	1.08	1	1.6	2.02	1.32
	Door closers	1.08	1	1.6	2.02	1.32
	Fitments	1.16	2.67	2.2	2.86	2.06
Services	ESM	1	2.67	1.14	2.86	1.8
	Electrical	1	2.67	1.14	2.86	1.8
	Plumbing	2.57	2.95	2.8	3	2.79
Substructure	Column	1.16	1.83	2.2	2.02	1.69
	Column foundations	1.16	1	2.2	2.02	1.46
	Damp-proofing membranes	1.16	1	2.2	2.02	1.46
	stumps	1.26	1.83	2.2	2.02	1.72
Superstructure	Ceiling	1.24	1.7	1.6	2.02	1.57
	External doors	1.86	1.83	2.2	2.02	1.94
	External wall	1.97	1.83	2.2	2.02	1.98
	Internal doors	1.13	1.7	1.6	2.02	1.53
	Windows	2.12	1.97	2.8	2.02	2.19

will have an impact to their sustainable building management. For example, they can easily distinguish a higher sustainability impact from mechanical and air conditioning units than cabinets if their perception on total sustainability aspect. It will also be the similar result for the same building elements if that council's focus is on environmental aspect only. The main implication of these findings is that they can be utilised to prioritise future maintenance and operation activities. To elaborate, local councils may only perform predictive maintenance tasks of only selected building elements for a given period of time due to the constraints of their budget. The selection of building elements will be mainly based on the decision-making process suggested here.

Conclusions

This research project previously established a comprehensive decision-making structure for the sustainable management of community buildings utilising four sustainable aspects (Environmental, Economic, Social and Functional) and their related criteria (See Table 3). This structure could well place in a decision-making model of which the main purpose was to evaluate sustainability impacts of building components. For this, individual impacts from criteria and aspects can be obtained with a numbering scale and their attached linguistic terms; however, significance contribution by individual aspects and criteria has to be considered to the final integrated impact. Hence, this paper focused on calculating those significance amounts; in other terms their weighting values of sustainability aspects and criteria. The problem's nature justified the application of AHP, widely used application in MADM, for this purpose. The method was mainly relied on pair-wise comparison data; hence, the research conducted an industry wide questionnaire across Australian local councils to capture them.

The range of the responses to the questionnaire was within 46 to 48, which is a remarkable outcome for a problem of this kind and increased the outcomes' validity. Data analysis was done in order to capture weighting values of sustainability aspects and criteria. Not only capturing weighting values data analysis also included the reliability check of the captured data; otherwise, results may not be accurate. Each data set confirmed the reliability of data for using in analysis and weighting results were presented for five data sets related to sustainability aspects, environmental criteria, economic criteria, social criteria and functional criteria. Those results confirmed that the environmental aspect is the most significant aspect among other aspects in terms of the sustainable management of community buildings. Water management was assigned the highest weighting value out of environmental criteria; therefore it was taken as the most significant criterion for the environmental aspect. Similarly, the highest priority was given to the criterion- 'life cycle cost' from economic aspect, 'local community engagement' from social aspect and 'impact of failure and response' from functional aspect.

Then, a case study was applied to perform sustainability impact assessment; hence, all the weighting values obtained here were taken into the decision-making model and configured them as the default values for sustainability aspects and criteria.

Particular impacts of different building elements for each criterion were obtained consulting building management team of that local council. Based on these weighting values and particular impacts values, sustainability impact values can be derived by applying on the decision-making structure as shown in Figure 1. The derived values were presented as the case study results in which that local council can easily measure and compare sustainable impact values of different building elements. The phenomenon can be mainly used for the planning of their future maintenance and operation tasks. More focus is given to the analysis of weighting calculation in this paper; hence, future works include the detailed analysis of the development of the decision-making model supported with case data. Two working models based on two methods: AHP, and combined AHP and Neuro-Fuzzy system will be presented in future publications.

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