CIB - UTILITY BASED SYSTEMS FRAMEWORK FOR EXISTING RESIDENTIAL BUILDING

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ABSTRACT
This study proposes an approach for conducting comparative assessments between renovation and new construction through the use of CIB utility theory systems and applies the methodology to an adaptive case study. To this end, the theoretical underpinnings of CIB were explained in the literature review, and the method of data analysis, selection of usability functions, and standard condition assessment scale were explained. The proposed model can be used to evaluate CIB utility theory systems and for life-cycle sustainability assessment (LCSA). The current findings revealed that the maintenance planning system and 5G information must be improved because they are the key to Taiwan’s future development. Considering that the aim of cost-optimal maintenance and renovation planning is to not only optimise the service life-cycle costs of building components but also to maintain appropriate conditions and the performance of the respective components, the model used in this study prioritises performance over cost. Therefore, proposals are made for the future development of LCSA considering stakeholders of various projects for new construction by enhancing objectivity and accessibility.

1. Introduction

Human activity is increasing global pollution and causing numerous environmental problems. Generally, no modern technologically and economically feasible alternatives exist in buildings. The green building design is based on scientific concepts, construction, operation, and maintenance of buildings; this design can impact the air we breathe and our health as well as the energy consumption (Chiang 2019; Mardani et al. 2017). The exploration of the future of energy balance and carbon capture technology has gained significant attention and become crucial in the real estate industry. Furthermore, countries are continuously and actively improving environmental management and implementation (Chiang 2019; Paul and Taylor 2008). Energy-renovation measures are not only critical in improving the energy performance of buildings but also in complying with the current living standards and regulations (Farahani, Wallbaum, and Dalenbäck 2019b; Sesana, Rivallain, and Salvallai 2020). The EU has adopted several directives to promote energy renovation. However, progress has stagnated because of the increased investment risks caused by the lack of information and transparency.

According to the US Department of Housing and Urban Development of Commerce, a residential building includes those that (a) consider only the physical structure, not the ownership, of a residential building; (b) a multi-family category that includes all buildings containing at least two housing units that vertically or horizontally adjacent to each other; and (c) those that count individual housing units. On the contrary, commercial buildings include medical buildings, hospitals, special care buildings, offices, retail buildings (i.e., financial buildings), multi-merchandise shopping buildings, those for beverage, and a miscellaneous catch-all category that includes everything else (Farahani, Wallbaum, and Dalenbäck 2019b).

In this analysis, 17 macro-level sustainability assessment indicators were selected and divided into three main categories: community service facility (CSF); individual economy and service (IES); and building environmental planning (BEP). The three-pillar conception (social, economic, and environmental) of sustainability commonly represented by three intersecting circles with overall sustainability at the center is ubiquitous (Purvis, Mao, and Robinson 2019). The notion of building life-cycle design must be permeated with innovative thinking, also considering the equipment and facilities life cycle present in the overall indoor space, and products’ and services’ sustainable environmental attributes, including raw materials, energy, and recyclability. Meeting environmental goals, ensuring basic functions, service life, economy, and the quality of products and services must be paramount. Life cycle assessment (LCA) thinking is increasingly seen as a key
concept for ensuring a transition toward more sustainable production and consumption patterns.

An increasing number of studies are applying the LCA to assess the impact of constructing new buildings or prioritizing refurbishment strategies for residential building portfolios. While the life cycle benefits of renovations are clear, uniform guidelines for the LCA of renovation projects and how to perform comparative assessments between renovations and new constructions are lacking (Dixit et al. 2012; Ramesh, Prakash, and Shukla 2010). Although several studies on similar topics have been performed, their aims are different. All studies had their own limitations, and none were practically applied to residential buildings (Dixit et al. 2012; Hasik et al. 2019). Among the different decisions to consider during the application of an LCA, the selection of an impact indicator is critical, as this choice significantly impacts the interpretation of the results. We also aim to identify and describe community service facility (CSF), individual economy and service (IES), and building environmental planning (BEP), termed as the triple bottom line (CIB) of residential buildings and encompassing building construction, operation, and disposal phases. To achieve this goal, this study investigates residential buildings under 10 stories, which are located in the New Taipei City, using research tools to construct an evaluation model for CIB and life-cycle sustainability assessment (LCSA) site evaluation.

The proposed CIB also contributes to increasing the sustainable performance of the housing industry, as it allows the assessment of the design against economic, environmental, and social attributes concurrently, which ensures a balanced consideration of the houses built on sustainable pillars. The paper presents a framework to apply the CIB for the levels/categorization of the condition of current status and future scenarios of residential building energy using multiple sources of data available to the infrastructure managers. The overall methodology proposes the use of three levels according to characteristics. Risk-conscious preferences are included to verify the model’s feasibility. The study comprises an introduction and a literature review of the framework for the case study to present the main focus of the research described in this thesis. The appropriate research methods and processes, data collection procedures, data analysis, and verification of validity and reliability were employed to explain the research design, collected data, case study, results and discussion, and conclusions.

2. Literature review

2.1. The AHP method be combined with utility theory

In the previous section, explain the research motivation and purpose. This chapter will provide a literature review. FDM technology was applied, as a screening decision factor to assess the effect of the CIB method on CSF, IES, and BEP and related aspects. The AHP technique was chosen to identify the relative importance and weights of selected attributes because it enables the selection of the most favorable option from among several alternatives during a multiple-criteria decision process. Regarding the current study’s AHP methods, a numerical scale ranging from 1 to 9 (Saaty’s scale) was implemented; this scale was used to assign the weights of criteria, sub-criteria, and alternatives. The first step entailed comparing the criteria and sub-criteria. In the next step, each alternative was compared with the criteria and sub-criteria; subsequently, the overall priority weights for the criteria, sub-criteria, and alternatives were calculated. The AHP is a multi-criteria decision-making model proposed by Saaty (1990). It is frequently applied for decision analysis in fields related to sustainability, the environment, economics, business, management, engineering, management consulting, etc. (Chiang et al. 2020; Saaty 1990, 2008), e.g., the indoor environment assessment (Chiang and Lai 2002); real estate developer’s product positioning (Chiang 2019); sustainability (Mardani et al. 2017) and sustainable system (Rehman and Ryan 2018).

The construction herein was performed using FDM and AHP based on the system index of residential building products; utility theory was used to develop the LCSA models for evaluation. This study uses consistent inspection as well as standard and relative weights to understand the distribution of expert and scholar opinions. In this study, the AHP was combined with utility theory to obtain the utility values. A well-known property of utility theory is that the value of the evaluative factors can provide decision makers with more valuable references.

2.2. Expected utility theory

Daniel Bernoulli’s proposal of the St. Petersburg paradox in 1738 is considered the origin of the hypothesis (Dozzi, AbouRizk, and Schroeder 1996; Luce 1956). Decision-making involves complex uncertainty risks and expresses people’s preferences and relative risk attitudes. The advantage of the utility theory is that it provides decision makers with a quantified mode of analysis to facilitate the enhancement of the objectivity of decisions (Chiang 2019; Dozzi, AbouRizk, and Schroeder 1996; Luce 1956). This mode of analysis has the following steps:

Each criterion has an exclusive linear utility function $u_i(y_i) = A_{yi} + B$ and a fuzzy scale value between $<y_{HL}, y_{L}>$, where $y_{ma}$ within the $y_{HL} - y_{L}$ range is the preferred point, $u_i(y_{ma}) = 1$, and $y_{mi}$ is the worst
point, $u_i(y_{mi}) = 0$. First, the values of A and B in $u_i(y_j) = A_{yi} + B$ are computed.

Specify the range of interest for each criterion, including the upper and lower limits $(y_U, y_L)$, threshold $(y_T)$, and preferred point $(y_M)$.

Each criterion has an exclusive linear utility function $u_i(y_j) = A_{yi} + B$ and a fuzzy scale value between $(y_H, y_L)$; here, $y_{ma}$ within the $y_H - y_L$ range is the preferred point, where $u_i(y_{ma}) = 1$, and $y_{mi}$ is the least desirable point, where $u_i(y_{mi}) = 0$. First, the values of A and B in $u_i(y_j) = A_{yi} + B$ are computed.

Because $u_i(y_{mi}) = 0$ and $u_i(y_{ma}) = 1$, the following equations are obtained:

$$u_i(y_{ma}) = A \times y_{ma} + B = 0, B = -A_{y_{ma}}.$$

$$u_i(y_{ma}) = A \times y_{ma} + B = 1, A = \frac{1}{y_{ma} - y_{mi}} \quad (1)$$

The expected utility value (EUV) is equal to the sum of each criterion’s relative ratings $u_i(y_j) \times$ weighting value ($W_i$) and can be obtained using the following equation $(u_i(y_j)=u_{ri})$:

$$\text{ExpectedUtilityValue(EUV)} = \sum_{i=1}^{n} (u_{ri} \times W_i) \quad (2)$$

After defining the fuzzy scale for $(y_H, y_L)$ and the values for $(y_{ma} \text{ and } y_{mi})$, the constants A and B, as well as the utility function for each criterion, can be obtained by solving Equation (2). As an example, relevant utility theory-related research includes risk management (Chiang et al. 2020), the product positioning of real estate developers was considered (Chiang 2019). The causal relationships within the overall industrial structure and the complex factors in the system environment were taken into account in the modeling process. Thus, the proposed model can be applied under the conditions of rapid changes in the market for residential buildings in order to select the most suitable renovation of residential buildings. The proposed framework is based on the CIB utility theory and information economics principles. The framework was applied to select renovation, and new construction project(s) based on residential safety and sustainable environmental criteria. CIB utility theory has the advantage of taking into account the decision-maker preferences in the form of utility functions defined over a set of tangible and intangible criteria.

Together with related previous studies, 17 potential factors that may affect CIB utility theory decisions are classified into three categories, as CSF relies on all the residents of the community to build a community planning method and focuses on social welfare, public services, and environment-friendly services to meet the needs of residents and improve the quality of life in the community. IES refers to those who are in the construction industry, engaged in self-employment to formulate projects related to corporate social responsibility, and can enhance corporate profits as well as services provided to consumers. BEP considers the shaping of internal spaces to create a more effective and pleasant living environment. This model comprises two parts: development and application. Therefore, a fuzzy logic inference system was constructed and the input standards were F1 (CSF), F2 (IES), and F3 (BEP), as shown in Figure 1.

3. Data analysis methods

3.1. The team members of FDM questionnaire

In this study, we identified the real-world challenges of implementing innovative building energy codes based on eight in-depth expert interviews. There were 30 team members of FDM, namely, 15 specialists in the industry including architects and real estate appraisers, 5 executives who had doctorates, 5 directors of government sectors, and 5 professors from prestigious universities.

This research hierarchy is divided into the category of “community service facilities” (CSF factors 1–6) consists of “Building Type,” “Transportation convenience,” “Evacuation distance,” “Social Welfare,” and ‘Social Mobility. Secondly, the category of “individual economy and service” (IES factors 7–12) consists of “Corporate Social Responsibility”, “5 G information”, “Servo mechanism”, “Transactional focus”, “Community participation mechanism,” and ‘After-sales service. Thirdly, the category of “building environment planning” (BEP factors 13–17) consists of “Water resource recycling”, “Daily energy saving”, “Barrier-free environment”, “Structure durability,” and “Maintenance plan”. The data acquired were organized and compiled into questionnaires with 17 factors (Table 1).

The survey questionnaire was divided into three parts. In Section i, through FDM, the experts and scholars classified and appraised the factors. In Section ii, employing AHP is used to analyze the individual facets and weights for each criterion. In Section iii, AHP was combined with the theory of utility to gain the expected utility value.

3.2. The FDM existing residential building of evaluation criteria

Double triangle fuzzy numbers were adopted, in combination with expert opinions, and grey zone tests were employed to identify convergence (Zu et al. 2020). The FDM utilised triangular fuzzy numbers to integrate the perceptions of experts and scholars and improve the limitations of the traditional Delphi method, which could only provide 50% of the information because of the use of a repeated questionnaire
survey. The FDM can semantically express meaning more precisely (Chiang et al. 2020).

Therefore, the triangular membership function and fuzzy theory were applied to classify the appraisal factors to select the CIB utility theory. Thirty questionnaires were issued for the preliminary survey, and 21 were completed and returned (70% response rate). FDM experts and scholars have a proportion of men higher than that of women, their age is between 40 and 60 years, the education level is still above university degree, the occupation is the highest in construction and real estate, and most middle and senior executives have qualifications of more than 10 years. Ishikawa et al. (1993) integrated expert opinions with fuzzy numbers based on the concepts of cumulative frequency distribution and fuzzy integral. Chiang et al. (2020) revealed that when FDM is applied for the factor, the threshold can be reduced when decision makers identify few measurement indicators; otherwise, screening can be performed to remove factors with a low discrimination index. We used Microsoft Excel for the pre-test analysis following. The analysis results are presented in Table 2.

There was an expert consensus threshold value \( G^* \) of 7.00. Three factors, namely, Community planning approach (CSF1), Servo mechanism (IES3), and Transactional focus (IES4), had a value less than 7.00 and were thus removed; 14 factors remained.

### 3.3. Introduction of AHP framework

As described in the previous section, the first stage involved determining the key factors by using FDM. In the second stage, an AHP expert questionnaire was conducted. Note that experts and researchers were the subjects of investigation at this stage. This model was designed to establish a hierarchical framework for selecting Taiwan's CIB utility theory and LCA, as well as various influential factors, to obtain the relative weight between different levels of factors. Thus, the CIB utility theory and LCA were used to plan subsequent support measures. The results of the investigation were then analyzed and applied to determine the order and weighting distribution of factors to reduce the hypothetical value, as this allows the decision-making process to be more objective and reflective of the actual demand.

### 3.4. Sample structure analysis

This study took more than 6 months (2020 January to June) to complete and had a very rigorous approach during the research process. As such, the results and
Table 1. Factors for assessment criteria items.

| Project aspect                  | Related factor                                      | Supporting documents (References) |
|---------------------------------|----------------------------------------------------|-----------------------------------|
| Community service facilities    | Community planning approach (CSF1) [A]              |                                   |
| (CSF)                           | Building Type (CSF2) [B]                            |                                   |
|                                 | Transportation convenience (CSF3) [C]               |                                   |
|                                 | Evacuation distance (CSF4) [D]                     | Proposed by experts               |
|                                 | Social Welfare (CSF5) [E]                          |                                   |
|                                 | Social Mobility (CSF6) [F]                         |                                   |
| Individual Economy and Services | Corporate Social Responsibility (IES1) [G]         | Proposed by experts               |
| (IES)                           | 5 G information (IES2) [H]                         |                                   |
|                                 | Servo mechanism (IES3) [I]                         |                                   |
|                                 | Transactional focus (IES4) [J]                     |                                   |
|                                 | Community participation mechanism (IES5) [K]       |                                   |
|                                 | After-sales service (IES6) [L]                     |                                   |
| Building environment planning   | Water resource recycling (BEP1) [M]                | Proposed by experts               |
| (BEP)                           | Daily energy saving (BEP2) [N]                      |                                   |
|                                 | Barrier-free environment (BEP3) [O]                |                                   |
|                                 | Structure durability (BEP4)                        |                                   |
|                                 | Maintenance plan (BEP5)                            |                                   |

Note: [A] = (Nadin 2007); [B] = (Coulter, Ham, and Findlay 2016); [C] = (Dieleman 2001); [D] = (Mayrand and Clergeau 2018); [E] = (Seo and Nam 2019); [F] = (Lyu et al. 2019); [G] = (Alvarado-Herrera et al. 2017); [H] = (Chih, Chih, and Chen 2010); [I] = (Qian, Chan, and Choy 2013); [J] = (Thomé and Junqueira Ribeiro 2016); [K] = (Moya et al. 2019); [L] = (Power 2008); [M] = (Wu et al. 2019); [N] = (Babazadeh et al. 2015); [O] = (Lee et al. 2015); [P] = (Sorgato, Melo, and Lambrerts 2016).

Conclusions from our questionnaire meet a certain standard. The questionnaire data from which were used to calculate the relative weighting values, the AHP data passed the consistency (CR ≤ 0.1).

3.5. Selection of utility function

In this study, CIB utility theory was implemented with energy performance improvement as an optimization criterion. Energy performance improvements, including the marginal investment costs of implementing energy efficiency measures and reduced operation costs (i.e., savings realized through energy-use reductions), were considered in the economic evaluation of the energy renovation plans (Farahani, Wallbaum, and Dalenbäck 2019b). To illustrate the application of the proposed framework, a hypothetical case study is provided, where input elicited from 21 engineering professionals is used to develop utility functions for a predefined set of selection criteria.

The evaluation criteria were determined based on a questionnaire composed by professionals and scholars. In addition to the participants who responded in the traditional binary way of “absolutely important” vs “absolutely unimportant” (0 or 100 points, respectively), other responses were processed using a utility function. The difficulty in determining the sustainability of the CIB utility theory systems is caused by the presence of the combination of different attribute measures in the sustainability function, which measures the overall sustainability. Four methodologies were used to solve the problem because of the large variation between assessment content and information attributes associated with the three criteria. Additionally, because various stakeholder groups tend to have different sustainability evaluation metrics, they must be consulted. In this study, the multi-attribute utility theory was used to develop an overall sustainability function for CIB utility theory-based systems. This approach consists of four processes:

- The determination of attribute utility functions.
- The assessment of attribute weights to determine the utility functions for each aspect.
- The assessment of aspect weights to determine the overall sustainability function for each stakeholder group.
- The determination of the overall sustainability function for community residents by combining the preferences of different stakeholders and experts through the use of a goal programming.

Multiple attributes were employed to develop an overall sustainability function for the CIB utility theory-based system. Experts determined utility functions for economic and ecological sustainability while stakeholders (i.e., producers, consumers, industrial producers, and policy makers) determined utility functions...
for external social sustainability and the aspect weights. The ability to quantify the estimation through the utility function with reliability or consistency using the residential community as an empirical field is imperative for the development of new systems (Table 4).

The CSF aspect (F1 (CSF) = CSF2 – CSF6). The foundation conditions and terrain issue Building Type (CSF2) are set as 80 due to ongoing improvement in building construction technologies, and the fact that for a construction base in Taiwan, the time needed from land development to completion of housing is at least 3 – 5 years. A study has indicated that the best distance for the public to walk to various public facilities is within 500 m. If the distance exceeds 1,200 m, it will be deemed rather inconvenient for the people. Meanwhile, as the walking distance will also affect the utility rate of public facilities, so the distance value of 300 m from Transportation convenience (CSF3) and Evacuation distance (CSF4) has a fuzzy range of 0 ̶ 100, is set as 80; the Social Welfare (CSF5) and Social Mobility (CSF6) aspects are set as 80 due to their great relationships to professional considerations, government policy and basic needs of community residents.

The IES aspect (F2 (IES) = IES1, IES2, IES5, and IES6) has a fuzzy range of 0 ̶ 100. The Corporate Social Responsibility (IES1) is set as 80. The 5 G information (IES2) entering the global commercial stage in 2020 will drive various innovative application services, drive industrial innovation and upgrade, and guide the model transfer and social growth. In view of the imminent arrival of the 5 G generation, it has a huge impact on all levels of technology, economic and social life, etc. Aspects are set as 90 to meet the user requirements on convenience. The Community participation mechanism (IES5) aspect is set as 70. The After-sales service (IES6) aspects are set as 90 due to their great relationships to professional considerations, building age and maintenance.

The BEP aspect (F3 (BEP) = BEP1 – BEPS) has a fuzzy range of 0 ̶ 100. The water resource recycling (BEP1) and Daily energy saving (BEP2) are set as 80 based on “energy efficiency” and “energy management”; The Barrier-free environment (BEP3) and Structure durability (BEP4) are set as 70; Maintenance plan (BEP5) is set as 80.

What follows are the utility values that have been predicted based on the AHP and utility theory. The calculated results show that the worst case will produce an expected utility value (EUV) of −121.40, and the best case will produce an EUV of 86.37 (Table 5).

### 3.6. Standard condition assessment scale

With regard to the assessment, setting a standard scale for the condition of an element is an extremely challenging task. Thus, for CIB utility theory-based systems, a standard reference for assessing the physical condition of the elements should consider 14 factors that influence effectiveness, and the efficiency should be compared to the standard index. To achieve this target, interviews were conducted with FDM experts to obtain their views and for them to rank three proposed standard scales. The selected experts have academic and field experience in construction management. They each performed an evaluation based on their own experience to select the best scale for assessing the conditions of elements implemented in CIB utility theory-based systems.

The proposed scales range from entirely poor to excellent with different ranges for each state. Based on expert opinion, the selected scale ranges from 15 to 85, which includes gradual changes from poor to good after 15 and gradual increments up to excellent from 50 to 84. With a score of over 85, the facility is considered in excellent condition up to the end of the scale at 100. The experts listed the performance indicators and expected characteristics, which were then divided into three levels according to their characteristics (Table 6).

### 4. Case study

This study was purposed to contribute to the existing LCSA framework in community service facilities and individual economies to demonstrate the usefulness of input–output modeling, and to emphasize the need for a practical sustainable impact evaluation technique. Based on a survey of related articles and site visits, to verify whether a solution is feasible or not to a built-up model, we will use the buildings under 10 floors in Taipei City as an example application. According to the provisions of the Construction Law, if the height of the building exceeds 10 floors, at least one elevator should be installed to reach the refuge floor and an elevator for emergency use should be installed.

Out of the 14 CIB utility theory systems, projects established by three communities were selected from the Taipei City area and surveyed in communities within 50 households. We selected projects or units located within the same region and with less differences as examples due to differences in location, real estate price, and completion time of the other housing units. We selected 30 residents each from Case Studies A, B, and C to participate in the survey for a total of 90 residents. The investigation period lasted for 8 weeks. The selected residents are very actively involved in community development and improvement. All questions were answered, and all questionnaires were returned with a response rate of 100%. Comparing the three case studies, Case Study A is found to be a better model, the input and output sets involved in quantized utility function values according to the respondents’ attitude toward risk and uncertainty.
In terms of adjusting these values, updating Tables 4–7 is necessary because renovation motivation is a decision element in any change in the entire decision-makers process, will affect the relationship between EUVs. Thus, decisions were made to maximize utility.

5. Results and discussion

With increasing concerns related to the integration of the social and economic dimensions of sustainability into LCSA, the traditional LCSA approach has been transformed into a new concept called LCSA. After analysis, daily energy-saving (BEP2) electricity use and commuting were found to play crucial roles in the majority of the categories of sustainability impact. Daily energy-saving electricity use is one of the most dominant components of environmental impacts, with more than 50% of greenhouse gas emissions and energy consumption throughout the life cycle stages of buildings in Taiwan (Chiang et al. 2020). The construction phase has the largest share in the income category, with 60% of the total income generated through the life cycle of residential buildings (Farahani, Wallbaum, and Dalenbäck 2019a). Based on the very rigorous approach, strategic maintenance and renovation planning were introduced to help decision makers take advantage. The difference in this research lies in the strengthening...
of the community service environment, which is a locality in simple terms. As far as urban development is concerned, improving the cognitive value of construction suppliers and competitiveness can help to a certain extent. In this section, we will explain the factors in three parts as follows:

6. Results of AHP analysis

It is noted from Table 3 in the 14 assessment aspects, 5G information (IES2) carries relatively more weight than the other factors. This research shows that the

Table 3. Relative weights of major criteria and minor criteria.

| Criteria | Level Wi | Overall Wi | Overall sequence |
|----------|----------|------------|------------------|
| (CSF2)   | 27.99%   | 9.33%      | 4                |
| (CSF3)   | 24.89%   | 8.30%      | 6                |
| (CSF4)   | 16.00%   | 5.33%      | 8                |
| (CSF5)   | 16.71%   | 5.57%      | 10               |
| (CSF6)   | 14.41%   | 4.80%      | 13               |
| (IES1)   | 29.19%   | 9.73%      | 2                |
| (IES2)   | 33.59%   | 11.20%     | 1                |
| (IES3)   | 22.32%   | 7.44%      | 7                |
| (IES6)   | 14.89%   | 4.96%      | 12               |
| (BEP1)   | 15.20%   | 5.07%      | 11               |
| (BEP2)   | 28.10%   | 9.37%      | 3                |
| (BEP3)   | 27.70%   | 9.03%      | 5                |
| (BEP4)   | 16.29%   | 5.43%      | 9                |
| (BEP5)   | 13.31%   | 4.44%      | 14               |

Wi = Wi * 100%

Table 4. For the quantitative values generated using the utility function.

| Criterion | \( y_i \), \( y_{ni} \), \( y_{mi} \), \( y_{ma} \) | A | B | Utility function \( u(y_i) = A_{yi} + B \) |
|-----------|----------------------------------|---|---|----------------------------------------|
| (CSF2)    | 0 100 40 80 0.025 100 1.00 0.025y_i - 1 |
| (CSF3)    | 0 100 40 80 0.025 100 1.00 0.025y_i - 1 |
| (CSF4)    | 0 100 50 80 0.033 167 0.033y_i 1.67 |
| (CSF5)    | 0 100 40 80 0.025 100 1.00 0.025y_i 1 |
| (CSF6)    | 20 90 50 70 0.050 250 0.050y_i 1.25 |
| (IES1)    | 20 90 50 70 0.050 250 0.050y_i 1.25 |
| (IES2)    | 10 80 40 80 0.025 100 0.025y_i 1.00 |
| (IES3)    | 20 80 50 80 0.033 167 0.033y_i 1.67 |
| (IES6)    | 10 70 40 60 0.050 200 0.050y_i 2 |
| (BEP1)    | 0 80 30 80 0.020 60 0.020y_i 0.6 |
| (BEP2)    | 0 70 30 60 0.033 100 0.033y_i 1 |
| (BEP3)    | 0 80 40 70 0.033 133 0.033y_i 1.33 |
| (BEP4)    | 0 100 50 80 0.033 167 0.033y_i 1.67 |
| (BEP5)    | 0 70 30 60 0.033 100 0.033y_i 1 |

Table 5. Expected utility value for criteria.

| Wi * 100% | \( y_{mi} \) | \( y_{ma} \) | Wi * (Wi) |
|-----------|----------------|----------------|------------|
| (CSF2)    | 9.33%           | 1.00           | 9.33       |
| (CSF3)    | 8.30%           | 1.00           | 8.30       |
| (CSF4)    | 5.33%           | 1.00           | 5.33       |
| (CSF5)    | 5.57%           | 1.00           | 5.57       |
| (CSF6)    | 4.80%           | 2.50           | 4.80       |
| (IES1)    | 9.73%           | 2.50           | 9.73       |
| (IES2)    | 11.20%          | 2.50           | 11.20      |
| (IES3)    | 7.44%           | 1.00           | 7.44       |
| (IES6)    | 4.96%           | 0.020          | 4.96       |
| (BEP1)    | 9.37%           | 0.020          | 9.37       |
| (BEP2)    | 9.03%           | 0.33           | 9.03       |
| (BEP4)    | 5.43%           | 0.33           | 5.43       |
| (BEP5)    | 4.44%           | 0.33           | 4.44       |

Table 6. List of Proposed Scales with their limits.

| Criteria | Wi * (Wi) |
|----------|-----------|
| (CSF2)   | 1.00       |
| (CSF3)   | 1.00       |
| (CSF4)   | 1.00       |
| (CSF5)   | 1.00       |
| (CSF6)   | 1.00       |
| (IES1)   | 1.00       |
| (IES2)   | 1.00       |
| (IES6)   | 1.00       |
| (ETU)    | 1.00       |

Table 7. For assessments of the overall living environment values.

| Criteria | Wi | A | B | C | EUI |
|----------|----|---|---|---|-----|
| (CSF2)   | 9.33% | 1.00 | 0.020 | 0.033 | 1.00 |
| (CSF3)   | 8.30% | 1.00 | 0.020 | 0.033 | 1.00 |
| (CSF4)   | 5.33% | 1.00 | 0.020 | 0.033 | 1.00 |
| (CSF5)   | 5.57% | 1.00 | 0.020 | 0.033 | 1.00 |
| (CSF6)   | 4.80% | 2.50 | 0.020 | 0.033 | 1.00 |
| (IES1)   | 9.73% | 2.50 | 0.020 | 0.033 | 1.00 |
| (IES2)   | 11.20% | 2.50 | 0.020 | 0.033 | 1.00 |
| (IES3)   | 7.44% | 1.00 | 0.020 | 0.033 | 1.00 |
| (IES6)   | 4.96% | 0.020 | 0.033 | 1.00 | 1.00 |
| (ETU)    | 4.96% | 0.020 | 0.033 | 1.00 | 1.00 |

Current network cannot always meet the data needs of consumers. During heavy usage, consumers may experience slow speeds, unstable connections, delays, and/or service interruptions. In view of the upcoming 5G information (IES2) era, it will have a huge impact on all levels of technology, economy, society, and life. People look forward to the convenience of 5G information deliveries and high acceptance of innovative technologies. 5G information (IES2) can drive various innovative application services, drive industrial innovation and upgrade, and guide the transfer of models and social growth, which will be helpful. The establishment and promotion of the smart city market domain is conducive to the digital economy and the creation of a government-leaping network society, thereby facilitating the concrete practice of high-quality digital city innovation. With regard to the degree of importance in the selection of CIB utility theory systems, "Corporate Social Responsibility (IES1)" is the foundation among all factors and is also a relatively important assessment criterion, followed by "Daily energy saving (BEP2)". This study only examined the key issues of green building from the perspectives of CIB utility theory systems consultants, architects, and engineers. In the study on the real estate assessment model, Ozsoy et al. (1996) proposed that the comfort of the external environment and the distance between public facilities deserve more attention in the architectural planning and design. The Top three secondary improvement aspects in terms of importance are "Maintenance plan (BEP5)", "Social Mobility (CSF6)" and "After-sales service (IES6)". In terms of Maintenance plan, due to the high proportion of old residential communities in Taiwan, but due to the lack of proper maintenance and
equipment, the repair of old buildings system and LCSA need to be enhanced. Sustainable design and comfort design are required in the interior design. Lastly, the implementation of sustainable energy policies and the promotion of various energy-saving and carbon reduction measures supplemented with environmental education shall also be conducted to achieve the goal of energy conservation and avoid energy waste. Accordingly, in constructing a new home, natural ventilation design shall be adopted. Large windows should be used to introduce natural sunlight and air into the building, providing sufficient indoor lighting and expanding the visual field. In terms of facilities, environmental friendly, recyclable materials and energy-saving equipment shall be used.

7. CIB utility theory systems

This model can help decision makers evaluate utility values to help decision-makers identify the best most suitable option among multiple alternatives taking into consideration multiple objectives and the decision-maker’s preferences. The model has the following applications:

As a self-assessment tool for building refurbishment, people looking to buy or rent housing.

As a means for private building developers to objectively evaluate risks when making decisions related to land development.

An economic input–output-based hybrid LCSA model was utilized to assess the sustainability of the residential buildings and help enterprises to improve customer satisfaction.

Finally, the results were used to define the type of input or develop a hypothesis on factors that influence each indicator; specifically, the range of interest for each criterion, including the upper and lower limits \((y_u, y_l)\), threshold \((y_T)\), and preferred point \((y_M)\), were specified. This process is essential for refurbishment strategy implementation.

8. Project characteristics and certification levels

This chapter will introduce the characteristics and classification of the project in terms of specific building type or project scale, project size, and certification level as indicated by law. The relatively high economic activities of residential buildings (i.e., commercial office buildings and factories) and different supply chain characteristics will affect all sustainable development categories. Because of the long lifetime of residential structures (often longer than 50 years), especially in terms of engineering, the assessment of technical and economic performance is essential for optimizing budget expenditure. The inclusion of all indirect factor chain-related impacts enables a society- and economy-wide analysis and macro-level LCSA. In summary, the proposed approach can be used as a model for consistent LCSA in other renovation projects and for demonstrating to designers, policy makers, and building owners the environmental benefits of adaptive reuse over new constructions because of the reduced need for new building materials. Experts agree that, when making building refurbishment and land development projects, one should prioritize urban landscapes, evacuation distance, barrier-free environment, and sustainability assessment methods for building projects. Therefore, the management of land resources and residential building systems is bound to be the mainstream trend of the 21st century.

9. Conclusions

In this study, we attempted to develop a whole-building CIB utility theory-based system that incorporates LCSA to improve the process of building renovation; the results provide a CIB utility theory-based reference for conducting comparative assessments for renovations and new construction projects; we also applied the methodology to an adaptive reuse case study. Energy efficiency measures are developed implemented in consideration of existing renovation measures. In this study, residential renovation criteria were extended to include occupant safety behaviors; as such, this study provides empirical evidence for a unique theoretical CIB framework that is based on utility theory.

Thus, changes in the life expectancy of building components influence the time allowed for making energy performance improvements. Furthermore, savings can be realized by reducing energy consumption. The model was designed to optimize the time-condition performance and budget constraint criteria. Given that cost-optimized maintenance and renovation planning are not only purposed to optimize the service life costs of building components, but also to maintain satisfactory conditions and levels of performance of the respective components, the proposed model was designed to prioritize performance over cost reduction; as such, delayed maintenance was not considered. In the pursuit of economic development, humane decisions that promote environmental sustainability must be made.

This is further discussed below. Construction and renovation plans can be formulated in a manner that promotes environmental protection. The findings of this study imply that future research directions should focus on 1) knowledge-sharing among project participants to assist organizational learning and innovation, thereby enhancing the capability of participants and competence of project teams; 2) government-led measures for the promotion of green buildings, given the changing external environment; 3) approaches that
include a comparison of the service life impacts of existing buildings to the sum of the service life impacts of components that will be involved in the processes of renovation, maintenance, and/or replacement; and 4) measures to ensure that developing countries can afford to prioritize the construction of green buildings.

This approach provides a comprehensive solution to ensure that residents can obtain housing in a maintenance planning system; however, 5G information must also be improved because these two elements are key factors for Taiwan’s future development. The optimization of maintenance activities (in terms of their technical and economic requirements) is essential for residential building safety managers and building owners to fulfill their societal expectations. Given that the aim of cost-optimal maintenance and renovation planning is not only to optimize the service life cycle costs of building components but also to maintain the appropriate condition and performance of the respective components, the proposed model prioritizes performance over cost, thereby minimize delayed maintenance. The experimental results of the CIB utility theory system demonstrate its high objectivity and potential value as a reference for future research. Regarding the difficulty of accessing private sector records, our case studies have focused on private residential communities in the New Taipei City area. Future system updates and maintenance will also have beneficial effects in the LCSA field. The current model is transferable to different regions, especially to developing countries, because it can adapt to the perspectives of stakeholders in other projects (such as owners, contractors, governments, and consumers).

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