A practice mining system for the delivery of sustainable retirement villages

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A Practice Mining System for the Delivery of Sustainable Retirement Villages

Abstract

With the wide recognition of sustainable development, a range of sustainable practices has been incorporated into the development and operation of retirement villages to provide a sustainable living environment for residents in Australia. The retirement village sector is seeking effective methods of reusing these historical practices to facilitate the future development and operation of sustainable retirement villages. However, this is challenging and there has been no research to date into this issue. Therefore, this study aims to develop a practice mining system (PMS) to address the research gap. By using multiple case studies for data collection and case-based reasoning (CBR) for data mining, the study develops the CBR-PMS, which comprises a Data Transforming and Location System, a Data Warehouse, and a Data Mining and Reusing Engine. The CBR-PMS is a data management and mining system that can be adopted to retain, capture, reuse, and revise prior sustainable practices to facilitate the future development and operation of sustainable retirement villages. Case studies and expert judgements are used in its demonstrations and validation, and satisfactory performance is achieved. It is concluded that the CBR-PMS is an effective tool for retaining and transferring prior practices and acts as an innovative tool of knowledge management and organizational learning in the retirement living sector. Although the CBR-PMS is at its conceptual stage and requires some automation to make it user-friendly, it provides practical insights into the development of a sustainable living environment and benefits the development of data mining systems for other sustainability initiatives.

Keywords

Practice mining system; Sustainability; Retirement villages; Case-based reasoning; Australia

1. Introduction

Sustainable development, which means meeting the needs of the present without compromising the ability of future generations to meet their own needs, has been widely accepted in both theory and practice (Hopwood, 2005). In recent decades, sustainable development has been increasingly incorporated into the development of communities to provide the public with a livable environment (Xia et al., 2015). It is believed that developing sustainable communities helps achieve a balance between environmental concerns and economic development, while simultaneously enhancing local social relationships (Bridger and Luloff, 1999). Consequently, various government-based sustainable community initiatives have emerged in different countries, such as *Sustainable communities: Building for the future* in the United Kingdom and *Working together for better sustainable communities* in Queensland, Australia (Department of Housing and Public Works, 2016; Office of the Deputy Prime Minister, 2003).

Retirement villages are a viable living option for older Australians, accommodating 5.7% of seniors aged 65 years and over in 2014 (Hu et al., 2017a). This penetration rate is projected to increase to 7.5% in 2025 due to population ageing and the benefits of living in retirement villages (Retirement Living Council, 2014). Similar to general communities, the development of retirement villages is suggested to embrace social, economic, and environmental sustainability features to deliver a sustainable living environment (Xia et al., 2015). Sustainable retirement villages can respond well to residents' social, economic, and environmental sustainability needs (Xia et al., 2015), and living there can benefit residents in many ways, such as improved social interaction, safety, affordability, respect, and protected privacy (Hu et al., 2017a).

Currently, an increasing number of village developers, both private and not-for-profit, have demonstrated their commitment to providing a sustainable living environment for their residents (Hu et al., 2017b). Consequently, various sustainable practices have been incorporated into the development and operation of retirement villages, such as innovative design, age-friendly site planning, and waste management (Zuo et al., 2014). Reusing these practices provides developers with useful insights into the future development and operation of sustainable retirement villages (Zuo et al., 2014). They especially help developers avoid repeating prior mistakes and to learn from past best practices by revisiting historical situations and reexamining the lessons learnt in those situations.

However, reusing historical sustainable practices is not easy in the Australian retirement living sector. First, it is hard to assemble prior practices, as sustainable practices are retained in different sites and there is a lack of databases for gathering and storing relevant information. Second, the reuse of sustainable practices is unstructured and intuition-based, for which it is difficult to define accurate rules to facilitate the reuse process. Moreover, developers do not usually have enough knowledge of data mining, and their reuse of past practices is mainly limited to their own projects, which hinders the effective reuse of previous experiences with a wider range of villages. Therefore, the Australian retirement village industry is calling for effective approaches to reusing historical sustainable practices to benefit the development and operation of sustainable retirement villages. Notwithstanding, there has been no research to date into this important issue. In response, this study aims to propose a strategy of effectively retrieving and reusing historical sustainable practices of village developments and operations. To achieve this aim, the study develops a practice mining system (PMS) based on case-based reasoning (CBR). CBR is adopted due to its strong data mining capabilities. It is expected that the CBR-PMS will not only benefit developers' knowledge management and organizational learning but also promote the reuse of best practices of other sustainability initiatives. In addition, the CBR-PMS expands the knowledge areas of environmental gerontology by incorporating knowledge management and organizational learning philosophies based on artificial intelligence technologies, which represents an advancement in the literature of developing an age-friendly living environment.

2. Literature review

2.1. Age-friendly retirement villages in the world

The provision of housing and care-services with age-friendly features for older people has become a consensus of policy makers and service providers around the world, which has consequently promoted the development of age-friendly communities (e.g., lifetime neighborhoods, livable communities) (Liu et al., 2009). Retirement villages are a long-term accommodation and care option for older adults in many industrialized countries, such as the United Kingdom, the United States, Australia, and New Zealand (Hu et al., 2017a). Encouraging the development of age-friendly environments to facilitate older adults' active ageing promotes the incorporation of age-friendly features in the retirement village setting (Bernard et al., 2007). An age-friendly retirement village promotes the residents' active ageing based on optimized physical and social environments and supporting infrastructure (Liddle et al., 2014). The development and operation of an age-friendly retirement village should focus on its "strategic and ongoing improvement process", "physical environment", "social environment", "supportive infrastructure", and "respect and social inclusion" (Liddle et al., 2014). Living in age-friendly retirement villages benefits residents in such ways as improved health, safety, reduced social isolation, and affordability (Bernard et al., 2007; Liddle et al., 2014).

It should be noted that age-friendly retirement villages focus more on the economic and social sustainability of their environments. First, age-friendly retirement villages place a high priority on residents' affordability to ensure that their living environments are economically sustainable, which is crucial given the residents' reduced financial capacity after retirement (Finn et al., 2011). In addition, age-friendly retirement villages provide residents with a socially-sustainable living environment (e.g., support, participation, safety, and engagement) such as in selecting a suitable location and delivering appropriate services and facilities (Sugihara and Evans, 2000; Liddle et al., 2014). However, environmental sustainability has been largely ignored in the development and operation of age-friendly retirement villages (Hu et al., 2017b). This is not consistent with older people being generally concerned with consumption of resources and their need for their communities to be more environmentally sustainable (Pillemer et al., 2011; Xia et al., 2014). In Australia, the development and operation of sustainable retirement villages alleviates this issue through incorporating green features into the delivery of an age-friendly living environment (Hu et al., 2015).

2.2. Sustainable retirement villages in Australia

Delivering a sustainable living environment in retirement villages is a new phenomenon in Australia, which is contributed to by an increasing level of public awareness of sustainable development, and a growing demand for delivering an age-friendly living environment to older adults (Barker et al., 2013). The residents' social, economic, and environment needs can be well satisfied in sustainable retirement villages. In particular, a sustainable retirement village enables its residents to be socially connected within their community to prevent their social isolation, loneliness, and depression (Buys, 2001). Additionally, a sustainable retirement village is affordable to residents, given their reduced financial capacity in older age (Finn et al., 2011). Moreover, a sustainable retirement village has green features (e.g., energy efficiency and a qualified indoor environment) to improve the health of its residents and the environment (Zuo et al., 2014).

The benefits resulting from residing in sustainable retirement villages have increased stakeholders' interests in their development. For instance, residents are concerned with the consumption of unsustainable resources, and would like their villages to be greener even though they may have to pay more (Barker et al., 2013; Xia et al., 2014). In addition, the Green Building Council of Australia has developed a Green Star rating tool for retirement living, which positively supports the development of sustainable retirement villages (Green Building Council of Australia, 2015). More importantly, many developers have incorporated sustainable strategies into the development of their villages (e.g., care and services provision and accessibility, energy efficiency, and affordable living) (Hu et al., 2017b). Consequently, a number of sustainable practices have been adopted. For instance, Xia et al.'s (2015) case study in an Australian private retirement village found that its sustainable practices were reflected in landscaping and design, the provision of facilities and services, internal communication, social activity organization, cost, and affordability. In not-for-profit retirement villages, Zuo et al. (2014) and Hu et al. (2018) found that sustainable practices were adopted in project location selection, design, construction, site planning, services and facilities provision, social activity organization, and cost arrangements. It is undoubtable that prior sustainable practices provide valuable insights into the development and operation of an appropriate living environment in retirement villages, and proposing appropriate strategies is vital for their good use.

2.3. Reusing practices in the development and operation of sustainable retirement villages

The unstructured nature of the decision-making process of project managers over the development and operation of sustainable retirement villages results in some challenges. In particular, it is difficult to determine the most appropriate strategies to respond to the residents' aged requirements effectively due to the lack of any accurate rules for reasoning. To address this issue, it is suggested to effectively capture and reuse the historical experiences of village developments and operations (Hu et al., 2018; Zuo et al., 2014). This provides a promising approach of promoting the development and operation of a sustainable living environment in retirement villages. For instance, according to Zuo et al., (2014), the technologies and techniques used in prior villages can be adopted easily and affordably to new village developments, and some environmentally friendly practices can be incorporated into existing operations.

Project managers encounter some issues resulting from the reuse of historical experience. For instance, as project managers propose strategies based mainly on their own experience and knowledge and their participation of project developments is limited, their experience in their reuse is therefore usually limited merely to the projects in which they participated. Strategies of addressing this issue are still lacking; requiring the development of experience mining systems that can be adopted to retrieve experience and knowledge from a large number of historical projects and reuse them in appropriate ways. The development of a CBR-based data mining system provides a feasible means of addressing this issue given the powerful data mining capabilities of CBR (Hu et al., 2016).

2.4. CBR and experience mining in the construction industry

The construction industry is experience-based, and construction professionals usually address problems by recalling and reusing their previous experiences and knowledge (Carrillo and Chinowsky, 2006). Past construction experience is valuable to construction organizations, as reusing these experiences provides a variety of benefits. For instance, reusing past experience is positively associated with the innovation, competitiveness, and business performance of construction organizations (Egbu, 2004; Kamara et al., 2002).

CBR is an artificial intelligence tool arising out of research into cognitive science, and its development is stimulated by a desire to understand people’s memory (Watson, 1994). CBR addresses a new problem by remembering previous similar situations and reusing information and knowledge of those situations (Watson and Marir, 1994). Its problem-addressing process therefore mimics the human mind intelligently based on previous experiences. CBR has been adopted in various fields to assist decision-making intelligently, such as in marketing (Changchien and Lin, 2005) and medicine (Holt et al., 2005). In the construction industry, CBR has been confirmed as an effective approach to capture and reuse experience to improve productivity (Hu et al., 2016) given the similar mind-sets of CBR and construction problem solving. For instance, CBR was successfully used to facilitate construction hazard identification through recalling and learning from historical experiences (Goh and Chua, 2009; Goh and Chua, 2010). CBR has additionally been adopted to address other such construction issues as design (Kumar and Raphael, 1997), cost estimation (An et al., 2007), construction tendering, bidding and procurement (Chua et al., 2001; Luu et al., 2006), and sustainable urbanization (Shen et al., 2013). The use of CBR in the construction sector has resulted in the development of such automated

CBR systems as EQUAL, used for contractor prequalification analysis (Ng, 2001), and CBROOF, used for the maintenance management of low-slope roofs (Morcous and Rivard, 2003).

3. Research methods

The development of a PMS includes the identification of historical practices and the development of a suitable model architecture for retrieving, reusing, and revising these practices (Shen et al., 2013). Thus, to develop a PMS to facilitate the development and operation of sustainable retirement villages, previous sustainable practices of village developments and operations should be identified, and a suitable experience mining model architecture proposed to store, retrieve, revise, and reuse these practices.

3.1. Identifying sustainable practices of village developments and operations

Currently, no existing databases contain the sustainable practices of village developments and operations in Australia. As sustainable practices are adopted in different such stages of project development and operation as design, site planning, construction, and maintenance (Hu et al., 2018), it is very challenging to include all practices in one study. Given the profound effects of site planning on the residents' daily life (e.g., safety, privacy, independence, and social interaction) (Carstens, 1993), only sustainable site planning practices are considered in this study. In addition, there are dynamic interactions between a village's site planning and its residents' perceptual, functional, and social changes associated with the ageing process, indicating the importance of designing a suitable village site (Carstens, 1993). Moreover, as it comprises a major part of village development, the selection of site planning ensures the representativeness of the practice mining system development process.

The major elements of site planning include the site entry/exit, site drive, main arrival court, unit and building entries, parking and building access, shared social space, pedestrian and bicycle circulation, and amenities and design detailing (Carstens, 1993). Here, case studies were employed to identify sustainable practices, and data were collected by interviews, direct observations, and documentation. Based on the three methods, both 'invisible' and 'concrete' sustainable practices able to be found. The 'invisible' practices are soft strategies used to improve the sustainability of a retirement village's living environment. They cannot be observed directly but can be retrieved based on interviews and document analysis. The 'concrete' practices are physical strategies used to satisfy the residents' sustainable living needs. These can be identified based on direct observations. The combination of the three methods ensures the comprehensiveness of the identified sustainable practices, and has been confirmed as an effective way of retrieving historical practices (Hu et al., 2018).

Eight retirement villages located at Queensland were selected and visited. Three of the villages are privately owned and another five are from the not-for-profit retirement living sector. All the villages are committed to providing a sustainable living environment for their residents. An interview with the Chief Executive Officer or manager was conducted in each retirement village. The participants had an average of nearly nine years work experience in the retirement living sector, and had accumulated rich knowledge and experience of village developments and operations. All the interviews were open-ended and radio-recorded, with each lasting for approximately 60 to 90 minutes. Direct observations were also conducted during the visits, and site photographs were taken to help record data. Such useful documents as site maps, retirement village brochures, and results of residents' satisfaction surveys were also collected. The collected data were analyzed by content analysis, using Hu et al.'s (2015) developed sustainable retirement village framework. The framework defines the three interrelated sustainability dimensions of sustainable retirement villages (financial affordability, environmental sustainability, and an age-friendly social environment). The specific implementation of the content analysis was based on iterative analyzing and coding, as described in Hu et al.'s (2018) not-for-profit retirement village case study. Consequently, 600 sustainable practices were identified in the eight retirement villages (Table 1).

Table 11. Distribution of the identified sustainable practices

Retirement village case	Number of identified sustainable practices	Case feature
Case_1	77 (P1-1 ~ P1-77)	Large; Private; Mix of villas and apartments;
Case_2	51 (P2-1 ~ P2-51)	Small; Not-for-profit; Villas;
Case_3	71 (P3-1 ~ P3-71)	Large; Private; Mix of villas and apartments;
Case_4	74 (P4-1 ~ P4-74)	Large; Private; Mix of villas and apartments;
Case_5	94 (P5-1 ~ P5-94)	Large; Not-for-profit; Mix of villas and apartments;
Case_6	63 (P6-1 ~ P6-63)	Large; Not-for-profit; Apartments;

Case_7	99 (P7-1 ~ P7-99)	Small; Not-for-profit; Apartments;
Case_8	71 (P8-1 ~ P8-71)	Medium; Not-for-profit; Villas;
Total	600	

Note: The retirement village size is determined based on Hu et al., (2017c).

3.2. Developing the CBR-PMS

CBR was adopted to develop the practice-mining framework. Its implementation involved the four activities of retrieval, reuse, revision, and retention (Fig. 1), to

- Retrieve the most similar case or cases;
- Reuse the information and knowledge retained in the retrieved case or cases to attempt to address the new problem;
- Revise the proposed solution if necessary;
- Retain the useful parts of the new solution for future reuse;

When there is a new case (problem), the reasoners' retrieve one or more similar cases from the case-base based on pre-defined similarity measurement criteria. The reasoners reuse a proposed solution suggested by the retrieved cases. Unless the proposed solution is successfully used to address the problem, the proposed solution should be revised to suggest a confirmed solution. After the new problem is solved, useful information of the solution and the new problem can be retained as a learned case, which will be reused for future problem solving. The case-base is also updated by adding the learned case. In this way, organizations can achieve self-learning.

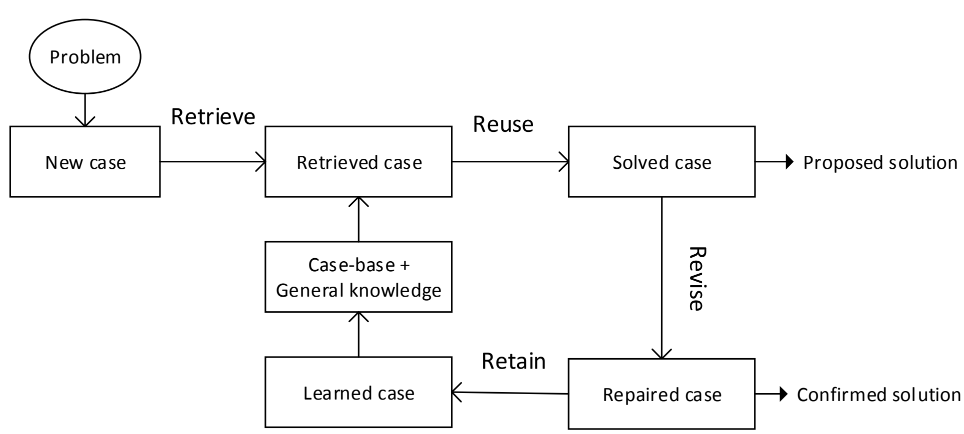

Fig. 1. The case-based reasoning process

Unlike a direct experience and knowledge sharing and reporting system, the CBR-PMS is a Decision Support System with a sophisticated architecture (Fig. 2). It is implemented on a Data Mining and Reusing Engine (DMRE) that is designed based on CBR and is adopted to capture and reuse past practices. As the identified sustainable practices are mainly retrieved from experts' experience and direct observations, they are extremely difficult to be used directly by the DMRE. It is thus necessary to transform the identified sustainable practices into standard formats and stored in a database before they can be captured and reused. This work is done by the Data Transforming and Loading System (DTLS), which transforms practices into pre-defined formats. The transformed data are stored in a Date Warehouse that is flexible enough to cope with a continuously increasing amount of data being input over time. Fig. 3 shows the system development process, including identifying sustainable practices and developing the CBR-PMS.

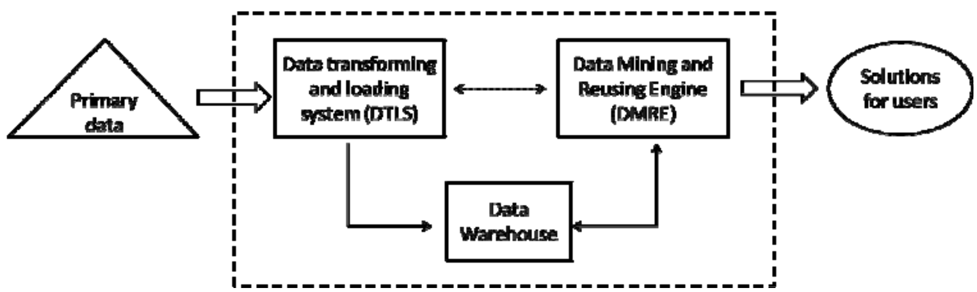

Fig. 2. The CBR-PMS architecture

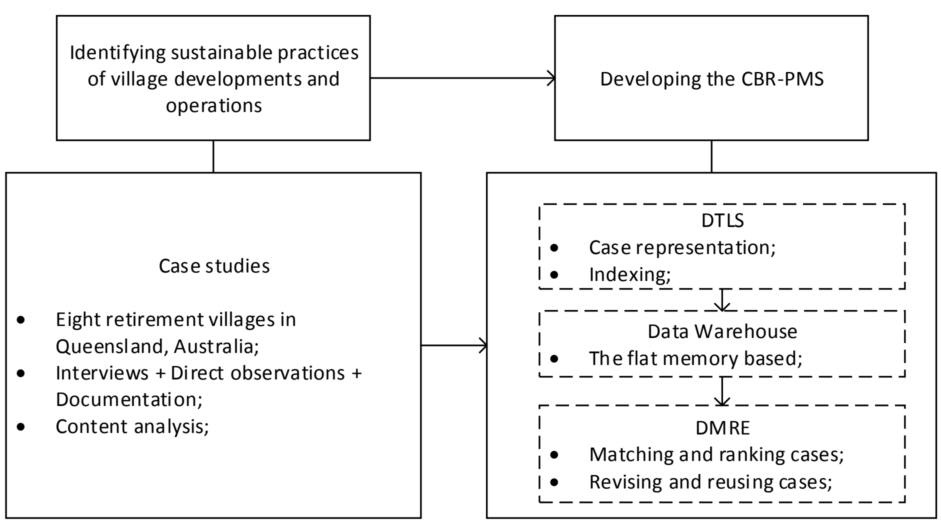

Fig. 3. The system development process

4. The Data Transforming and Loading System (DTLS)

The DTLS transforms the collected data into pre-defined formats to make them usable in the DMRE. It includes the two tasks of case representation (4.1.) and indexing (4.2.).

4.1. Case representation

Cases contain prior contextualized pieces of knowledge, representing experiences, and need to be represented in appropriate ways for effective retrieval (Kolodner, 1992). Case representation determines the knowledge contained in historical cases, and the formats in which knowledge can be represented.

4.1.1. Knowledge contained in cases

Typically, a case comprises the three major parts of problem, solution, and outcome (Watson and Marir, 1994). The problem describes the state of the world when a case was happening. The solution shows the methods adopted to address the problem, and the outcome indicates the state of the world when the solution was implemented. These three parts might not be all included in a case (Kolodneer, 1991). Based on the problem that will be addressed, reasoners can determine which parts are contained in the historical cases. In the CBR-PMS, the historical cases comprise sustainable practice cases and retirement village cases.

A *sustainable practice case* describes a specific practice adopted to address a problem in the development and operation of retirement villages. First, sustainable practices are used to meet the residents' specific requirements (e.g., safety, affordability, and energy saving), and can be grouped into one of the three sustainability dimensions (social, economic and environmental). Second, a sustainable practice is implemented in a specific location of a retirement village (e.g., site entry/exit, bathroom, or community center), and belongs to a village sub-system (e.g., site planning, unit design, or on-site facilities provision). Finally, a sustainable practice can be either a physical measure or a soft strategy.

A linguistic structure that contains the above knowledge was adopted to describe sustainable practice cases in terms of the problem and solution of a sustainable practice. For example, to satisfy the "*Age requirement*" of residents to facilitate the development of the "*Sustainability dimension*" of retirement villages, a developer took the "*Practice category*" measure/strategy of the "*Specific sustainable practice*" at the "*Practice location*" by improving the quality of "*Retirement village sub-system*". Table 2 shows how a sustainable practice is described through taking the "*Site entry/exit towards a minor street to ensure residents' safety*" as an example.

Table 2. Knowledge contained in the sample sustainable practice case.

Practice Description (Problem)	Age requirement: Safety
	Sustainability dimension: Social sustainability;
	Practice category: Physical measurement;
	Practice location: Site entry/exit;
	Sub-system of a village: Site planning;
Sustainable practice (Solution)	Site entry/exit towards a minor street;

A *retirement village case* contains the two knowledge parts of problem and solution. The *problem part* of a retirement village case outlines its main characteristics. Seventeen indicators were identified as the main features of a retirement village based on the research team members' knowledge and developers' descriptions of their retirement village projects on their official websites. Five experienced village development experts (comprising a chief executive officer, a resident services manager, a development manager, and two retirement living managers) were invited to review the proposed 17 indicators in order to determine whether they are sufficient and comprehensive. All these experts possess rich knowledge and experience of village developments and operations, with an average of 10.5 years of working experience in the Australian retirement living sector. Consequently, the chief executive officer suggested adding the "Value propositions" indicator as it reflects the developers' ideas and actions in providing services for residents. In addition, the resident services manager and the two retirement living managers suggested deleting some of the indicators to avoid repetition, such as "Number of residents", "Mean age of residents", "Percentage of female", and "Age of targeted residents". As the aim of the identifying indicators is to depict a retirement village case, in as much detail as possible, the "Value propositions" indicator was added and other indicators were retained. Eighteen indicators were finally identified and used (Table 3). Appendix A contains more detailed descriptions of these indicators. These indicators can depict a comprehensive picture of a retirement village case; covering, financial arrangements, resident characteristics, village physical features, and value propositions. The *solution part* of a retirement village case contains all the sustainable practices used in it. The knowledge contained in the sustainable practices has been discussed above.

Table 3. Knowledge contained in a retirement village case

Description of a retirement village
(1) Type of developer;
(2) Site location;
(3) Accommodation type;
(4) Number of units;
(5) Number of residents;
(6) Village size (m^2);
(7) Mean entry contribution;
(8) Range of entry contribution;
(9) Mean on-going costs;
(10) Range of on-going costs;
(11) Level of residents' health condition;
(12) Tenure and contract arrangement;
(13) Mean age of residents;
(14) Age range of residents;
(15) Percentage of female residents;
(16) Approximate development budget;
(17) Target customer (years old);
(18) Value propositions;
Solutions
All sustainable practice cases

4.1.2. Case representation formats

The historical cases need to be represented in such appropriate formats as feature vector representation, structured representation, or textual representation to facilitate their retrieval (Bergmann et al., 2005). For a retirement village case, the feature-vector knowledge representation approach is adopted to represent the knowledge contained in the "Description of a retirement village" (Table 3). The feature-vector representation approach uses a vector of attribute-value pairs to represent knowledge, and is the simplest and most frequently used knowledge representation method (López, 2013). A feature is a property/characteristic of an objective, and a value is the number(s) or symbol(s) assigned to a feature. The combination of *n* features is represented as an *n*-dimensional column vector called a feature vector. By using this method, it is possible to describe the 18 indicators of a retirement village case in a direct and clear way that can be easily used and understood by developers. This is crucial, as developers usually do not have sufficient case representation knowledge, and the method facilitates their use and understanding of the CBR-PMS in practice. In addition, this knowledge representation method also facilitates the case retrieval process.

The knowledge representation of the solution part of a retirement village case is equal to the representation of sustainable practice cases. The semantic network case representation approach is used to present sustainable practice cases. A semantic network is a graph structure for representing knowledge in patterns of interconnected nodes and links (arcs or arrows) (Sowa, 2006). The nodes represent objects or concepts and the links represent the relations between nodes. The links in such networks may assert category membership or a part-to-whole property, which can be described as *is-(a)*, *has-(a), part-of*, *a-member-of, and a-kind-of* relationships. Other kinds of relationships can also be represented by such labelled links as *made-of* and *located-at*. Several reasons contribute to its use. First, the semantic network method supports the natural language understanding task (Allen and Frisch, 1982), which will facilitate the knowledge representation of sustainable practices, as practices are natural language-based. In addition, the semantic network method facilitates the retrieval of relevant facts due to the stored facts of an object being in one node and inheritance of properties (Allen and Frisch, 1982). This is a key consideration, as the CBR-PMS aims to capture and reuse prior experience. Moreover, the suggested linguistic structure of sustainable practices has interrelated connections between different elements (sustainability dimensions, age requirements, practice categories, practice locations, and village sub-systems). The semantic network method can represent these relationships easily based on defined nodes and their links. Appendix B illustrates the knowledge representation format of sustainable practice cases. The nodes are determined based on the elements of sustainable practices in the problem description part of Table 2. The links clearly show their relationships, including *Made-of*, *Member-of*, *Located-at*, and *Has-a*. Therefore, the linguistic structure adopted to describe sustainable practices can be represented in a graph.

4.2. Indexing

Indexing means assigning appropriate labels, called indices, to historical cases when they enter into the case memory, so that they can be recalled under appropriate circumstances (Kolodner, 1992). There are two sets of indices in the DTLS. The first set, Retirement Village Project Description Indices, outlines the main characteristics of a retirement village case and is used to retrieve past retirement village cases. The second set, Sustainable Practice Description Indices, is adopted to retrieve specific sustainable practices.

4.2.1. Retirement village project description indices

Though both manual and automated methods have been proposed and used to assign indices to historical cases, artificial intelligence experts state that people tend to make a better choice than algorithms (Watson and Marir, 1994). Therefore, the assignment of indices to a retirement village case relied on the village development experts' knowledge. This method has been commonly used and is particularly suitable for such unstructured situations as in the study (Ng and Luu, 2008). In the CBR-PMS, the first 17 indicators of a retirement village case (Table 3) were adopted as indices, which were confirmed by four experienced retirement village managers. The "value proposition" indicator is not used as it mainly provides contextual information of a case and contributes little to the selection of practices.

4.2.2. Sustainable practice description indices

The semantic network (Appendix B) facilitates the indices identification of sustainable practices. The nodes of the semantic network are used as the indices. These nodes are situational variables that are adopted to describe the context in which a specific sustainable practice is implemented. This is a feasible method for identifying indices for text-based cases (Goh and Chua, 2009). Five indices were identified and used to index sustainable practices, including age requirement, sustainability group, practice category, location and village sub-system.

5. Data warehouse

The data warehouse refers to the case-base organization issue, which means the determination of the way in which historical cases are stored. Various methods can be adopted to organize historical cases in the case-base (e.g., flat memory, hierarchical organizations, discrimination networks, and redundant discrimination networks), and its determination mainly depends on the research context (Kolodner, 1992).

The flat memory is used to develop the data warehouse in the CBR-PMS, and cases are stored sequentially in a simple list. Several reasons contribute to its use. First, the entire case library can be searched using this method. As a result, the accuracy of case retrieval is a function only of the selected matching algorithms. In addition, it is cheap to add new cases in the flat memory. As an increasing number of practices are available, it is important to have a cheap way to add them. Moreover, the flat memory can be easily understood, employed, and maintained by developers.

6. The Data Mining and Reuse Engine (DMRE)

The DMRE is the core component of the CBR-PMS, which mines historical similar cases and reuse solutions of these cases. Specifically, it is designed to capture similar historical cases based on defined indices and matching algorithms (6.1.) and revise and reuse their retained solutions (6.2.).

6.1. Matching and ranking cases

Retrieving similar historical cases is the most important task of the DMRE. It begins with the determination of the matching algorithms. The matching algorithms are used to compute the similarity values between the input case and historical cases. Historical cases can be ranked based on their similarity values, and similar cases can be retrieved.

6.1.1. Similarity of retirement village cases

Various matching algorithms are available (e.g., nearest neighbor algorithm, induction, knowledge guided induction, and template retrieval), and their selection depends on the research context (Watson and Marir, 1994). The nearest neighbor algorithm is used in this study. This is the most straightforward method of identifying the nearest neighbors to a query example and use them to determine the class of the query (Cunningham and Delany, 2007). It has the advantage of decreasing retrieval time. The approach determines global similarity based on a weighted sum of indices' local similarities (Watson and Marir, 1994). A typical algorithm for calculating nearest neighbor matching is used (Cunningham and Delany, 2007):

$$Global\ Similarity\ (Case_I, Case_R) = \sum_{i=1}^{n} W_i \times S_i(f_i^I, f_i^R) \quad (1)$$

where $Case_I$ is the input case and $Case_R$ is a historical case, n is the index number (n = 17 in this study), W_i is the weight of the index i, S_i is the local similarity function of the index i, f_i^I and f_i^R are the values of index i in the input case and the historical case respectively.

It is important to determine the weight and local similarity function of each index in the application of the nearest neighbor algorithm. There are various different weight determination methods (e.g., genetic algorithm, feature counting, manual generation, and statistical analysis), and their selection relies heavily on the research context. The weight of each index in the DMRE is determined by using feature counting. This method defines the weight of each index as unity, implying that the indices have equal importance. This is because, in the absence of any specific information about an index, there is no reason for any index to be more important than another (Doğan et al., 2006; Koo et al., 2011). In addition, mathematics-based weight determination methods cannot be adopted, as the retrieval and reuse of sustainable practices are un-structured. The feature counting method has been widely employed in the development of CBR-based systems to address unstructured issues, and has been confirmed as an appropriate weight allocation method (Hu et al., 2016).

The local similarity function of each index is determined based on their own characteristics. Four different kinds of local similarity functions are proposed in the DMRE. First, the exact match function is adopted to calculate the local similarity of the indices of F_1, F_2, and F_{12}. The local similarity $S_i(f_i^I, f_i^R)$ is unity if the f_i^I is equal to the f_i^R; otherwise, the similarity $S_i(f_i^I, f_i^R)$ is zero. It is hard to reach a precise similarity assessment of the indices F_3 and F_{11}, as their values have internal logical relationships. To address this issue, a taxonomy tree is used to determine the local similarities of the indices of F_3 and F_{11} through showing the logical relationships of their values based on their locations in the tree. This method avoids the ignorance of the interrelationships between different values. It is suggested that a higher similarity value will be given if two values are closely located in the taxonomy tree (Chua and Loh, 2007). Figs 4 and 5 show the taxonomy trees used to calculate the local similarities of F_3 and F_{11}. The similarity values between different nodes are clearly defined.

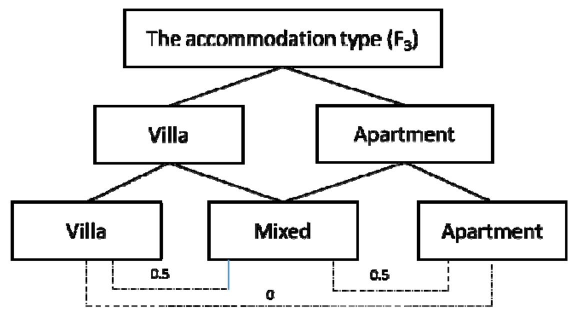

Fig. 4. The taxonomy tree for the "The accommodation type (F_3)" index

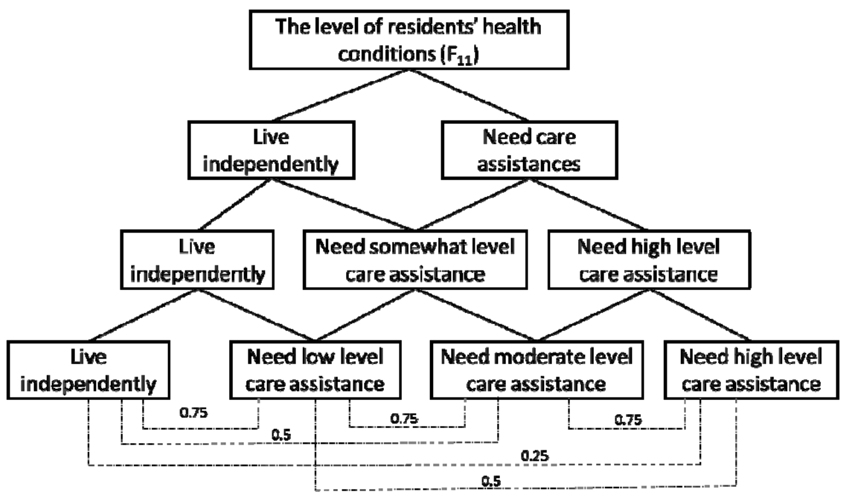

Fig. 5. The taxonomy tree for the "The level of residents' health conditions (F_{11})" index

The following similarity function is adopted to calculate the similarity of the quantitative indices of F_4-F_7, F_9, and F_{13}-F_{17}

$$S_i(f_i^I, f_i^R) = \begin{cases} 1, if\ Deviation \le 5\% \\ 0.9, if\ 5\% < Deviation \le 10\% \\ 0.8, if\ 10\% < Deviation \le 15\% \\ 0.7, if\ 15\% < Deviation \le 20\% \\ 0, if\ 20\% < Deviation \end{cases} \quad (2)$$

where $Deviation = \frac{|f_i^R - f_i^I|}{|f_i^I|} \times 100\%$, f_i^I and f_i^R are the values of the index i in the input case and historical cases respectively.

The local similarity of F_8 and F_{10} is calculated based on the following similarity function (3) if the value intervals of the F_8 or F_{10} are A=[a, b] and B=[c, d] in the input case and historical cases respectively.

$$S_t(f_t^A, f_t^B) = \frac{L(A \cap B)}{L(A) + L(B) - L(A \cap B)} \quad (3)$$

where L denotes the length of a corresponding interval and $A \cap B$ the intersection of the two intervals of A and B.

6.1.2. Similarity of sustainable practice cases

The semantic network is used to represent sustainable practices in the CBR-PMS (Appendix B). In a semantic network, the weight distribution of nodes ranges from 0.1 to 0.5 and their determination relies on the location of a node (Goh and Chua, 2009; Lu et al., 2013). More specifically, a node that is near the network root will be given a higher weight as it is more influential on the categorization of values (Goh and Chua, 2009). Thus, weights are regarded as having incremental similarity due to a match on the node (Goh and Chua, 2009). The global similarity between sustainable practices P_1 and P_2 can be determined by

$$Global\ Similarity\,(P_1, P_2) = \frac{\sum W_i}{\sum W_i + \sum W_j} \quad (4)$$

where i is a code of common nodes to P_1 and P_2, j is a code of different nodes to P_1 and P_2, W_i and W_j denote the weights of common nodes and different nodes respectively. $Global\ Similarity\,(P_1, P_2)$ measures the proportion of weights represented by the common nodes to the weights of all nodes. Its value ranges from zero to unity. Zero indicates the two sustainable practices are entirely distinct, whereas unity indicates the two practices are identical.

6.2. Revising and reusing cases

6.2.1. Revising and reusing historical retirement village cases

Based on the calculated similarity values of retirement village cases, the reasoners can determine the most similar cases. Only the case with the largest global similarity value will be retrieved and reused, as the most similar case has the highest possibility of providing developers with the most useful solutions. In contrast, if more than one case is reused, it may lead to a highly complex issue. This is mainly because a number of sustainable practices covering various aspects of village developments and operations are stored in retrieved cases, and some of these sustainable practices conflict between cases. Although different case revision methods are available (e.g., structural adaption, null adaption, and derivational adaption) (Watson and Marir, 1994), the retrieved similar case is reused directly, based on the null adaptation strategy in the CBR-PMS. The null adaptation strategy is a direct and simple technique that applies the retrieved solutions to the current problem without modification (Watson and Marir, 1994). Several reasons contribute to the use of this method. First, the aim of retrieving prior retirement village cases is to provide developers with a whole picture of past sustainable practices used, to guide their village developments and operations. Although there may be some differences between the input case and retrieved cases, it is not necessary to consider these differences in order to provide an overall picture. In addition, the retrieval of historical retirement village cases usually takes place during the early stages of village development. It is not meaningful, and will be costly to make, the retrieved solutions exactly match the current situation, as uncertainties exist and changes will occur in the succeeding stages of village developments and operations.

6.2.2. Revising and reusing historical sustainable practice cases

Historical sustainable practices that have the similarity value of unity will be retrieved for reusing given that these sustainable practices can provide the most valuable references to cope with the problem that a developer is confronting. The structural adaptation strategy will be used to revise retrieved solutions if necessary in order to make the retrieved solutions suitable for the current problem. As structural adaptation applies adaptation rules directly to the stored solutions to make them match an input situation (Watson and Marir, 1994), their adoption ensures that the retrieved cases are revised based on the unique features of the current problem. It has also been widely used to address unstructured problems (Hu et al., 2016).

A two-step-based structural adaptation strategy is designed in the CBR-PMS, comprising deletion and modification. In the first step of deletion, if developers are not willing to pay any additional costs for the use of sustainable practices, the retrieved practices that need additional costs should be deleted. Otherwise, the retrieved practices can be retained for further consideration. This is because reusing sustainable practices may result in additional costs, which concerns both residents and developers (Barker et al., 2013; Xia et al., 2015; Zuo et al., 2014). In terms of the modification, if the retrieved practices are not capable of addressing the current problem, the retrieved solutions should be modified. The modification is an unstructured decision-making process that relies on the input of expert knowledge of village development. The two-step-based structural adaptation has been confirmed as a feasible approach to addressing unstructured problems (e.g., suggestions proposing construction safety strategies) (Fan et al., 2015). After the new problem is solved, its useful parts can be retained in the case-base for future reuse.

7. Demonstration and validation

Case studies are widely used to demonstrate the performance of CBR models, as this method can validate their accuracy, usability, and efficiency through testing real cases (Fan et al., 2015). This section presents two demonstrations exemplifying the mining process of the CBR-PMS and validating its performance. The first demonstration shows the retrieval process of a similar retirement village case based on pre-defined rules, while the second illustrates the application of CBR-PMS to suggest specific sustainable practices for an input problem.

7.1. Demonstration of retirement village cases and validation

The demonstrated retirement village case is a not-for-profit village development located in an urban area of Queensland. It provides residents with mixed accommodation of villas and apartments. The main characteristics of the case are summarized in Table 4.

Table 4 Description of the retirement village input case.

Index	Indicator	Value
F_1	Type of developer;	Not-for-profit
F_2	Site location;	Urban
F_3	Accommodation type;	Mixed
F_4	Number of units;	120
F_5	Number of residents;	165
F_6	Retirement village size (m^2);	50,000
F_7	Mean entry contribution (AUD);	360,000
F_8	Range of entry contribution (AUD);	320,000 – 400,000

F_9	Mean on-going costs (AUD/WEEK);	100
F_{10}	Range of on-going costs (AUD/WEEK);	90 – 110
F_{11}	Level of residents' health condition;	Live independently
F_{12}	Tenure and contract arrangement;	Licenses
F_{13}	Mean age of residents;	75
F_{14}	Age range of residents;	65 – 85
F_{15}	Percentage of female residents (%);	37%
F_{16}	Approximate development budget;	30,000,000
F_{17}	Target customer (years old);	60 – 100

After the CBR-PMS receives the description of the input case, the global similarity of each historical case is calculated based on the pre-defined similarity calculation rules of retirement villages. For instance, as the F_1 value of the input Case is "not-for-profit" and that of the Case_1 is "private", the local similarity of the index F_1 between the input case and Case_1 is zero. As the F_4 value of the input Case is "120" and that of the Case_5 is "127", the local similarity of the index F_4 between the input case and the Case_5 is 0.9 based on the calculated deviation of 6.06%. The local similarities of other indices can also be determined based on the pre-defined rules. As shown in Table 5, a local similarity value has been allocated to each index of each retirement village, and their global similarity can be determined based on the nearest neighbor algorithm of Eq. (1). The Case_5 is the most similar case as it has the largest global similarity of 13.07. Thus, the sustainable practices retained in the Case_5 are retrieved and reused as suggestions for the development of the input project. A further qualitative comparison of the input case with the Case_5 was conducted. This method provides a direct way of validating the results of the CBR-PMS based on the user's subjective judgment, which is a feasible and acceptable approach for assessing CBR models (Bareiss, 1989). Based on the comparison, many similarities between the input case and the Case_5 were found. For instance, both cases are urban not-for-profit projects and provide residents with mixed accommodation. They also have similarities in unit and resident numbers, size, living costs, tenure and contract arrangements, resident features, and development budget. The results indicate that the CBR-PMS can be used to retrieve historical similar retirement village cases effectively.

Table 5. Similarity of historical retirement village cases

Case	Local Similarity																	Global Similarity
	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}	F_{12}	F_{13}	F_{14}	F_{15}	F_{16}	F_{17}	
Case_1	0	1	1	0	0	0	1	0.14	0	0.33	1	0	0.8	0.65	0.9	0	0.35	7.17
Case_2	1	1	0.5	0	0	0	0	0	0.9	0	1	0	0.9	0	0	0	0	5.3
Case_3	0	1	1	0	0	0	0	0	0	0	0.75	0	0.8	0.59	0	0	0	4.14
Case_4	0	1	1	0	0	0	0.8	0	1	0	0.5	0	0.9	0.54	0.7	0	0	6.44
Case_5	1	1	1	0.9	0.9	0.8	0.8	0.33	1	0.77	0.5	1	0.8	0.59	0	0.8	0.88	13.1
Case_6	1	1	0.5	0.9	1	0.7	0	0.02	1	0.65	0.5	1	1	0.8	0	0	0.88	11
Case_7	1	1	0.5	0	0	0	0.9	0	0	0	1	1	0.8	0.56	0.9	0	1	8.66
Case_8	1	1	0.5	0	0	0.8	0.8	0	0	0	1	1	0.7	0	0.9	0	1	8.7

7.2. Demonstration of sustainable practice cases and validation

As a variety of sustainable practices is used in the development and operation of sustainable retirement villages, it is difficult to include them all in a single demonstration case study. The demonstrated case study focuses on the identification of site planning practices to promote residents' social friendliness. A well-designed retirement village site can meet such residents' requirements as easy way-finding, social interaction, and safety (Carstens, 1993). The demonstrated input sustainable practice case is that a developer expects to promote its residents' social interaction at the site entry/exit using physical strategies, as the site entry/exit of a retirement village is a place where the residents' social activities usually take place (Carstens, 1993). The case description is shown in Table 6. The description of the case can also be found in the semantic network of site planning, which is marked as P-i in Fig. 6. Another two examples of P1-2 and P1-37 are also shown.

Table 6. Description of the input sustainable practice case

Practice description: • Age requirement: Social interaction; • Sustainability dimension: Social sustainability; • Practice category: Physical measurement; • Practice location: Site entry/exit; • Sub-system of a village: Site planning;

After the CBR-PMS receives the description of the input case, the global similarity of each historical sustainable practice case is calculated based on the pre-defined similarity calculation rules of Eq. (4). For instance, there are three common and four different nodes between P-i and P1-37 (Fig. 6). Based on Eq. (4), the similarity between the P-i and P1-37 is:

$$Global\ similarity\ (P-i, P1-37) = \frac{\sum w_i}{\sum w_i + \sum w_j} = \frac{0.5+0.4+0.3}{0.5+0.4+0.3+(0.2+0.1+0.2+0.1)} = 0.667$$

By adopting the same method, the global similarity values between the P-i and all other historical sustainable practices can be calculated. Based on their similarity values, the ranking of historical sustainable practices can then be determined. Of the 600 historical sustainable practices, nine practices with the similarity value of unity are retrieved (Table 7).

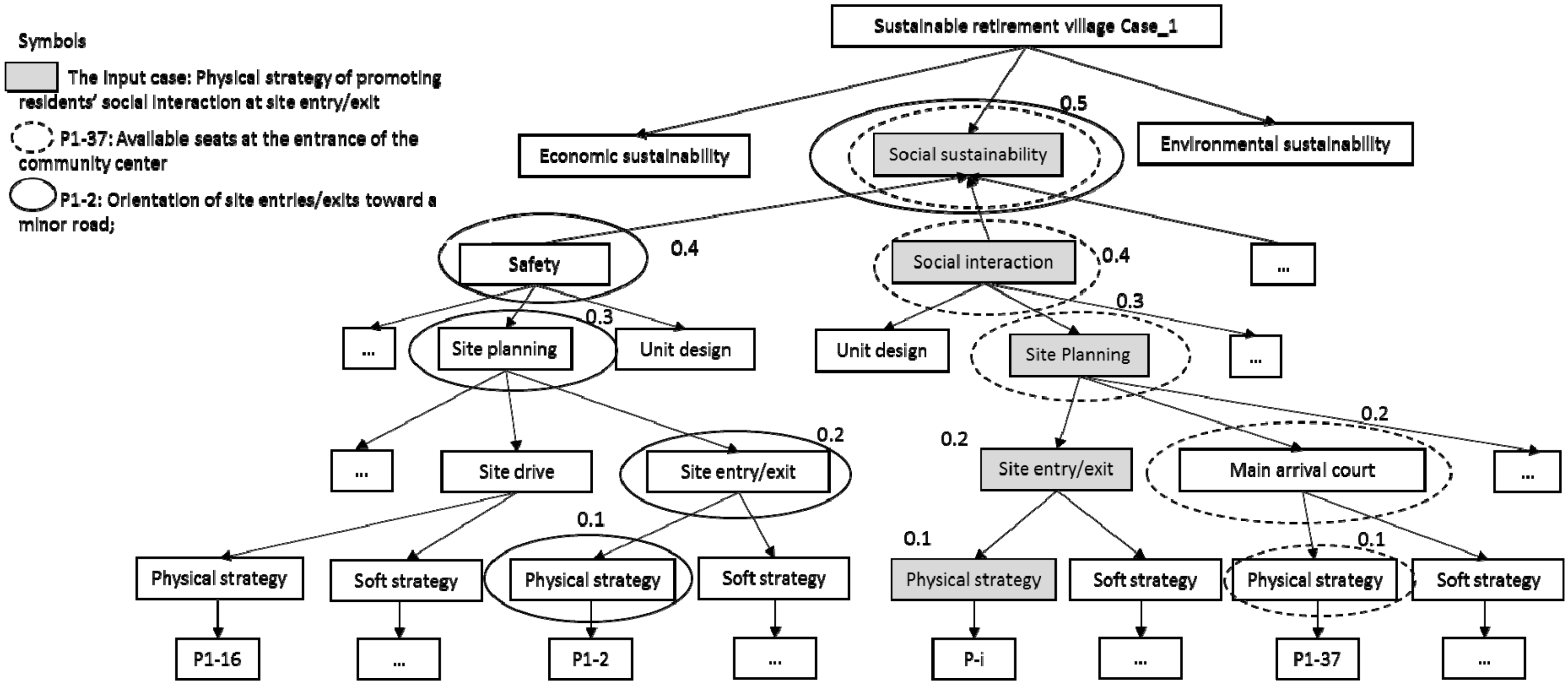

Fig. 6. Semantic network of the demonstration case

Table 7. Retrieved sustainable practices

Retirement village case	Sustainable practice
Case_1	P1-6: The location of the retirement village site entry/exit is near public transportation (e.g., bus and train stations);
	P1-7: At the retirement village entry/exit, the on-site walkway is closely connected with the walkway of the surrounding neighborhood/community;
Case_2	P2-7: At the retirement village entry/exit, the on-site walkway is closely connected with the walkway of the surrounding neighborhood/community;
Case_4	P4-10: The location of the retirement village site entry/exit is near public transportation (e.g., bus and train stations);
	P4-13: A covered drop-off area with seats is designed/provided at the retirement village entry/exit;
Case_5	P5-10: The location of the retirement village site entry/exit is near to shopping centers;
Csse_7	P7-9: A covered drop-off area with seats is designed/provided at the retirement village entry/exit;
	P7-13: At the retirement village entry/exit, the on-site walkway is closely connected with the walkway of the surrounding neighborhood/community;
	P7-14: Resident amenities, their mailboxes for instance, are designed/provided at the site entry/exit;

After deleting the repetitive sustainable practices, five practices are finally identified (Table 8). To validate the performance of the CBR-PMS in terms of its ability to mine sustainable practices, experienced village managers were invited to express their perceptions of the usefulness of the retrieved practices in promoting the residents' social interactions. This method can investigate the experts' acceptance of the retrieved cases, which provides an appropriate validation approach (Ng and Smith, 1998). The method is also consistent with artificial intelligence experts' suggestion that a CBR system can be assessed subjectively by domain experts and semi-experts (Bareiss, 1989). Six village development experts participated in the assessment. First, an executive general manager, who was working in the headquarters of a leading village developer in Australia and has more than 15 years of working experience in the retirement living sector, conducted a holistic evaluation of the usefulness of the retrieved practices. The manager confirmed the usefulness and practicality of the practices, and stated that they can positively influence the residents' life and enjoyment. A further five village development experts were also invited to express their perceptions of the usefulness of the practices through a questionnaire survey. These five experts (two retirement living manages, a resident services manager, an integrated retirement community manager, and a business manager) were working for leading private or not-for-profit village developers in Australia. They have rich knowledge and experience of village developments and operations, with an average of 10.4 years of working experience in the sector. Table 8 shows the questionnaire survey results. For instance, four of the five managers strongly agree that the Practice 1 can promote the residents' social interactions. It can therefore be concluded that the retrieved practices are useful in promoting the of residents' social interactions based on the results in Table 8. In addition, previous studies also confirm these retrieved sustainable practices as feasible strategies promoting the residents' social interactions at the site entry/exit area (Carstens, 1993).

Table 8. Usefulness of the retrieved sustainable practices in promoting the residents' social interactions

Practices	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
Practice 1: The location of the retirement village entry/exit is near public transportation (e.g., bus and train stations);	4	1			
Practice 2: At the retirement village entry/exit, the on-site walkway is closely connected with the walkway of the surrounding neighborhood/community;	1	4			
Practice 3: A covered drop-off area with seats is designed/provided at the retirement village entry/exit;	4		1		
Practice 4: The location of the retirement village entry/exit is near shopping centers;	2	3			
Practice 5: Resident amenities, their mailboxes for instance, are designed/provided at the site entry/exit.	3	1	1		

The retrieved sustainable practices should be further examined and selected based on the suggested two-step revision strategy. As the sustainable practice reuse process is context-based, it needs to consider the restricted conditions of the input project and requirements of developers. Domain expert knowledge may also be helpful in the process. The following discussion is an assumed situation that is adopted to show how the reuse process operates. First, it is assumed that the developer is not concerned with the additional costs resulting from reusing sustainable practices. Therefore, all the retrieved sustainable practices can be retained for further modifications. In addition, as this is an established village project, the location of the site entry/exit cannot easily be changed. Thus, the Practice 1 and Practice 4 (P1-6, P4-10, and P5-10) can hardly be reused. In addition, as the retirement village has its internal walkways connected with its surrounding neighborhood walkways, the Practice 2 (P1-7, P2-7 and P7-13) will also not be used. Consequently, only the Practice 3 and Practice 5 will be further considered. Given the developer has established its mail delivery system on-site, the mailboxes suggested in the Practice 5 can be changed into other amenities (e.g., covered tables or barbecue facilities) based on the current project characteristics and its developer's needs. In addition, based on the Practice 3, the developer can also consider designing a covered drop-off area with seats at the site entry/exit to promote the social interactions of the residents.

8. Conclusions

The increasing popularity of retirement village development has resulted in a large number of sustainable practices being available in the Australian retirement village sector. These practices contain useful knowledge and experience of village developments and operations. Reusing this knowledge and experience can assist developers in making decisions regarding the provision a sustainable living environment for residents. To make better use of historical sustainable practices, the practice mining system of CBR-PMS was developed in this study. The CBR-PMS is a data mining system that can contain, capture, and reuse historical sustainable practices to deal with developer issues in the delivery of sustainable retirement villages. It comprises the three components of DTLS, Data Warehouse, and DMRE. The DTLS transforms the collected data into standard formats by using the case representation methods of feature-vector and semantic networks. The transformed data are stored in the Data Warehouse by the flat memory method. Based on the matching method of the nearest neighbor algorithm, the DMRE retrieves similar cases, and revises and reuses their solutions to address a new problem.

The CBR-PMS is an innovative tool to manage and share knowledge in the retirement living sector, facilitating developers' knowledge management and organizational learning. Using the CBR-PMS can provide many benefits because of its ability to transfer previous industry practices. First, the CBR-PMS facilitates the development and operation of sustainable retirement villages by effectively reusing past experience. Compared with the traditional process of retrieving historical experience based on the managers' own intuition, the main advantage of the CBR-PMS is that it provides a relatively accurate way of retrieving and reusing historical experience from a wider range of historical projects. Second, the CBR-PMS promotes cleaner production of the retirement living sector. In particular, developers can use the CBR-PMS to learn from prior sustainable strategies (e.g., methods of energy efficiency) to modify their current practices or guide the development of new projects in green ways. Although the CBR-PMS is specifically designed for reusing sustainable retirement village practices, its development process offers valuable insights into the development of similar data-mining systems adopted to capture and reuse best practices of other sustainability initiatives (e.g., green buildings, sustainable urbanization, sustainable communities, and sustainable cities). In addition, as the development and operation of retirement villages is not an exclusive Australian phenomenon, the CBR-PMS has the potential to be used in the retirement village sector of other countries.

The main limitations of CBR-PMS are its relatively conceptual nature and the need for some parts to be further tailored to improve its efficiency. For instance, the weights used for case retrieval need to be derived more precisely. The CBR-PMS also requires some degree of automation to make it user-friendly, which can be achieved based on such tools as Microsoft Visual Studio. Moreover, as reusing historical practices is an unstructured issue that is hard to be done based on accurate rules, the determination of some parameters in the CBR-PMS relies heavily on industry practitioners' subjective judgements, which may possibly be biased to some extent. Moreover, as the development of sustainable retirement villages is a new phenomenon and no previous studies have explored the practice of reusing successful solutions to similar problems in the retirement living sector, it was not possible to compare the performance of CBR-PMS with any alternative technologies – suggesting the need to explore the possibility of adopting other technologies to develop data mining systems to enable such comparisons to be made in future.

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Appendices

Appendix A. Indicator description of a retirement village case

Code	Indicator	Type	Value
F_1	Type of developer	Categorical	Not-for-profit; Private
F_2	Site location	Categorical	Rural area; Suburb area
F_3	Accommodation type	Categorical	Villa; Apartment; Mixed (villa and apartment)
F_4	Number of unit	Quantitative	Any positive numerical value
F_5	Number of residents	Quantitative	Any positive numerical value
F_6	Village size	Quantitative	Any positive numerical value (acres OR m^2)
F_7	Mean entry contribution	Quantitative	Any positive numerical value (AUD)
F_8	Range of entry contribution	Quantitative	Any positive numerical value range (AUD)
F_9	Mean on-going costs	Quantitative	Any positive numerical value (AUD each week)
F_{10}	Range of on-going costs	Quantitative	Any positive numerical value range (AUD each week)
F_{11}	Level of residents' health conditions	Categorical	Live independently; Need low levels of care assistance; Need moderate levels of care assistance; Need high levels of care assistance; Mixed;
F_{12}	Tenure and contract arrangement	Categorical	Leasehold; Freehold; Loan/Licenses; Rental; Mixed; Others
F_{13}	Mean age of residents	Quantitative	Any positive numerical value (years old)
F_{14}	Age range of residents	Quantitative	Any positive numerical value range (years old)
F_{15}	Percentage of female residents	Quantitative	0~100%
F_{16}	Approximate development budget	Quantitative	Any positive numerical value (AUD)
F_{17}	Target customer	Quantitative	Any positive numerical value range (years old)
F_{18}	Value propositions	Linguistic	A description of value propositions of the retirement village

Note: AUD = Australian Dollars

Appendix B. Semantic network representation of sustainable practice cases