The study on computer aided building renovation simulation

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Abstract

Many global organizations have invested significant resources to create sustainable environments during the last decade. As the economic, environmental and social aspects of built environment sustainability are considered, building renovation has received increasing attention as a viable alternative to redevelopment or reconstruction, reducing the tremendous cost, abating environmental impacts and maintaining better social relationships with neighbors. Building simulation is very useful to accurately determine the thermal performance and energy consumption of buildings, especially for improving buildings at the design stage. However, the results predicted by the simulations are only valid if the model is properly calibrated. Calibration means technical and operational adjustments of the computer model that represents the building. For this purpose, many techniques have been developed, which are based either on long or short term measurements of some building parameters. It is a laborious process, in which the user has to insert several input parameters in the simulation programmer and, at the same time, collect responses from the actual building operation. The algorithm developed in this study is very effective and suitable for solving complicated and large-scale combinational, discrete and determinate problems. The data module of the system is flexible, and data for cost score and assessment items can be modified or customized according to actual requirements in different regions and countries. Although the system development is based on major characteristics of office buildings, the flexible data module employed in the system can also provide users with high feasibility and flexibility to define different assessment items, renovation actions, as well as their corresponding cost and score for other building types to conduct optimization. Future efforts to continuously improve the system and to promote its application to contribute towards more sustainable built environments are expected.

Keywords: Computer aided, Building renovation, Simulation

1 Introduction

Many global organizations have invested significant resources to create sustainable environments during the last decade [1]. As the economic, environmental and social aspects of built environment sustainability are considered, building renovation has received increasing attention as a viable alternative to redevelopment or reconstruction, reducing the tremendous cost, abating environmental impacts and maintaining better social relationships with neighbors.

There are a number of methods and models developed for evaluating existing building conditions and supporting decisions pertaining to building renovation. The TOBUS method was developed to offer a tool for selecting office building's upgrading solutions considering the assessment of the degree of physical degradation, extent of any degradation, extent of the necessary work to renovate the building and the costs [2]. Kaklauskas et al. have developed a multivariate design method and multiple criteria analysis for building refurbishment, determining the significance, priorities and utility degree of comparative building refurbishment alternatives and selecting the most recommended variant at the end [3]. The above-mentioned researches proposed several specific methods to deal with a variety of complicated building renovation problems as far as a building renovation is concerned. However, their focuses on sustainable renovation and energy performance improvement were mainly inadequate.

Building simulation is very useful to accurately determine the thermal performance and energy consumption of buildings, especially for improving buildings at the design stage [4]. However, the results predicted by the simulations are only valid if the model is properly calibrated [5]. Calibration means technical and operational adjustments of the computer model that represents the building. For this purpose, many techniques have been developed, which are based either on long or short term measurements of some building parameters. It is a laborious process, in which the user has to insert several input parameters in the simulation programmer and, at the same time, collect responses from the actual building operation [6]. According to Heo et al. [7], the purpose of a calibration is not just to find the ideal combination of factors that generates results closer to measurements. Calibration should consider the uncertainties in the input parameters (at least in the most important ones), uncertainties in the measurement methods and in the theoretical conception of the algorithm used.

There is a topic that is poorly addressed in the literature in dealing with calibration analysis, which corresponds to the model itself used in the performance simulations. Such models should represent the physical behaviour of the building correctly [8]. High levels of detail may affect modelling time and the simulation steps [9]. However, large amounts of simplifications, without considering the thermal and physical phenomena involved, may lead to erroneous conclusions. Calibration and uncertainty analysis techniques should be applied in computer models, since these models represent a simplification of reality. With these techniques, one can determine the level of imperfection of the models, before performing forecasting and decision making [10]. There are few studies that deal with the analysis of computer models. In this study the word "model"

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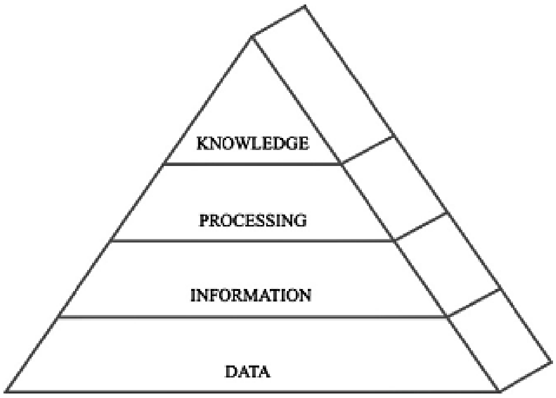

FIGURE 1 Scheme of the process "from data towards knowledge"

means the geometry characteristics and shape of the building. Such models do not need to represent a building as it is architecturally, but rather its thermal behaviour. According to De Wit [11], the modelling uncertainties arise from commonly applied physical assumptions and simplifications in a computer model. Some authors have proposed various methods of simplification, trying to reproduce the physical behaviour of a building in a few representative parameters [12].

The objective of this research is to develop an integrated decision support system for office building renovation that not only assesses current condition but also provides sustainable renovation implementation solutions for decision makers. These solutions must optimize the trade-off between improved quality and investing cost for each suggested renovation action. For the decision support system, solutions are determined by a novel hybrid approach combining A* and genetic algorithms (GA). More specifically, in order to achieve the decision support goal, we develop the system in these three steps: (1) sustainable criteria and their corresponding assessment items for existing office buildings are established; (2) three modules of the decision support system are developed: rule-based assessment, data management and the algorithms module; (3) for system validation, zero-one goal programming (ZOGP) and genetic algorithms are adopted to validate the effectiveness of the algorithm used in this system. To validate the approach, an office building renovation project finished in 2005, is introduced as a case study to compare differences in energy performance among different scenarios. The implications for these differences and potential benefits of the system are also illustrated.

2 Related Works

The estimated lifespan of components in a building varies dramatically. For support systems such as the building structure and exterior skin, their lifetime can be more than 50 years. However, during that lifetime, infill systems such as interior facilities, mechanical or electrical systems and so on, may undergo renovation from time to time [16]. This periodic renovation provides opportunities to upgrade the internal and external environment, increase the value of existing buildings, provide more modern accommodation, and attract new owners or occupants [17]. Taking sustainability into account, through renovation owners can implement cost-effective measures trans-forming their buildings so they become resource-efficient and environmentally sound for the long run [13-15]. Office buildings have one of the highest levels of energy consumption compared with other building types. The annual energy consumption in office buildings varies between 100 and 1000 kWh per m2, depending on geographic location, type and use of office equipment, operational schedules, type of envelope, use of HVAC and lighting system and so on. [18] . In the US, annual average energy use intensity for office buildings is nearly 300 kWh per m2. For HVAC and lighting systems, the energy use accounts for 70% of total office building energy consumption in the US and 72% in the UK. [19]. Moreover, predictions indicate a massive growth in energy consumption and conditioned area in the EU during the next 15 years, from 1200 Mm2 (3 m2/inhabitant) cooled to 2200 Mm2 (5 m2/inhabitant), increasing approximately 50% [20]. For buildings, the trend of increasing energy consumption will continue during subsequent years thanks to both the expansion of built area and new energy uses. Therefore, improving energy efficiency in existing buildings has become a critical mission of global sustainability.

Retrofitting of buildings is the process of replacing or adding parts of the building shell or installations while renovating is restoring the look s and performance of building parts to their original state or better. The need for renovation arises when buildings start to age, because of deteriorating materials and other external influences such as weather. The building's initial quality, use and maintenance also significantly affects, when the need for renovation arises. In addition, if buildings are not maintained sufficiently there can be an accumulated need for renovation. Lastly, renovations can be initiated when buildings need to be improved or transformed to meet the demands of new occupants or operations. Energy renovation is renovating and/or retrofitting with the aim of improving the energy performance of a building, i.e. sustainable retro fitting and renovation of a building. In addition to lowering the energy consumption, energy renovations should guarantee the market value of the buildings with rising energy prices and increased requirements in building regulations. In northern Europe heating and electricity account for the majority of buildings' energy consumption, therefore most energy renovation measures aim at improving the buildings' performance in relation to thermal losses and electricity consumption. These measures include e.g. improving the thermal insulation of building components, replacing windows and glass, replacing technical installations, changing energy supply, and improving the operation of the building.

3 Computer Aided Simulation

3.1 THE CRITERIA

Many global organizations have made great efforts to promote sustainability in built environments. The Leadership in Energy and Environmental Design (LEED), developed by the US. Green Building Council (USGBC), is one of the most recognized built environment assessment systems [21]. Six major criteria: sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, and innovation and design process provides a suite of standards for environmentally sustainable built environments [22]. BRE Environmental Assessment Method (BREEAM) is an environmental assessment tool to measure the sustainability of new or existing buildings in the UK. BREEAM Offices is now a widely used means of reviewing and improving the environmental performance of office buildings. Criteria include energy, health and well-being, transport, water, materials, waste, land use and ecology, and pollution, among other things [23]. The Green Building Challenge is a collaboration of more than 20 countries committed to develop a global standard for environment assessment. A spreadsheet tool (GBTool) was developed for participating countries to incorporate their regional energy and environmental priorities into the framework [24]. Seven general performance issues, including site selection, energy and resource consumption, environmental loadings, indoor environmental quality, functionality and controllability of building systems, long-term performance, and social and economic aspects, are suggested as criteria [25]. Although LEED, BREEAM, and GBTool differ in terminologies, structure, and performance assessment procedures, the common concerns regarding various environmental impacts provide a good reference for establishing criteria for assessing sustainable office buildings. In this research, sustainable renovation means implementing specific actions which improve or upgrade building quality with regards to sustainability, and ensuring these actions are cost-effective and within the owner's budget. Therefore, certain criteria concerning new construction assessment, public and social issues, transportation, and infra-structure are not considered. These are the criteria considered in our decision support system.

3.2 THE STRATEGY

In order for the building maintenance to be successfully managed, it is necessary to obtain an accurate data on the building condition in every moment. It means that the data has to be available, uniform and sorted, i.e. there has to be a database in the digital form. By overviewing the information on a building, it is possible to control and direct its functioning. The usage of these data is possible only with the existence of a digital database organized and sorted in a quality fashion. The survey of the sorted data leads to the information that is processed and sub-sequently leads towards the knowledge, as presented in Fig. 1. Quality database should contain not only all the documentation related to the construction of a building, but also all interventions and activities performed on the building in the past during the maintenance period. Computer networking allows these data to become available to a larger number of users, i.e. maintenance managers. A company can have numerous benefits from the experience reported and saved by using digital databases for maintenance and then using that experience as one of the most feasible resources. It is clear that regular inspections are the bases for preventive maintenance, not only of structural elements, but also of all other elements in a building. Interventions that may follow have to be uniformly coordinated and based on experts' opinions. By sorting the input data in an adequate manner, one can follow the behaviour of individual building elements and predict their behaviour in the future, which is the objective of the maintenance management. Based on these findings, a model for data collecting has been formed and presented. The model presents the base for the process of building rational usage and facility management, as for this and the environmental management. The designed program is not a decision making tool and it does not contain algorithms that will affect its outputs. The basis of its use is the collection, selection of data and their presentation in a proper manner. It is not designed to predict future costs of building maintenance, since it is not anticipated that the program makes decisions about future activities. It was conceived as a tool for maintenance managers that facilitates planning of maintenance activities and, in many ways directly and indirectly, contributes to the reduction in maintenance costs. Since it sorts all the information about the activities on the object in several different manners, the program has the potential to be developed towards the establishment of reports about the planned intervention prices. It is planned that in the future use, among other things, by selecting specific interventions from the existing databases and their prices, the program predicts future maintenance costs. In the shown model of the database, all elements in a building are divided into construction, installations, finishing works and equipment. Within each element type, the category of the element is defined, and within each category, elements are de fined by a name and a code.

3.3 THE FRAMEWORK

The principle line of the main idea to construct the framework of the intelligent evacuation system is as follows: On the basis of the evacuation lifesaving system of the buildings, establish a system which takes the front -end information acquisition as the data source, the main control module of the intelligent evacuation system as the core, the intelligent emergency lighting and evacuation indication escape system as the front-end display device, and guiding the stream of people and fixing the evacuation facilities as the carriers, with the purpose of evacuating the personnel. Establish and utilize the scientific and application results of the superior information technology, and intelligent and dynamic adjustable system of the intelligent buildings. This system is available to be implanted with the intelligent main engine system of the intelligent buildings and be contained in the building automation system (BAS). Moreover, it will organically combine with the communication network system (CNS) and office automation system (OAS), and then become a part of the building intellectualization technology. The basic motion procedure of the system is as follows: take the content acquired from the front-end information acquisition as the data source, input the data to the main control module of the intelligent evacuation system embedded in the main intelligent engine of the buildings. Through the operation of the background and after generating the command, output it to the intelligent emergency lighting, evacuation indication and escape system; directly guide the crowd to conduct the personnel evacuation by adopting the fixed evacuation de vices of the buildings as the carriers through its front-end display device

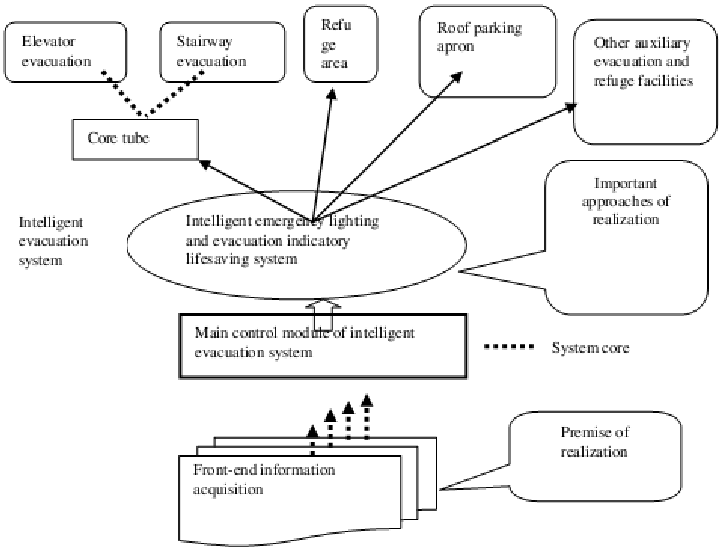

FIGURE 2 Sketch of Intelligent Evacuation System Composition

(voice, stroboflash, two - way adjustable indication, luminous flux indication, digital display, etc.). Among them, the front-end information acquisition provides necessary basis support for the system, while the main control module of the intelligent evacuation system is the core of the system.

The main control module of the intelligent evacuation system is the core of the whole system. The main control module contains several sub - models that are embedded in the module and determine the generation of the intelligent command. Each sub- model represents the basic principles and basis of the intelligent command generation. They also have their own model equation, namely, the arithmetical operation. Besides, the achievement of the model equation should have fire science theory, fire risk evaluation methodology and other related ones as its theory basis and support, which not only can lay solid foundation for truly simulating the intelligent evacuation system and guiding the personnel evacuation, but also can reflect and verify the scientificalness, rationality, and effectiveness of the established intelligent evacuation system. Thus, it is feasible to put forward new thought on studying personnel evacuation and obtaining optimized personnel evacuation proposals. The composition of the main control module of the intelligent evacuation system is shown in Fig. 2.

FIGURE 3 Southeast facade of the building before and after renovation

The intelligent emergency lighting and evacuation indicatory lifesaving system are important front -end display devices for realizing the function of intelligent evacuation system. The system still adopts fire -control evacuation indicatory sign lamp with different functions on the basis of the current system. In addition, through the integration of stroboflash, voice, two-way adjustment, and vision-succession signal lamp, it strengthens the signal from the sensory organs (e.g. vision, hearing, etc.) of the evacuation personnel, which is favourable for the personnel to escape from the fire scene. The integration of the front-end information acquisition with the intelligent fire alarming system enables the intelligent emergency lighting and evacuation indicatory escape system to obtain comprehensive and accurate information. What's more, it can obtain relevant dynamic information in real time when the status of the fire scene changes. After the back ground operation of the main control module of the system, it can generate optimal safe evacuation routines through intelligent judgment, and adjust the evacuation guiding direction of the evacuation lamps in the buildings in real time. The abundant technology of front-end information acquisition enables the intelligent evacuation indicatory escape system to separate from the initial version which only can realize the initial function (e.g. linkage, etc.) and cannot carry out intelligent analysis and dynamic adjustment, as well as incapability of being running through and applied in the whole evacuation process. Thus, it can actually achieve the purpose of guiding the personnel to escape from the fire region "safely, accurately and rapidly". In addition, the effect of the new intelligent emergency lighting and evacuation indicatory escape system should run through the whole process from the initial -phase escape, metaphase refuge to the last - phase rescue. Besides, the partition setting problem of the module should be taken into account. Once the lamp of some part is damaged due to the fire, the normal operation of the whole system should not be affected. Therefore, it is necessary to delay the effect time of the intelligent emergency lighting and evacuation indicatory escape system. Various advanced voice system and fire scene information display devices are indispensable in the intelligence emergency lighting, evacuation indication and escape system. For instance, it is necessary to set voice guidance devices on the evacuation route and specific position inside the core tube; set monitoring information display screen of the core tube in the necessary parts (e.g. pre-chamber of the core tube, etc.) so as to display the real-time status information, elevator arrival time, the number of the people who are waiting, etc.; set a screen for displaying the real - time elevator status in the elevator, etc.

4 Case Studies

The selected case study was the renovation of a disused wine storage building, a project supported by the Council of Cultural Affairs (CCA). The building was originally built in 1979 for storing different kinds of wines and beers for the Tobacco and Alcohol Monopoly Bureau, an organization inherited from the Japanese government during the Colonial Period. During the opening of markets, privatization of state-owned enterprises, and the change of social structure, this building increasingly lost its function, and after 1998 became an obsolete urban space. In 2004, CCA decided to revitalize some of the unused built environments through sustainable urban regeneration, and this building was selected because of its special historic value and cultural heritage. As far as sustainability is concerned, this building had many existing problems such as insufficient greenery and waste management systems, unfit insulation in roofs and exterior walls, unfavorable ventilation and indoor thermal capacity, inefficient water appliances, and so on. The renovation project was finished in 2005 and transformed the wine storage warehouse into an office building. The total floor area is 2190 m2 with three stories and one basement and the renovation budget was US$910,000. Fig. 3 shows the southeast facade of this building before and after renovation. This project was a successful implementation of sustainable building renovation, qualifying under the green building certification system, and provides an excellent example to test the developed system. Since the system focuses on sustainable renovation, some construction items such as temporary work, demolition, and structural enhancement that are not directly related to sustainability are excluded when considering the sustainable renovation cost. Therefore, the modified budget for sustainable renovation was US$580,465. Using the system, a set of optimal solutions can be found in 0.05 s and the score increases from 1 to 40.9 (out of the full score of 44.0), which represents a satisfactory result. However, the acquired result needs to be validated systematically.

5 Conclusion

In advanced countries, buildings have become one of the fastest growing energy consumption sectors. As the importance of global sustainability increases, improving the energy performance of existing buildings is undoubtedly considered to be one of the most sustainable and feasible measures for creating sustainable buildings and for improving energy consumption profiles, thereby reducing greenhouse effects. Much attention is still required for developing structured and systematic mechanisms to support the decision-making process for encouraging effective and efficient energy performance upgrades for existing buildings. Researchers should not only be concerned with energy consumption simulation and prediction, but also with adopting more energy-efficient renovation strategies to minimize environmental impacts. To develop a web-based interactive decision support system in the near future, an effective and robust search algorithm is required. Based on test results of the decision context of this research, the developed hybrid approach GAA* has more advantages than ZOGP and GA not only in algorithm efficiency but also in solutions satisfaction. A comparison of the energy performance including energy consumption, life cycle energy cost, between a real project and the system's results demonstrates the potential of its practical applications. In summary, the system provides a generalized analysis process for dealing with sustainable renovation assessment and solutions selection. The algorithm developed in this study is very effective and suitable for solving complicated and large-scale combinational, discrete and determinate problems. The data module of the system is flexible, and data for cost, score and assessment items can be modified or customized according to actual requirements in different regions and countries. Although the system development is based on major characteristics of office buildings, the flexible data module employed in the system can also provide users with high feasibility and flexibility to define different assessment items, renovation actions, as well as their corresponding cost and score for other building types to conduct optimization. Future efforts to continuously improve the system and to promote its application to contribute towards more sustainable built environments are expected.

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