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Using Historic Cases to Formulate Appropriate Sustainable Building Refurbishment Strategy

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Abstract: *Existing buildings are indispensable in a society and they will continue to exist until they reach the end of their service or economic life. While it is crucial to upkeep existing buildings, enhancing their sustainability is equally important as the energy performance of some older properties is usually less than satisfactory. Despite that, it is never easy for citizens to establish which is the most suitable sustainable refurbishment strategy for their properties. If historic cases can be captured and represented systematically, owners and occupants living in properties of similar types can review the outcomes of these cases to decide whether some sustainable building refurbishment solutions adopted by the others before are applicable to their property. In the paper, a prototype case-based reasoning model for sustainable building refurbishment is proposed. This paper demonstrates how to make use of the proposed model to retrieve and reuse previous cases to derive suitable sustainable building refurbishment strategies for existing buildings.*

Keywords: ***Sustainable refurbishment, case-based reasoning, energy, emissions reduction***

Introduction

Construction facilities are extremely durable and will continue to exist if they are properly maintained (Levine *et al*., 2007). While the values of existing buildings are unquestionable, the energy performance of some existing properties is not comparable to that of the new built in general. Facing the global challenge of climate change, the building sector must react by identifying solutions to reduce energy usage arising from existing buildings (Imboden, 2000).

Hong Kong being a developed economy has a strong demand for electricity. According to EPD (2010), over 90% of various end use of electricity is related to the use of building facilities. In 2009, 37,694 million kWh of electricity was consumed generating a carbon dioxide equivalent of 24.5 million tonnes (EMSD, 2010). Many organisations and citizens aware of the impacts of energy saving and have begun to change their behaviour or replace electrical appliances with the more energy efficient ones.

However, a significant reduction in the carbon footprint of existing buildings necessitates a comprehensive improvement of building components and/or building services equipment in holistic manner (Taylor *et al*., 2010). This is particularly the case for buildings in urban metropolis like Hong Kong as most of them are of multi-storey nature and owned / occupied by different inhabitants. Sustainable building refurbishment should, therefore, be carefully planned so as to maximise the opportunity for emission reduction.

Apart from the technical issues, the support of owners and occupants in multi-storey buildings towards a sustainable building refurbishment programme should not be underestimated as any major improvement works would cost and may affect their daily life. Failing to address the concerns of building owners and occupants could affect the success of a sustainable building refurbishment schemes. However, it is never easy to anticipate the outcomes of a sustainable building refurbishment scheme as every building is unique and the expectations of owners and occupants could be totally different (Egbu, 1997).

The experience gained from previous sustainable building refurbishment schemes could help owners and occupants envisage the potential benefits and pitfalls brought by a potential sustainable building refurbishment solution and hence increase their confidence in accepting a proposal. Case-based reasoning being a modelling approach to remember, retrieve, reuse and revise historic cases for decision support (Aamodt and Plaza, 1994) may have a strong avenue for sustainable building refurbishment decisions.

In this paper, a case-based reasoning model is proposed to assist owners and occupants formulate appropriate sustainable refurbishment strategies. The paper begins by unveiling the characteristics of the case-based reasoning approach. Based on some historic cases, a prototype case-based reasoning model is developed and the features of the case-based reasoning model for sustainable refurbishment are exemplified. The paper concludes with the way forward of the case-based reasoning model for sustainable building refurbishment.

Research Method

The research began with a major literature review to identify the historic cases for sustainable building refurbishment around the world. Through the collected cases, the features in terms of project characteristics, owner / occupant requirements, emission reduction goal, sustainable refurbishment solutions chosen, initial cost, operating cost, effectiveness in energy / emission reduction, disruption to the owner / occupant, etc. can be identified (*cf:* Augenbroe and Park, 2002). Interviews were then carried out to confirm whether the features as identified in the literature are applicable to Hong Kong.

Since the building type and climatic condition of Hong Kong are not the same as other countries, the sustainable building refurbishment solutions could be quite different. Moreover, as buildings in Hong Kong are of multi-storey multi-occupant nature, it is sensible to divide the sustainable building refurbishment options according to different functional areas, e.g. for common areas and residential units. The possibility of applying the identified sustainable building refurbishment options were examined through a questionnaire survey.

The last stage of research involved the development of a prototype case-based reasoning model for sustainable building refurbishment decisions. This involved the design of case structure based on the findings of the preceding stages. With that, the case repository was set up by inputting the historic cases into the model. Then, the case retrieval mechanism was devised based on the mega-knowledge and near-match comparison concepts. The output interfaces were designed to allow the users compare the cases and review the case outcomes.

Case-Based Reasoning

Case-based reasoning is an artificial intelligence technique that solves new problems by adapting solutions that were used to solve old problems (Riesbeck and Schank, 1989). Case-based reasoning mimics the way of human problem solving by recalling and adjusting similar decisions made in previous cases. This would not only reduce the time for decision making, it should also prevent the same mistakes from being replicated in the current case.

More important, the case-based reasoning approach lends itself to complex dynamic environment as it allows similar rather than exact scenario be retrieved for decision support. This is particularly relevant to the sustainable building refurbishment problems as the project characteristics and occupant expectations could vary from one case to another. For those reasons, case-based reasoning has been applied to many construction management domains such as architecture design, contractor prequalification, procurement selection, etc.

Through the case-based reasoning approach, the features and outcomes of historic cases are identified and stored in the case repository. When there is a new problem, the characteristics of the new problem will be used to identify similar historic cases. Similar cases will be retrieved and similarity scores will be provided so as to denote the degree of similarity. Users can examine the retrieved cases. In case the cases retrieved are not comparable to the current problem, further retrieval can be conducted until a relevant historic case is identified. Given the retrieved cases may be slightly different from the current problem, adaptation have to be performed to fine-tune the solution in order to warrant the best result.

System Architecture

The proposed case-based reasoning prototype for sustainable building refurbishment consists of five modules namely: input, knowledge and data, case-based reasoning, analytical, and output. The components of these five modules and the relationships between various modules and components are shown in Figure 1.

The data input module allows decision-makers to enter the features of a project as well as the owners / occupants expectations. Once the necessary information is fed into the case-based reasoning module, cases that are similar to the input parameters are retrieved. The sustainable building refurbishment methods used along with the lessons learnt and the satisfaction of the retrieved case(s) are made available to decision-makers for scrutiny.

If the retrieved cases are different from the building in question or if the results of the green refurbishment actions are not as satisfactory as desired, decision-makers can adapt the solutions. Otherwise, they can simply adopt the solutions. Besides, data related to thermal performance and costs along with knowledge on human behaviour and perceptions are stored

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in the data and knowledge module. Decision-makers can check the results of the cases retrieved against the expected thermal performance of a sustainable refurbishment action.

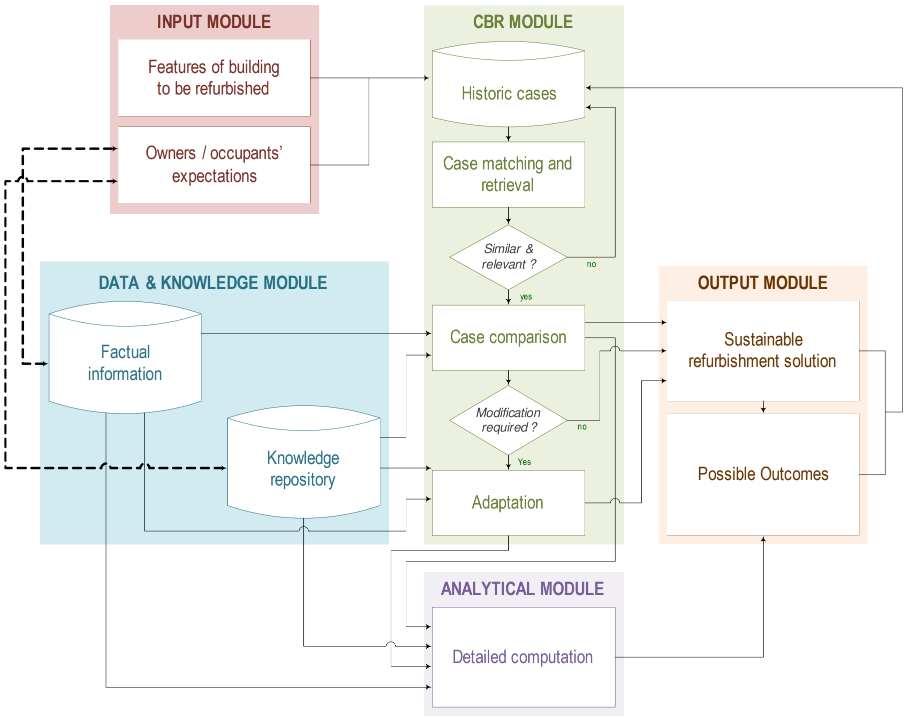

Figure 1: Architecture of the prototype case-based sustainable building refurbishment model

Based on the adopted or adapted solutions and the relevant information and knowledge, detailed analyses are performed by the analytical module to estimate the energy consumption, carbon emissions, and costs before and after the refurbishment is introduced. The preferred sustainable refurbishment solution, amount of GHG reductions, anticipated costs, predicted disruption, and mitigation measures are reported through the output module.

Prototype Case-Based Reasoning Model

The prototype case-based sustainable building refurbishment model was developed using a case-based reasoning tool known as COLIBRI Studio. The reasons for choosing COLIBRI Studio are because it provides the visual builder tools and it is integrated into the popular Eclipse integrated development environment. These should eliminate the tedious work of developing the case matching and retrieval mechanisms.

Using COLIBRI Studio, an interface for users to capture the existing sustainable building refurbishment cases is developed. The features of historic cases including the basic information, pre-refurbishment assessment, refurbishment measures adopted, and the post-refurbishment assessment can be entered through the interface. As shown in Figure 2, a list of possible values is provided under each parameter so as to simply the data entry process. The inputted data is stored in the case-base for subsequent case comparison and retrieval.

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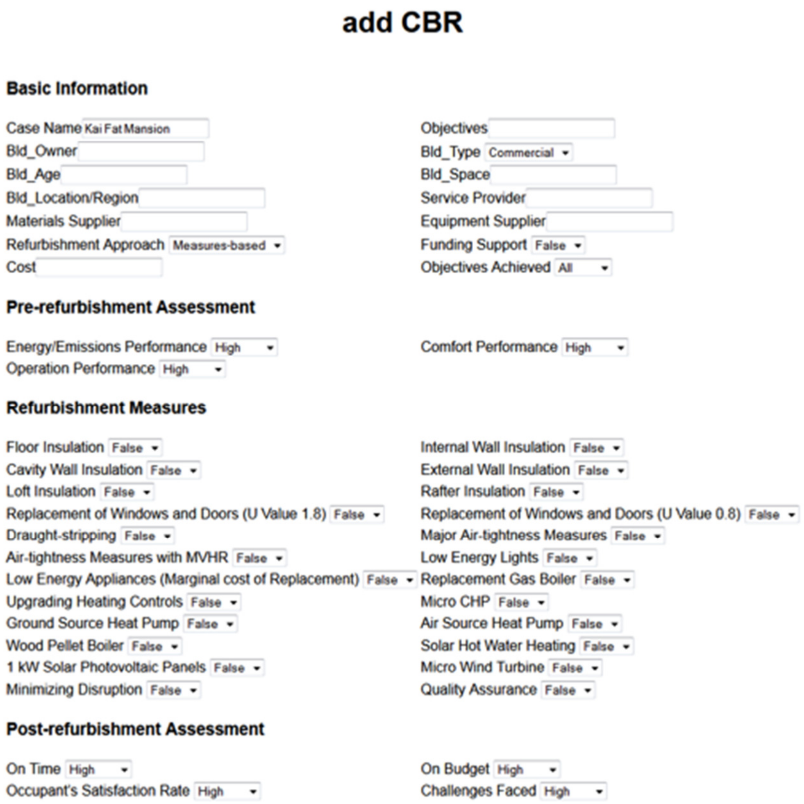

Figure 2: Capturing an existing sustainable building refurbishment case in the model

Figure 3: Querying for a similar historic sustainable building refurbishment case

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When decision-makers want to retrieval a historic case to facilitate them making a sustainable building refurbishment decision, they should fill in the details related to the features of the building in question as well as the owner / occupant requirement through the user interface (Figure 3). In case users are unsure of the value for any parameter, they can simply leave it blank as this should not significantly affect the result of retrieval.

A nearest neighbour approach is used for case comparison whereby the degree of similarity of each parameter between the present case and each of the historic case is evaluated. The overall similarity scores of the historic cases can then be calculated. Those cases with the highest overall similarity scores will be reported (Figure 4). Decision-makers can examine the basic information of the retrieved cases. Should they convince the retrieved case is generally comparable to the present case, they can bring up the case details for further scrutiny.

2 Retrieved cases

Select	Time_cert...	Cost_cert...	Speed	Flexibility	Responsi...	Complexity	Price_co...	Risk_allo...	Quality	Procurem...	Tendering...	Contract_t...	Client_rati...
hku_...	false	false	High	High	Low	High	High	Low	Good	Competiti...	Selective ...	C21	Good
hku_...	false	true	Low	Medium	Low	High	Medium	High	Basic	Design a...	Selective ...	C22	Better

Add to Basket | Quit

Figure 4: Historic cases with high similarity scores are retrieved

While the retrieved sustainable refurbishment solutions might work well in the historic case, they may not result in the best outcomes in the present building in question. As a result, it is necessary to analyse the likely outcomes of those sustainable building refurbishment solutions under the current situation. Using the prototype model, the data inputted by the users and retrieved from the historic case will be fed into the energy model for energy performance analysis (Figure 5). This should help delineate which sustainable building refurbishment options would result in the greatest energy saving and emission reduction.

Manager HecResult

Level of Refrubishment	Refurbishment methods	Energy saving (kWh)	Percentage of Energy Saving	CO2 Emission Reduction (kg)	Percentage of Emission Reduction
1	Simple coating	114.25	0.012924208144796381	47.879999999999995	0.008043868314416466
1	Reducing storage temperature of electronic water heater	-1291.5	-0.1460972850678733	-1084.86	-0.18225712154506782
1	Reconfiguring air conditioner's temperature	374.0	0.04230769230769231	314.15999999999997	0.05277906578231155
1	Using induction cooker	263.15999999999997	0.0	221.05439999999996	0.03713726992319012
2	T5 flourescent	12.2202	0.0	10.264968	0.001724520694312844
2	LED lighting	5.537734375	0.0	4.651696875	7.814878258371469E-4
2	Compact flourescent lighting	5.249363636363635	0.0	4.409465454545454	7.407928039543062E-4
2	Electronic ballast	14.454	0.0	12.14136	0.0020397556599399233
2	Installing low-flow aerated showerhead	0.0	0.0	0.0	0.0
3	Stopping the draught	159.12	0.018	133.6608	0.022455093441928916
3	Tinted glazing	-16.824771007566703	-0.0019032546388650117	17.22	0.002892970183255045
3	Reflective glazing	12.3752289924333	0.0013999127819494684	41.748	0.007013688688184182
3	Double / multiple glazing	-2.3847710075667052	-2.697704759690843E-4	29.349599999999995	0.004930750156240549
1	Level 1 sum	-540.09	-0.06109615384615385	0.0	0.0
2	Using LED	-507.8780656250001	-0.06109615384615385	27.058024875	0.004545764180089914
3	LED & Reflective glazing	-336.3828366325668	-0.04169624106420439	202.466824875	0.03401454631020301

return

Figure 5: Energy performance analysis of a refurbishment case

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Conclusions

A prototype case-based reasoning model for sustainable building refurbishment has been developed. By referring to similar historic cases, owners / occupants can visualise the potential energy saving and emission reduction of different sustainable refurbishment solutions. This should increase the chance of success of sustainable building refurbishment schemes especially when the properties are of multi-storey multi-occupants nature. The next stage of development will focus on the other aspects such as the life cycle cost and disruption, and the findings of the subsequent stages will be reported when they become available.

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