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# Combination of sustainability and circular economy to develop a cleaner building industry

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ABSTRACT

The building construction industry is responsible for utilizing plenty of natural resources, water, and energy in the entire product life-cycle on one hand and producing air, water, and soil pollutions particularly in the operation phase on the other hand. Thus, regarding the high frequency of these projects, it is important to develop an integrated assessment framework to consider both sustainability in the development and circuity in the economy to ensure a cleaner building industry. This study aims to combine Sustainability and Circular Economy as two critical performance criteria in the context of building industry projects in order to move toward the integrated assessment model. Since the Circular Economy (CE) is related to a cradle-to-cradle life-cycle approach, the Prospective Multiple Attribute Decision Making (PMADM) utilities are utilized in this study. Afterward, an empirical study is used to weigh up the framework and assess different locations as an application of the proposed model. In this regard, two different mathematical approaches are used to ensure the reliability of the weigh-up results (Analytical Hierarchy Process (AHP) and Indifference Threshold-based Attribute Ratio Analysis (ITARA)). Finally, the case study alternatives are evaluated based on the weighted integrated framework by using Combined Compromise Solution (CoCoSo). As a result, these two different mathematical approaches successfully converged and confirmed the results and ratings. Also, the integrated framework ensures both sustainability and local environmental resiliency in developing the building industry projects simultaneously.


## 1. Introduction

Every construction development needs energy, natural resources, and raw materials to consume and make products and by-products such as pollution, waste, and emissions. In this process, inputs need to be sustained, and the outputs need to be safely recycled at the end of the product life-cycle to be reused in the future. In comparison, output reuse helps in terms of sustainability; on the other hand, the ability to safely return the used material to the environment helps enhance the system's resiliency. As such, these crucial aspects need to be integrated and simultaneously applied in assessment frameworks. Researchers emphasize this combination of sustainability and resiliency by changing the common linear approach in the material life-cycle to a circular one to have a more sustainable development process. The term "Circular Economy" (CE) has been used increasingly in various fields and industries to signify the safe return to the environment phase in the final step of the material life-cycle.

The primary purpose of development is to satisfy human needs and expectations [13]. This is why every nation strives to excel and try to outdo each other in development and construction projects. The building industry is a significant contributor to development due to a large number of building projects worldwide. Even a small change in the building industry's means and methods could make a big difference on a global scale. Besides, buildings, whether in the construction phase or operation, have a tremendous impact on the environment [32]. This is why building projects' sustainability assessment has been regarded as highly important both by academia and the industry. There are many Green Building (GB) assessment frameworks in the building industry that have gained a large share of the global market.

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**Nomenclature**

*Acronyms*

AHP Analytical Hierarchy Process
CE Circular Economy
CoCoSo Combined Compromise Solution
GB Green Buildings
MCDM Multiple Criteria Decision Making
ITARA Indifference Threshold-based Attribute Ratio Analysis
MADM Multiple Attribute Decision Making
PMADM Prospective Multiple Attribute Decision Making

*Common Parameters*

$A_i$ $i^{th}$ alternative
$C_j$ $j^{th}$ criteria
$x_{ij}$ Given score to the $i^{th}$ alternative related to the $j^{th}$ criteria
$w_j$ $j^{th}$ criteria weight

*CoCoSo Parameters*

$R_{ij}$ Normalized value of the $x_{ij}$ in CoCoSo methodology
$S_i$ Summarized weight of the $i^{th}$ alternative
$P_i$ Multiplication weight of the $i^{th}$ alternative
$k_{ia}$ Arithmetic mean of sums of $(S_i\&P_i)$ related to the $i^{th}$ alternative
$k_{ib}$ Sum of relative scores of $(S_i\&P_i)$ related to the $i^{th}$ alternative
$k_{ic}$ Balanced compromise of $(S_i\&P_i)$ related to the $i^{th}$ alternative
$k_i$ Final ranking score related to the $i^{th}$ alternative

*ITARA Parameters*

$\alpha_{ij}$ Normalized value of the $x_{ij}$ in ITARA methodology
$IT_j$ Indifference threshold related to the $j^{th}$ criteria
$NIT_j$ Normalized value of $IT_j$
$\beta_{ij}$ $i^{th}$ position in the ascending sorted value of the $\alpha_{ij}$
$\gamma_{ij}$ Ordered distance of the $\beta_{ij}$ values related to the $j^{th}$ criteria
$\delta_{ij}$ Considerable distance of $\gamma_{ij}$
$\upsilon_j$ Aggregation weight related to the $j^{th}$ criteria

GB is the best available alternative for the usual non-sustainable building construction industry, as it incorporates all three sustainability pillars in a systematic way [34]. GB industry helps to have a more sustainable economic development by decreasing the occupants' operational costs [48]. For instance, the building's energy-oriented design using the shading, building orientation, and best HVAC option helps to cut the costs of energy consumption. Also, GBs are socially sustainable by providing better living and working conditions for the inhabitants [8]. As a consequence, the GB industry is developed primarily to be an environmentally-friendly alternative to traditional buildings [22]. Besides, GBs have life-cycle solutions for the environmental problem through energy distribution and the HVAC system optimization for better thermal comfort [3], productivity maximization and reuse options [27], $CO_2$ emissions, as well as other greenhouse gasses, and soil pollutants minimization also, noise and light pollutants decreasing [22], designing to need less water and virtual water by using more water sensitive technologies, also, designing to require less operational energy [33], better raw materials utilization with lower embodied energy and a higher ability to be finally recycled, also treatment and recycling options maximization [25].

CE helps reduce raw material usage and consequently the negative environmental impacts [7]. The circularity concept in the CE literature is to ensure the recycling options at any stage of the project, product, and material life cycles. This study aims to develop a decision framework to facilitate the comprehensive view of sustainability and CE in a single framework to further GB's strategic decisions.

As is illustrated in Fig. 1, this study contributes to the body of knowledge by developing a comprehensive CE model for building projects based on the literature and experts' judgment. Consequently, an indicator-based CE assessment framework based on the CE model for buildings is developed. Then, the sustainability assessment framework is developed based on the literature review and green building rating systems. Finally, the comprehensive assessment framework has been designed to incorporate both sustainability and CE concepts, which can be applied to any building project. A case study is then undertaken based on the comprehensive decision-making model using AHP for the hierarchical criteria set. In this context, PMADM provides assistance to cope with future uncertainties in the criteria' hierarchical framework.

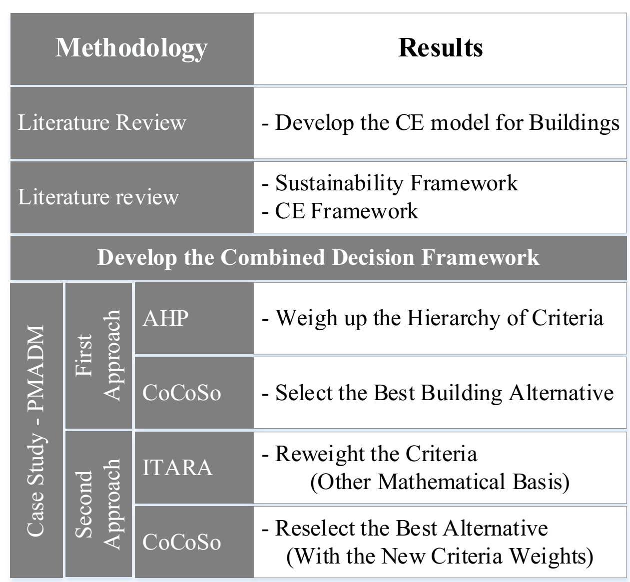


**Fig. 1.** Methodology flow in the paper.

Consequently, CoCoSo is applied for the alternative assessment concerning the weighted criteria set. At the final step, criteria weighting, an essential requirement in the building assessment process, is controlled by another methodology with a different mathematical basis to ensure accuracy. For this purpose, ITARA is applied to the alternative selection decision matrix and reweighted the criteria set. Then, CoCoSo methodology for alternative selection is recalculated with the new weighed criteria framework. The accuracy of the framework and the selection process is confirmed once the results of both methodological routes have converged.

## 2. Literature review

Sustainability and its three main pillars (i.e., environment, economic, and social) are multidimensional concepts with inherent complexities [14]. The sustainability assessment deals with criteria sets and always a hierarchy of the criteria as a representative of the study's related field [15]. Hence, Multiple Criteria Decision Making (MCDM) methods are widely used in the sustainability assessment of buildings [28], public rental housing projects with an integrated sustainability assessment framework [5], developing an evaluation system for the GB industry projects in China [43], and an Iranian residential building assessment tool [50]. Based on the literature, MCDM methodologies are applied to gather the experts' opinions on different problems such as selecting the sustainability criteria, selecting the alternative sets, screening the criteria sets, weighing up the criteria set, and selecting and ranking the best alternative. On the other hand, more than 100 MCDM methodologies and their extensions are developed [38] and can be applied to sustainability assessment studies. In a recent publication, the application of MCDM methodologies for heritage building sustainability assessment is reviewed [29]. A literature review is recently published to illustrate the building sustainability rating systems both in academia and the industry [26]. Another review paper was conducted to evaluate the application of green technologies in the GB industry projects [44]. Also, the application of MCDM methodologies in the low-carbon buildings [4] or the renovation of the constructed buildings as well [35].

Today a variety of green building rating systems are proposed in different countries from the United States (LEED) to the United Kingdom (BREEAM), Australia (GS), Canada (GG), Japan (CASBEE), and many other countries around the world. Some of the essential criteria in most green building rating systems are energy, site, indoor, land, outdoor environment, material, water, and innovation [42]. Generally, rating systems considered three steps of classification (different impacts are categorized), characterization (effects are assessed), and valuation (Assessed results are aggregated) [9]. Green building rating systems are beneficial by maximizing the buildings' performance, particularly in the operation condition, and minimizing the environmental footprints [31]. Contrary to the rating systems' profitability, these systems' primary focus is on the environment, and slightly on social sustainability pillars and economic aspects are rarely considered [1]. One of the widely used rating systems developed by the World Bank Group is Excellence in Design for Greater Efficiencies (EDGE), which is applied in more than 170 countries [6]. This system is primarily designed to build projects in developing countries where there is only limited governmental support for green building industries. EDGE uses a preliminary design certification to enable the owners to use it as a strong marketing tool while the building is still under construction. Just like academic sustainability assessment frameworks, green building rating systems are developed based on the criteria sets, their weighting, and assessing the building against the criteria, whether pre-weighted criteria (BREEAM) or credits and points (LEED) [10].

In traditional building construction and green building practices, the pivotal idea is the supply chain's linear approach. Take-make-use-dispose is the primary strategy and mental default in this industry. However, unsustainable collision is inevitable in the shrinking environment [24]. The CE approach's transition is of primary importance in every industry and mainly green buildings concerning building projects worldwide. This transition needs modifications in the products' design, supply chain, and business model [47]. Consequently, various studies were carried out to apply the CE concept to the building projects from heritage buildings [11] to develop a life-cycle costing model for building projects [23]. To assess the CE, a comprehensive quantitative framework is needed [39].

The broader view of the CE makes it necessary to cope with future uncertainties. Regular MCDM techniques mostly calculate based on discrete and definite criteria sets. However, in sustainability studies, considering the future conditions add to the complexity of the problem. Prospective Multiple Attribute Decision Making (PMADM) has been recently proposed [16]. With the contribution of this method, the assessment becomes more accurate. Addressing future uncertainties is a great advantage, particularly in interdisciplinary studies like sustainability and Futures Studies [17].

In this study, a comprehensive assessment framework is developed based on a combination of the CE and sustainability assessment frameworks around academia or the industry.

## 3. Methodology

Based on the previous literature review and expert judgment, a CE model is developed for the building projects (see Fig. 2). The model combines the circular life cycle, different phases of the project, product, material life cycles, other options for returning to the environment, and linear versus the circular approaches to the development. The return to the environment can be done in various ways and at different stages. For instance, a product may be reused at the end of its life without any need for re-manufacturing. When the options move from reuse to re-manufacturing, recycling, and safe disposal, cost, time, and energy for resolving the turbulence entering the environment are higher and more critical.

Most of the other references in the literature mainly focus on the product and production phases [24] as well as material and their recycling points in the life-cycle [40]. Another study put more emphasis on human development and its framework in the CE concept [41]. In contrast, this study takes the construction and its supply chain of materials as the major priority.

### 3.1. Sustainability assessment framework

Three sustainability pillars make up the top-level criteria for the sustainability assessment framework. Other criteria beneath the pillars are defined based on academic and industrial literature of the sustainability assessment tools for building projects. Green building rating systems can be used as prominent references, particularly for sustainability's environmental and social pillars. Hence, at the first step, Environmental indicators and social indicators were defined based on a study that reviews 15 different green building rating systems [42]. As mentioned in the literature review, sustainability's social and economic pillars have not received enough attention in green building rating systems compared to the environmental pillar. Hence, the social indicators are developed further herein based on a previous study on the buildings' sustainability assessment framework [2]. Finally, the economic aspects are divided into the capital and operating costs (from energy to maintenance and other utility costs).

(1) Lazar & Chithra [26]
(2) Nayak et al. [30]
(3) Shan & Hwang, [42]
(4) He et al. [21]

The sustainability assessment framework is developed based on frequent industrial and academic references as presented in Table 1. The theoretical concerns are four review papers conducted to illustrate sustainability indicators for the building industry. On

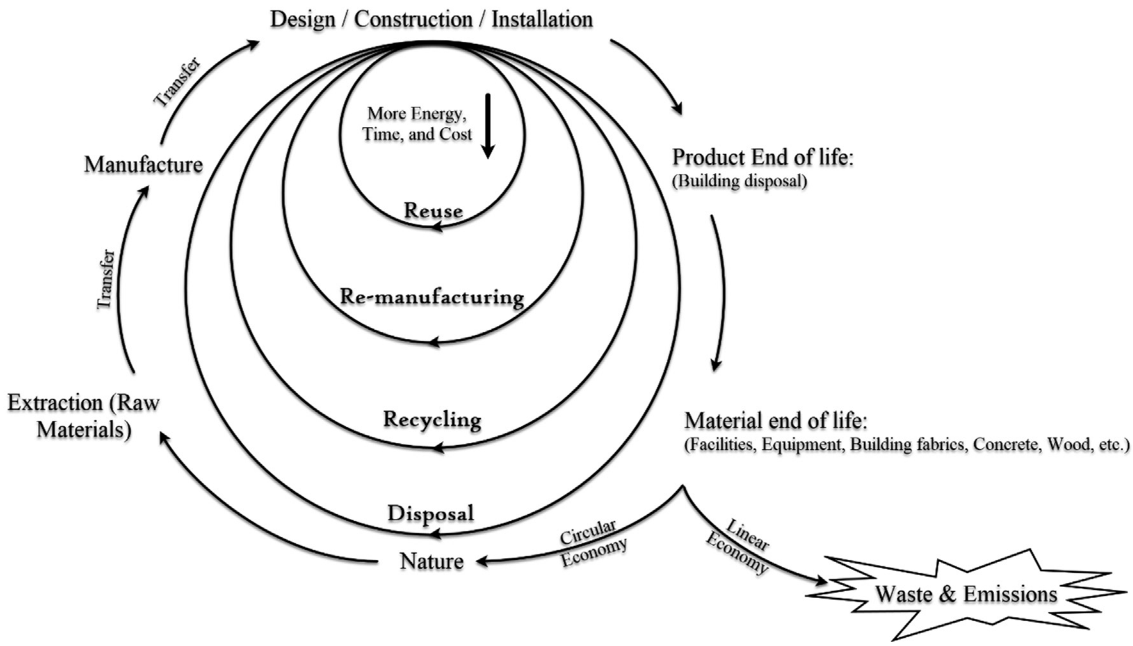


**Fig. 2.** CE model for buildings.

**Table 1**
The indicator-based sustainability assessment framework.

| Pillars of Sustainability | Sustainability Indicators | Industrial | | | | Academic | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | LEED | BREEAM | EDGE | UN-SDG | 1 | 2 | 3 | 4 |
| Social | Hydrothermal Comfort | X | X | X | X | X | | | X |
| | Acoustic Comfort | X | X | | | X | | | X |
| | Visual Comfort | X | X | | | X | | X | X |
| | Social and Cultural Aspects | X | X | | X | X | | X | |
| | Accessibility and Transportation | X | X | | X | X | | X | X |
| Environmental | Material | X | X | X | X | X | X | X | X |
| | Water | X | X | X | X | X | X | X | X |
| | Indoor Environment | X | X | X | | X | X | X | X |
| | Outdoor Environment | X | X | X | X | X | | X | X |
| | Pollutions (emissions to air, water, soil) | X | X | X | X | X | X | X | X |
| Economic | Energy Consumption (operational costs) | X | X | X | X | X | X | X | X |
| | Financial (initial costs) | | X | X | | X | X | X | |

Sources [26,30,42,21].

the other hand, the industrial section is investigated on the US sustainability rating system (LEED), BREEAM from the UK as a representation of the developed countries, and EDGE from the International Finance Corporation (IFC) developed in cooperation with the World Bank for developing countries. Also, UN sustainability goals and criteria are investigated to make sure a comprehensive sustainability framework is developed.

The indicator-based sustainability assessment framework is developed based on the Table 1 and is used as a branch of the objective function (see Fig. 3).

### 3.2. CE assessment framework

Based on the CE model (Fig. 2), the life-cycle is broadened to cover the cradle-to-cradle phases. According to the CE literature, various implemented procedures, standards, and regulations on the CE in different countries are implemented. One of the well-established CE assessment frameworks is a monitoring framework from the European Commission used in other previous studies as CE indicators [12]. As there is no consensus about the CE decision-making frameworks and the CE's dependency on the future and end of the material phase, the Prospective Multiple Attribute Decision-Making (PMADM) is proposed by researchers to cope with these uncertainties [16]. One of the PMADM methodology's novel contributions is the Supportive-backup criteria that can assist decision-makers with all possible scenarios in the future [51]. In this study, the sub-criteria of the CE assessment is defined as Supportive of future uncertainties (see Table 2). As a result, these Supportive (Sub-Criteria) would explain every uncertain criterion, which would help follow a uniform procedure by all decision-makers. Also, criteria Supportive aims to reach a common understanding of the problem circumstances, improving the results' accuracy.

CE has been used in various ways in previous studies. However, based on academic and industrial literature, one measurement method is an indicator-based assessment framework. The developed CE indicator set is the second branch in the objective function for the comprehensive assessment framework presented in Fig. 3.

### 3.3. Combination of assessment frameworks

This study's key idea is to develop a comprehensive decision framework to take both sustainability and return to the environment options into account. Thus, the sustainability and CE assess-

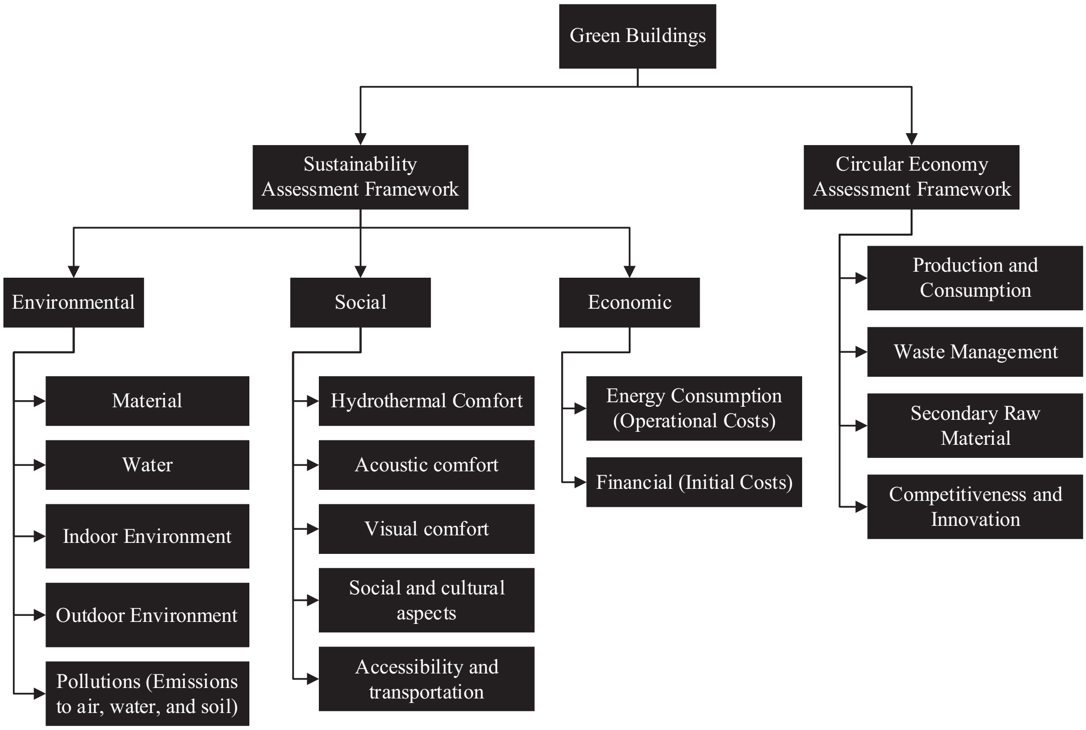


**Fig. 3.** The comprehensive hierarchical assessment framework.

**Table 2**
The indicator-based CE assessment framework.

| CE Indicators | Sub Criteria (Supportive in PMADM) |
|---|---|
| Production and consumption | self-sufficiency for raw materials |
| | Green public procurement |
| | Waste generation |
| | Food waste |
| Waste management | Recycling rates |
| | Recycling/recovery for specific waste streams |
| Secondary raw material | Contribution of recycled materials to raw materials demand |
| | Trade-in recyclable raw materials |
| Competitiveness and innovation | Private investment, jobs, and gross value added related to circular economy sectors |
| | Number of patents related to recycling and secondary raw materials |

Source: created by authors.

ment frameworks are generated based on the literature review and are combined as two criteria sets in a hierarchy of the decision-making comprehensive objective function.

### *3.4. Proposed MCDM methodologies*

The case study is followed by two approaches and by using the most suitable MCDM methodologies. The main rationales behind this selection of tools are as follows:

- AHP: Regarding the hierarchical objective function, the AHP methodology has the highest coincidence with the problem circumstances. AHP is used to evaluate and weigh up the criteria set in this study.
- ITARA: Criteria weighting plays a pivotal role in the assessment framework and the preference of the alternatives. Thus, considering the inherent uncertainties in the sustainability and CE assessment frameworks in dealing with unpredictable future priorities, the ITARA is used to laterally assess the criteria with a different approach to ensure the consistency and convergence of the results. ITARA uses the novel technique of the "indifference threshold" for the criteria assessment and is suitable for the complicated condition of this study.
- CoCoSo: Concerning the calculated criteria weights, CoCoSo is a new MCDM methodology that emphasizes the criteria weights. The methodology recognizes with computing different weighting matrices and calculating various relative weight measures for alternatives and end up with an aggregation method to find the alternative ranking. Thus, CoCoSo has the highest compatibility with the conditions of the problem.
- PMADM: Prospective Multiple Attribute Decision Making (PMADM) is a novel approach to cope with future uncertainties. Wherever the MCDM assessment encounters a complicated future circumstance, PMADM would be a solution. This methodology can be attached to every MCDM and enhance the predictability and accuracy of the results. Consequently, in this study, PMADM is utilized to address the inherent uncertainty of the problem.

Considering the hierarchy of the criteria, AHP is selected to assess the criteria in mutual comparison matrices. Then the alternatives need to be evaluated based on the criteria set by using the CoCoSo methodology. In the following, these applied methodologies are briefly explained:

#### *3.4.1. AHp*

There are six comparison matrices. The first one is to compare sustainability vs. CE at the top of the criteria hierarchy. Then, the sustainability pillars and CE criteria are at the next level of the criteria set. Finally, three comparison matrices have been introduced for the criteria set at the third level relating to the sustainability sub-criteria, such as material, water, and visual comfort. The applied AHP is based on the Saaty methodology [36]. Due to its extensive use in various applications, AHP is not presented here.

For more information on this methodology, please refer to the referenced paper [37].

### 3.4.2. CoCoSo

Based on Fig. 3, there are 16 criteria in assessing the alternatives in the CoCoSo decision matrix. Refer to the following criteria set:

C1 Material
C2 Water
C3 Indoor Environment
C4 Outdoor Environment
C5 Pollutions (Emissions to air, water, and soil)
C6 Hydrothermal Comfort
C7 Acoustic comfort
C8 Visual comfort
C9 Social and cultural aspects
C10 Accessibility and transportation
C11 Energy Consumption (Operational Costs)
C12 Financial (Initial Costs)
C13 Production and Consumption
C14 Waste Management
C15 Secondary Raw Material
C16 Competitiveness and Innovation

CoCoSo is a novel MCDM methodology that is recently developed [49]. The methodology is used in this paper as follow:

Step 1. Decision matrix

The decision matrix is based on the experts' opinions for "m" alternatives and 16 criteria, which is presented in the following:

| | Criteria | | |
|---|---|---|---|
| | ($C_1$) | ... | ($C_{16}$) |
| Alternatives | ($A_1$) | $\begin{bmatrix} x_{11} & \cdots & x_{1,16} \\ \vdots & x_{ij} & \vdots \\ x_{m1} & \cdots & x_{m,16} \end{bmatrix}$ | |
| | ... | | |
| | ($A_m$) | | |

where, $x_{ij}$ represents the importance of i$^{th}$ alternative concerning j$^{th}$ criterion.

Step 2. Normalization

As shown in the equations below, the normalization is done for cost criteria and beneficial criteria differently. The cost criteria are the ones that one seeks to reduce as much as feasible. In contrast, the beneficial criteria are the criteria for which the intention is to increase as much as possible.

$$R_{ij} = \begin{cases} \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} For beneficial criteria \\ \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} For cost criteria \end{cases} \quad (1)$$

where, $R_{ij}$ is the normalized value of the decision table related to the i$^{th}$ alternative and j$^{th}$ criterion.

Step 3. Weighted matrix

The weighted matrix is calculated in two different ways - Summarize weight ($S_i$) and multiplication weight ($P_i$)- as follows:

$$S_i = \sum_{j=1}^{16} w_j r_{ij} \quad (2)$$

$$P_i = \sum_{j=1}^{16} (r_{ij})^{w_j} \quad (3)$$

Where, $w_j$ is the value of weight for the j$^{th}$ criterion.

Step 4. Relative weights

In this step, three parameters (i.e. $k_{ia}, k_{ib}, k_{ic}$) are calculated based on the weighted matrix as follows:

$$k_{ia} = \frac{P_i + S_i}{\sum (P_i + S_i)} \quad (4)$$

$$k_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i} \quad (5)$$

$$k_{ic} = \frac{\lambda(S_i) + (1-\lambda)(P_i)}{\left(\lambda \max_i S_i + (1-\lambda) \max_i P_i\right)} \quad (6)$$

where $\lambda$ is a decision parameter between 0 and 1 which is selected by the decision-maker.

Step 5. Final ranking

The final ranking index ($k_i$) is calculated based on the relative weighting as follows:

$$k_i = (k_{ia} k_{ib} k_{ic})^{1/3} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}) \quad (7)$$

### 3.4.3. ITARa

ITARA is a threshold-based novel MCDM methodology developed primarily for material selection problems [45]. This methodology is applied to stakeholder selection combined with MARCOS and CCSD in a recent study [46]. ITARA is briefly applied to this study to calculate the criteria weights according to the following procedure [20]:

Step 1. Indifference threshold

In the first step, the decision matrix is created as follows, and every alternative is evaluated by the criteria set. Next, experts have to identify criteria indifference thresholds for the similarity of their scores. If a weighting difference is within this threshold, experts presume them at a similar importance level. For more details and in-depth concepts, refer to the referenced paper (Eqs. (13)–(15)).

| | Criteria | | |
|---|---|---|---|
| | ($C_1$) | ... | ($C_{16}$) |
| Alternatives | ($A_1$) | $\begin{bmatrix} x_{11} & \cdots & x_{1,16} \\ \vdots & x_{ij} & \vdots \\ x_{m1} & \cdots & x_{m,16} \end{bmatrix}$ | |
| | ... | | |
| | ($A_m$) | | |

Indifference threshold: $IT_j, j = \{1, \cdots, 16\}$

$x_{ij}$ stands for the importance of the i$^{th}$ alternative regarding the j$^{th}$ criteria.

Step 2. Normalization

Decision matrix items, as well as indifference thresholds, have to be normalized as follows:

$$\alpha_{ij} = \frac{x_{ij}}{\sum_i x_{ij}} \quad (8)$$

$$NIT_j = \frac{IT_j}{\sum_i x_{ij}} \quad (9)$$

Where:

$\alpha_{ij}$ is the normalized value following the $x_{ij}$.

$NIT_j$ is the normalized value for the "Indifference Threshold".

Step 3. Sorting

The decision matrix for every criterion has to be sorted as follows:

$$\beta_{ij} \leq \beta_{i+1,j}, \forall i \epsilon \{1, \cdots m-1\} \quad (10)$$

where, $\beta_{ij}$ stands for the ranked normalized values.

Step 4. Ordered distance

Ordered distance between the sorted $\beta_{ij}$ is calculated as follows ($\gamma_{ij}$):

$$\gamma_{ij} = \beta_{i+1,j} - \beta_{ij}, \forall i \epsilon \{1, \cdots m-1\} \quad (11)$$

Step 5. Considerable distances

Every ordered distance greater than the indifference threshold is significant and needs to be considered in the weighting process. Thus, considerable distances ($\delta_{ij}$) are calculated as follows:

$$\delta_{ij} = \begin{cases} \gamma_{ij} - NIT_j For \gamma_{ij} > NIT_J \\ 0 For \gamma_{ij} < NIT_J \end{cases} \quad (12)$$

Step 6. Aggregation and weighting

The aggregated value is dynamic in this methodology and calculated based on lp-metric (Lebesgue spaces), and in this study, The Euclidean norm is selected to be applied. Thus, the value of P is set to be 2 (2-norm) to calculate the square root of the considerable differences as follows:

$$v_j = \left( \sum_i \delta_{ij}{}^p \right)^{1/p} \overset{here p=2}{\rightarrow} \sqrt{\sum_i \delta_{ij}{}^2} \quad (13)$$

$$w_j = \frac{v_j}{\sum_j v_j} \quad (14)$$

Where:

$v_j$ is the aggregation value for the j^th criterion.
$w_j$ is the calculated weight for the j^th criterion.

Criteria weights are measured based on the calculated w in the mentioned equation.

*3.4.4. PMADm*

PMADM is a novel technique for future studies such as sustainability and inter-generational goals encountered with multiple unforeseen conditions, technology advancement, and sustainable development priorities by future conditions. This methodology since its development gains a large share of the scientific MCDM applications [16]. PMADM has to be developed per problem case and regarding the condition of the problem. However, some of the previous contributions of the methodology are as follows:

- *Limiters/Boosters:* Every alternative needs to be considered in different scenarios based on the estimated limiters and/or boosters. In this regard, every alternative needs to be assessed considering different future scenarios and finally aggregate to find the real importance of the alternative based on whole and possible present information and predictable future circumstances [15].
- *Multi-Aspect Criteria:* Considering the future conditions of intended criteria when it comes to happening. For instance, water pollutions at the operating condition are related to at least two years after the decision-making process. To cope with this future uncertainty, the methodology proposes to combine criteria and/or define a new criterion that is predicted to be important in the future [18].
- *Supportive/Backup Criteria:* One of the most important contributions of the PMADM is to elaborate criteria with some supportive and backups to make sure the same understanding and considering all the future concerns at the decision-making phase [51].

Concerning the ambiguity and lack of consensus in the CE indicators and its assessment framework, this study utilized supportive criteria to elaborate on the main criteria in the CE model. The defined criteria supportive are presented in Table 2.

For instance, waste management is an important, general, and vague criterion in the CE decision framework. Experts with various background may have different interpretations such as local legitimacy, project policy, recycling procedure, construction methods, and supply chain of the materials. So, in this study, experts are provided with an identical perspective to ensure the valid results that are "recycling rates", and "recycling/recovery for specific waste streams". As a result, not only the experts will have an aligned view in their judgment, but their tenet regarding the uncertain, future-oriented criteria would also be converged.

## 4. Case study

As an application of the comprehensive assessment framework, a locating problem is conducted as an empirical study to implement the proposed decision support tool. The study is to find the best location for constructing a residential project with respect to the sustainability comprehensive view and the CE life-cycle approach. In this case study, a private investment company that has previously had other economical, legal, and commercial assessments reached a list of five alternatives and sought a comprehensive sustainability assessment to select the best alternative.

So, an investment problem for five residential buildings is regarded as the case study. The cases are in different cities ($A_1$: Tehran; $A_2$: Isfahan; $A_3$: Shiraz; $A_4$: Tabriz; $A_5$: Mashhad) with a common owner and similar conditions. The only criterion for selecting the best alternative to make the investment and initiate the construction project is the life-cycle comprehensive sustainability assessment. These five cases are high-quality building projects concerning regular building projects in the country.

The locating project is carried out after the feasibility and preliminary conceptual study. Thereafter, the architectural design and detailed design would be provided based on the requirements of the location. Thus, this is an abstract assessment of the location based on the major characteristics of locations such as local building regulations, available suppliers, access to infrastructure, and garbage collection as well as recycling systems.

The comprehensive assessment tool developed in this paper using the methodologies' hierarchy is applied to this real investment case study to evaluate five options for high-quality building construction projects. These five projects are at the feasibility study stage in different locations with similar characteristics such as building area, consultant team, and building materials. However, cases are located in different cities with different cultures, municipal regulations and procedures, material chains, and recycling systems. Thus, the methodologies are followed from weighting the criteria by combining AHP and PMADM techniques and assessing the projects by CoCoSo methodology.

Criteria are evaluated in six comparison matrices, and the framework is customized to have the criteria weightings based on the specific condition of these projects. Table 3 is a sample for these comparison matrices, which is derived from the panel of experts (other comparison matrices are presented in Appendix A).

According to the AHP methodology, all of the criteria hierarchy is weighted, and the results are presented in Fig. 4.

**Table 3**
Comparison matrix to evaluate sustainability vs. CE at the highest level.

| Green Building Comparison | Sustainability | Circular Economy |
|---|---|---|
| Sustainability | 1 | 2.00 |
| Circular Economy | 0.50 | 1 |

Source: created by authors.

Based on the results, considering all three levels in the objective hierarchy, 16 criteria are weighted ($\sum w_i = 1$) and the final weighting results are presented in Table 4 as follows:

In this section, the ITARA methodology measured the criteria weights based on the alternative decision matrix as the following (see Table 5):

All of the ITARA calculations are summarized in Table 6. The following steps are presented as an example of the calculations:

Normalized value related to the 1st criteria and the 1st alternative ($\alpha_{11}$)

$$\alpha_{1,1} = \frac{x_{1,1}}{\sum_i x_{ij}} = \frac{3.95}{22.72} = 0.174$$

Normalized value related to the first criterion ($NIT_1$)

$$NIT_1 = \frac{IT_1}{\sum_i x_{ij}} = \frac{0.3}{22.72} = 0.013$$

$\beta_{ij}$ is the sorting value of the $\alpha_{ij}$ in an ascending order.

Ordered distance of the first and second sorted normalized values $\left(\gamma_{1,1}\right)$.

$$\gamma_{1,1} = \beta_{2,1} - \beta_{1,1} = 0.181 - 0.174 = 0.007$$

Considerable distance between first ordered distance and NIT ($\delta_{1,1}$).

$$\left.\begin{array}{r}\gamma_{1,1} = 0.007\\ NIT_1 = 0.013\end{array}\right\} \rightarrow \gamma_{1,1} < NIT_1 \rightarrow \delta_{1,1} = 0$$

**Table 4**
Calculated criteria weights.

| Criteria | | Total Weight |
|---|---|---|
| C1 | Material | 0.042 |
| C2 | Water | 0.082 |
| C3 | Indoor Environment | 0.021 |
| C4 | Outdoor Environment | 0.013 |
| C5 | Pollutions (Emissions to air, water, and soil) | 0.039 |
| C6 | Hydrothermal Comfort | 0.032 |
| C7 | Acoustic comfort | 0.015 |
| C8 | Visual comfort | 0.005 |
| C9 | Social and cultural aspects | 0.007 |
| C10 | Accessibility and transportation | 0.013 |
| C11 | Energy Consumption (Operational Costs) | 0.264 |
| C12 | Financial (Initial Costs) | 0.132 |
| C13 | Production and Consumption | 0.157 |
| C14 | Waste Management | 0.079 |
| C15 | Secondary Raw Material | 0.035 |
| C16 | Competitiveness and Innovation | 0.062 |

Source: created by authors.

The aggregation value of the 1st criteria ($v_1$).

$$v_1 = \sqrt{\sum_i \delta_{ij}^2} = \sqrt{(0.01)^2 + (0.002)^2} = 0.0102$$

The 1st criterion weight ($w_j$).

$$w_1 = \frac{v_1}{\sum_j v_j} = \frac{0.01}{0.864} = 0.012$$

After finalizing the criteria weights with AHP and PMADM, five alternatives are assessed based on the presented CoCoSo methodology. Alternatives are rated for the beneficial or cost criteria. The calculation process (beneficial row in Table 6 is represented with one, and costs are shown by 0) can be followed through Tables 6–8.

Apart from the AHP weighting calculated in Table 4, the criteria are weighted based on the decision matrix using ITARA methodol-

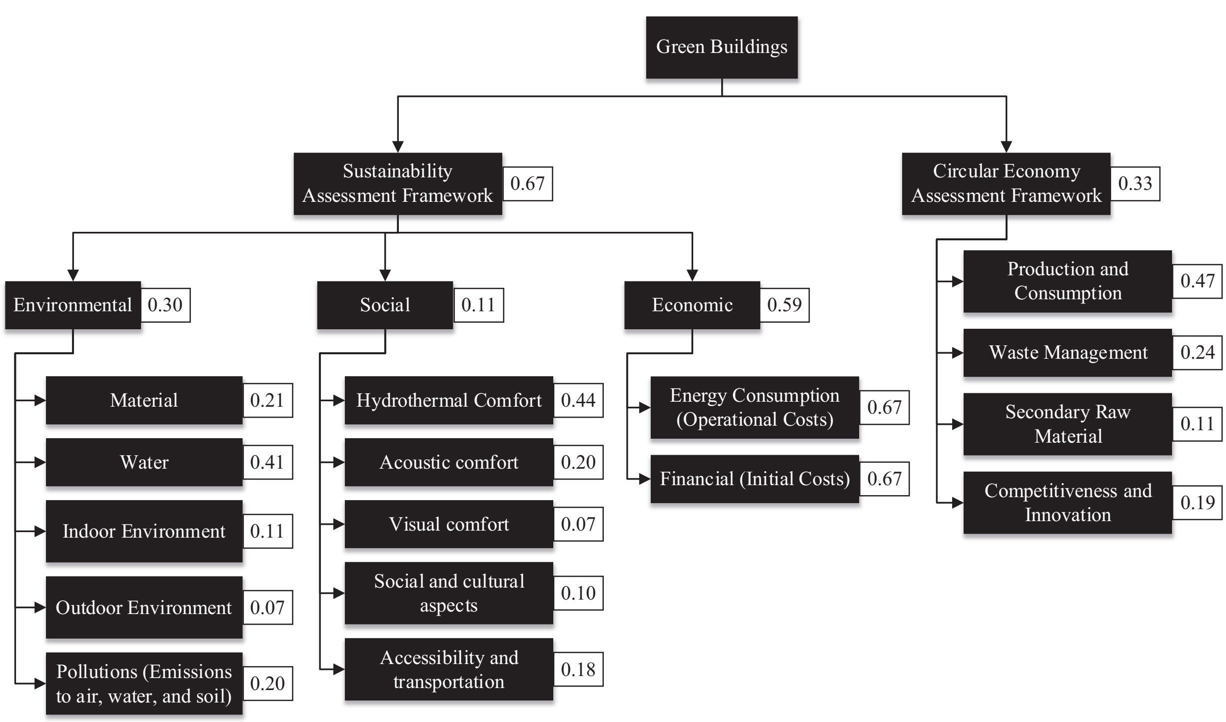


**Fig. 4.** Weighted criteria hierarchy.

**Table 5**
ITARA calculation process.

| | | Criteria | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ | $C_8$ | $C_9$ | $C_{10}$ | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{14}$ | $C_{15}$ | $C_{16}$ |
| Alternatives | 1 | 3.95 | 4.27 | 3.82 | 2.39 | 4.34 | 4.1 | 3.7 | 2.73 | 2.14 | 5 | 4.15 | 5 | 2.38 | 1.61 | 4.19 | 4.94 |
| | 2 | 5 | 3.37 | 4.27 | 4.13 | 3.03 | 4.06 | 5 | 4.46 | 3.48 | 3.31 | 5 | 4.46 | 1.27 | 1.35 | 2.64 | 3.49 |
| | 3 | 4.65 | 2.24 | 2.05 | 1.65 | 1 | 3.06 | 4.44 | 5 | 5 | 4.99 | 3.34 | 3.97 | 4.16 | 4.28 | 3.59 | 2.75 |
| | 4 | 4.12 | 2.56 | 4.05 | 3.33 | 3.11 | 2.8 | 4.35 | 4.5 | 3.15 | 3.01 | 2.53 | 3.81 | 2.08 | 2.99 | 2.54 | 3.94 |
| | 5 | 5 | 3.5 | 2.62 | 4.57 | 4.22 | 3.43 | 2.59 | 3.08 | 4.14 | 4.54 | 4.59 | 4.38 | 3.03 | 1.01 | 2.54 | 2.64 |
| IT | | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| $\alpha$ | 1 | 0.17 | 0.27 | 0.23 | 0.15 | 0.28 | 0.23 | 0.18 | 0.14 | 0.12 | 0.24 | 0.21 | 0.23 | 0.18 | 0.14 | 0.27 | 0.28 |
| | 2 | 0.22 | 0.21 | 0.25 | 0.26 | 0.19 | 0.23 | 0.25 | 0.23 | 0.19 | 0.16 | 0.25 | 0.21 | 0.1 | 0.12 | 0.17 | 0.2 |
| | 3 | 0.21 | 0.14 | 0.12 | 0.1 | 0.06 | 0.18 | 0.22 | 0.25 | 0.28 | 0.24 | 0.17 | 0.18 | 0.32 | 0.38 | 0.23 | 0.15 |
| | 4 | 0.18 | 0.16 | 0.24 | 0.21 | 0.2 | 0.16 | 0.22 | 0.23 | 0.18 | 0.14 | 0.13 | 0.18 | 0.16 | 0.27 | 0.16 | 0.22 |
| | 5 | 0.22 | 0.22 | 0.16 | 0.28 | 0.27 | 0.2 | 0.13 | 0.16 | 0.23 | 0.22 | 0.23 | 0.2 | 0.23 | 0.09 | 0.16 | 0.15 |
| NIT | | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 | 0.01 | 0.02 | 0.03 | 0.02 | 0.02 |
| $\beta$ | | 0.17 | 0.14 | 0.12 | 0.1 | 0.06 | 0.16 | 0.13 | 0.14 | 0.12 | 0.14 | 0.13 | 0.18 | 0.1 | 0.09 | 0.16 | 0.15 |
| | | 0.18 | 0.16 | 0.16 | 0.15 | 0.19 | 0.18 | 0.18 | 0.16 | 0.18 | 0.16 | 0.17 | 0.18 | 0.16 | 0.12 | 0.16 | 0.15 |
| | | 0.21 | 0.21 | 0.23 | 0.21 | 0.2 | 0.2 | 0.22 | 0.23 | 0.19 | 0.22 | 0.21 | 0.2 | 0.18 | 0.14 | 0.17 | 0.2 |
| | | 0.22 | 0.22 | 0.24 | 0.26 | 0.27 | 0.23 | 0.22 | 0.23 | 0.23 | 0.24 | 0.23 | 0.21 | 0.23 | 0.27 | 0.23 | 0.22 |
| | | 0.22 | 0.27 | 0.25 | 0.28 | 0.28 | 0.23 | 0.25 | 0.25 | 0.28 | 0.24 | 0.25 | 0.23 | 0.32 | 0.38 | 0.27 | 0.28 |
| $\gamma$ | | 0.01 | 0.02 | 0.03 | 0.05 | 0.13 | 0.01 | 0.06 | 0.02 | 0.06 | 0.01 | 0.04 | 0.01 | 0.06 | 0.03 | 0 | 0.01 |
| | | 0.02 | 0.05 | 0.07 | 0.06 | 0.01 | 0.02 | 0.03 | 0.07 | 0.02 | 0.06 | 0.04 | 0.02 | 0.02 | 0.02 | 0.01 | 0.04 |
| | | 0.02 | 0.01 | 0.01 | 0.05 | 0.07 | 0.04 | 0 | 0 | 0.04 | 0.02 | 0.02 | 0 | 0.05 | 0.12 | 0.06 | 0.03 |
| | | 0.00 | 0.05 | 0.01 | 0.03 | 0.01 | 0 | 0.03 | 0.03 | 0.05 | 0 | 0.02 | 0.02 | 0.09 | 0.11 | 0.04 | 0.06 |
| $\delta$ | | 0.00 | 0 | 0.02 | 0.03 | 0.11 | 0 | 0.04 | 0 | 0.04 | 0 | 0.03 | 0 | 0.04 | 0 | 0 | 0 |
| | | 0.01 | 0.03 | 0.05 | 0.04 | 0 | 0 | 0.02 | 0.05 | 0 | 0.04 | 0.03 | 0.01 | 0 | 0 | 0 | 0.02 |
| | | 0 | 0 | 0 | 0.03 | 0.05 | 0.02 | 0 | 0 | 0.02 | 0.01 | 0.01 | 0 | 0.03 | 0.1 | 0.04 | 0.01 |
| | | 0 | 0.03 | 0 | 0.01 | 0 | 0 | 0.01 | 0.01 | 0.03 | 0 | 0.01 | 0.01 | 0.06 | 0.09 | 0.02 | 0.04 |
| v | | 0.01 | 0.04 | 0.06 | 0.06 | 0.12 | 0.02 | 0.05 | 0.06 | 0.05 | 0.05 | 0.04 | 0.01 | 0.08 | 0.13 | 0.05 | 0.05 |
| w | | 0.01 | 0.050 | 0.065 | 0.067 | 0.141 | 0.022 | 0.053 | 0.064 | 0.063 | 0.052 | 0.044 | 0.014 | 0.093 | 0.151 | 0.053 | 0.055 |

Source: created by authors.

**Table 6**
Decision matrix (Based on the AHP weights).

| | | Criteria | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ | $C_8$ | $C_9$ | $C_{10}$ | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{14}$ | $C_{15}$ | $C_{16}$ |
| | Weight | 0.042 | 0.082 | 0.021 | 0.013 | 0.039 | 0.032 | 0.015 | 0.005 | 0.007 | 0.013 | 0.264 | 0.132 | 0.157 | 0.079 | 0.035 | 0.062 |
| | Beneficial | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 |
| Alternatives | $A_1$ | 3.95 | 4.27 | 3.82 | 2.39 | 4.34 | 4.1 | 3.7 | 2.73 | 2.14 | 5 | 4.15 | 5 | 2.38 | 1.61 | 4.19 | 4.94 |
| | $A_2$ | 5 | 3.37 | 4.27 | 4.13 | 3.03 | 4.06 | 5 | 4.46 | 3.48 | 3.31 | 5 | 4.46 | 1.27 | 1.35 | 2.64 | 3.49 |
| | $A_3$ | 4.65 | 2.24 | 2.05 | 1.65 | 1 | 3.06 | 4.44 | 5 | 5 | 4.99 | 3.34 | 3.97 | 4.16 | 4.28 | 3.59 | 2.75 |
| | $A_4$ | 4.12 | 2.56 | 4.05 | 3.33 | 3.11 | 2.8 | 4.35 | 4.5 | 3.15 | 3.01 | 2.53 | 3.81 | 2.08 | 2.99 | 2.54 | 3.94 |
| | $A_5$ | 5 | 3.5 | 2.62 | 4.57 | 4.22 | 3.43 | 2.59 | 3.08 | 4.14 | 4.54 | 4.59 | 4.38 | 3.03 | 1.01 | 2.54 | 2.64 |

Source: created by authors.

ogy, and the final criteria weights are presented in Table 5. Alternatives are recalculated based on the ITARA weights, and the last rating scores are presented in Table 9.

As shown in Tables 8 and 9, alternative ranking is similar regarding both AHP and ITARA methodologies. According to the results, the third building project is selected as the best alternative regarding the comprehensive assessment framework based on both the sustainability criteria and returning to the environment (CE) options in a cradle-to-cradle life-cycle assessment. The third alternative is related to the city of Shiraz, which has a structured recycling system. The city is less industrial and has a more resilient environment. Besides, Shiraz has a mild climate concerning other alternatives, influencing the experts' judgments for this alternative.

Using two different methodologies for criteria weighting which has different mathematical approaches used to ensure the reliability of the results and at the same time to convince the investment project's owner of the study. AHP weigh-up the entire hierarchy of the criteria by using expert judgment while the ITARA employs the diversity of the alternatives' scoring as an indicator of the criteria importance. In other words, these two methodologies have a fundamental contrast forasmuch as ITARA with respect to AHP is the

**Table 7**
Normalized Decision matrix (Based on the AHP weights).

| | | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ | $C_8$ | $C_9$ | $C_{10}$ | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{14}$ | $C_{15}$ | $C_{16}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternatives | $A_1$ | 1 | 0 | 0.203 | 0.747 | 0 | 1 | 0.461 | 0 | 0 | 1 | 0.344 | 0 | 0.384 | 0.183 | 1 | 1 |
| | $A_2$ | 0 | 0.443 | 0 | 0.151 | 0.392 | 0.969 | 1 | 0.762 | 0.469 | 0.151 | 0 | 0.454 | 0 | 0.104 | 0.061 | 0.370 |
| | $A_3$ | 0.333 | 1 | 1 | 1 | 1 | 0.2 | 0.768 | 1 | 1 | 0.995 | 0.672 | 0.866 | 1 | 1 | 0.636 | 0.048 |
| | $A_4$ | 0.838 | 0.842 | 0.099 | 0.425 | 0.368 | 0 | 0.730 | 0.780 | 0.353 | 0 | 1 | 1 | 0.280 | 0.606 | 0 | 0.565 |
| | $A_5$ | 0 | 0.379 | 0.743 | 0 | 0.036 | 0.485 | 0 | 0.154 | 0.699 | 0.769 | 0.166 | 0.521 | 0.609 | 0 | 0 | 0 |

Source: created by authors.

**Table 8**
CoCoSo Methodology and results (Based on the AHP weights).

| | | S | P | kia | kib | kic | ki |
|---|---|---|---|---|---|---|---|
| Alternatives | $A_1$ | 0.37 | 10.44 | 0.18 | 2.97 | 0.66 | 1.97 |
| | $A_2$ | 0.20 | 11.43 | 0.19 | 2.24 | 0.71 | 1.72 |
| | $A_3$ | 0.77 | 15.59 | 0.27 | 5.48 | 1.00 | 3.38 |
| | $A_4$ | 0.67 | 12.61 | 0.22 | 4.66 | 0.81 | 2.83 |
| | $A_5$ | 0.29 | 9.22 | 0.15 | 2.43 | 0.58 | 1.66 |

Source: created by authors.

**Table 9**
CoCoSo Methodology and results (Based on the ITARA weights).

| | | S | P | kia | kib | kic | ki |
|---|---|---|---|---|---|---|---|
| Alternatives | A1 | 0.36 | 10.49 | 0.18 | 2.59 | 0.65 | 1.81 |
| | A2 | 0.29 | 11.07 | 0.19 | 2.38 | 0.68 | 1.75 |
| | A3 | 0.87 | 15.74 | 0.27 | 5.22 | 1.00 | 3.29 |
| | A4 | 0.46 | 12.35 | 0.21 | 3.17 | 0.77 | 2.18 |
| | A5 | 0.25 | 9.26 | 0.16 | 2.00 | 0.57 | 1.47 |

Source: created by authors.

unconscious criteria weighting and no one can exert intentional or accidental influence on the assessment results.

As it is described in Fig. 5, criteria weights are similar in most of the criteria while in criteria 5, 11, and 12 the difference is higher which is normal regarding the inherent contrast among these methodologies.

Despite this deviation in the criteria weights, alternatives are scored and ranked the same. Fig. 6 is presented to illustrate this similarity of the study results in the project investment problem.

## 5. Discussion

In this study, the assessment framework is mostly developed for building construction projects. As it can be acquired from GB rating systems, the subjected building projects in this study can vary from residential to commercial building projects. Besides, the assessment framework in this study is extensive due to combining the sustainability and CE frameworks. Thus, this comprehensive view can be applied to various applications along with the building construction phase. In the midst of these applications, the following can be stated:

- conducting a comprehensive feasibility study.
- selecting the best project alternative.
- adopting the best construction method.
- finding the best supplier or supply chain.
- selecting the best location for the project.

In this study, the locating problem is scrutinized in an investment optimization problem. The main motivation in this regard is reaching the ultimate involvement of the criteria in the hierarchy of the decision goals. This involvement of the criteria is ensured in a locating project by confronting different municipal strategies, various recycling systems, diversity in the natural resources, and supply chains.

Buildings are subjected to various assessments, from performance to energy and environment. Sustainability assessment as a comprehensive tool integrates the economic, environmental, and social aspects simultaneously. On the other hand, the development pattern's circularity plays an important role in the strategic and intergenerational goals. This study combined these two concepts to have a more comprehensive framework, which can be used to assess building projects. As a result, the strategic goal includes both sustainability (for the integrity of the environmental, social, and economic criteria) and circularity (for the returning options to the environment) at the same time (See the top level of the hierarchy in Fig. 3). The next step in the comprehensive assessment process is to identify and develop two different assessment criteria sets for sustainability and CE separately to cover the rest of the hierarchical goals fully. In this study, based on the comprehensive literature review of scientific and industrial resources, the goals' hierarchy was developed and presented in Fig. 3.

The chain of methodologies used in this study is selected and arranged to help arrive at a less ambiguous answer in a more efficient way to the assessment problem at hand. More specifically, to

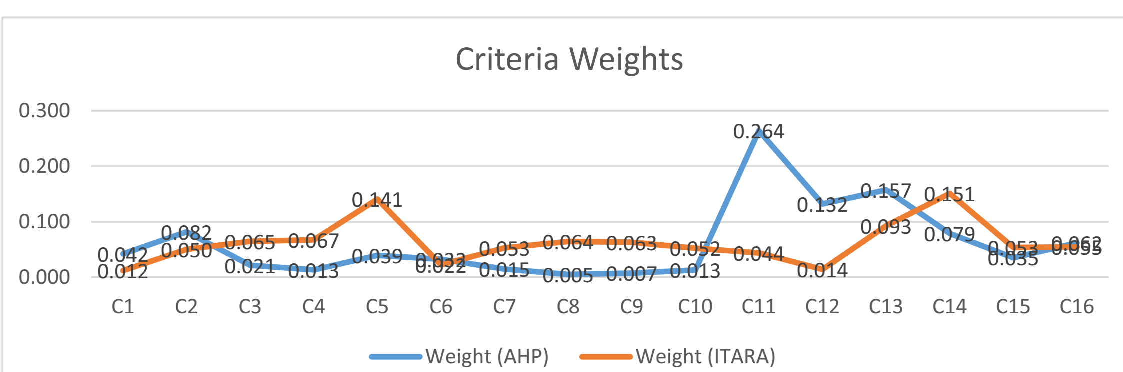


**Fig. 5.** Criteria weights comparison.

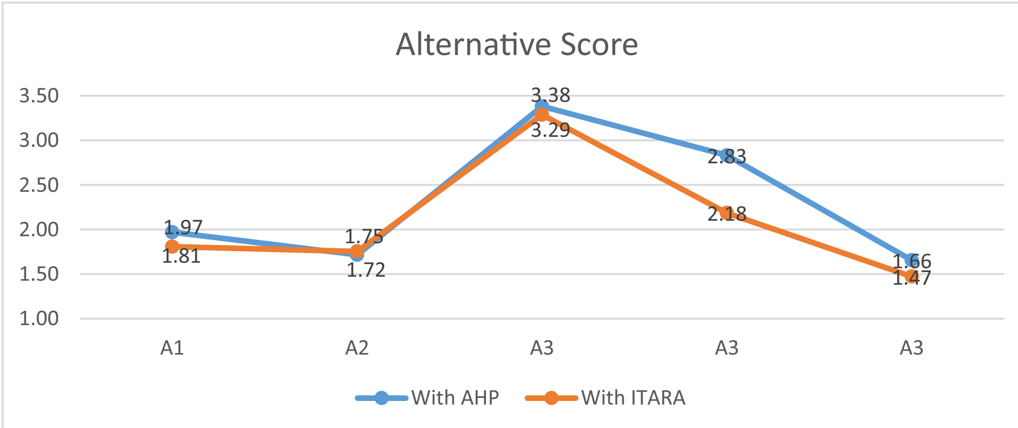


**Fig. 6.** Alternative scores comparison.

deal with the hierarchical nature of the problem, AHP has been used; while to address the future uncertainties and complexities of the criteria set particularly for the CE branch, criteria supportive retrieved from PMADM literature is adopted for the criteria weighting, which is applied to the case study (see Tables 3, 4). Next, for the assessment process and selecting the best building alternative, CoCoSo, an efficient brand new MCDM methodology, is applied to evaluate the alternatives. The case study has been assessed through the proposed method, and the results are presented in Tables 5–9.

The case study is an investment problem that depends on multiple criteria and concerns. However, based on this study's comprehensive view, the assessment is carried out to find the best alternative regarding the sustainability goals on the one hand and circularity on the other hand. Thus, the results ensure the selected alternative is the best one regarding multiple criteria such as energy efficiency, environmental friendliness, social development, minimum utility prices, highest reuse, and recycling rate.

## 6. Conclusion

There are various green building rating systems to promote sustainability and reduce negative environmental effects in the building industry projects. However, these rating systems are primarily focused on the environmental aspect of sustainability. On the other hand, due to natural resources and growing development industries' finiteness, returning to the environment through reuse, remanufacture, and recycling options need to be emphasized more in building construction projects.

This study aims to develop a sustainability assessment framework that can be individually used as an assessment tool for building industry projects. Moreover, an indicator-based CE decision-making framework with PMADM methodology is developed to factor in future uncertainties. Finally, these two decision support frameworks are combined in a hierarchical objective function to have a comprehensive solution for building sustainable and resilient developments. A real case study is considered to find the best alternative for investment in a residential building project among five options located in different cities. Based on the results, the third alternative is the best project to be invested in, based on the life-cycle and the comprehensive sustainability assessment tools developed.

In this study, various MCDM methodologies are adopted. AHP is applied in order to evaluate the criteria hierarchy and reach the weighted decision framework. In this weighting process, the future uncertainties are considered by using a PMADM methodology from the literature, which has enhanced the hierarchical weightings' accuracy. Due to the high importance of the criteria weights, this stage is recalculated and rechecked by another methodology, called ITARA. As a result, the criteria are weighted by various participants. Finally, the alternatives are evaluated by using both criteria weightings with CoCoSo and AHP methodologies. Thus, the MCDM methodology chain has been carefully selected and applied to the case study to reach a highly reliable result based on the developed CE model and comprehensive building assessment framework.

The results contain a sustainability assessment framework, CE indicator-based assessment tool, and finally, a comprehensive decision tool that can be used in further studies in the building project industry. Criteria are developed for different types of buildings from residential to office, education, hospital, hotels, and retail. However, the weighting and procedure in the case study are carried out for the residential building projects. Hence, the weights have to be revised by the experts' panel for other types of buildings.

This study can be used by policymakers and building construction developers to integrate the sustainability and CE concepts and take both the sustainable and resilient environment into account for future development. The strategic investments can also be oriented toward this comprehensive approach to ensure the clean and green construction industry.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix A

Data entry for the comparison matrices for the AHP calculations

| Green Building Comparison | (1) | (2) |
|---|---|---|
| Sustainability (1) | 1.00 | 2.00 |
| Circular Economy (2) | 0.50 | 1.00 |

| Sustainability Assessment Comparison | (1) | (2) | (3) |
|---|---|---|---|
| Environmental (1) | 1.00 | 4.00 | 0.33 |
| Social (2) | 0.25 | 1.00 | 0.25 |
| Economic (3) | 3.00 | 4.00 | 1.00 |

| Circular Economy Assessment Comparison | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Production and Consumption (1) | 1.00 | 3.00 | 4.00 | 2.00 |
| Waste Management (2) | 0.33 | 1.00 | 2.00 | 2.00 |
| Secondary Raw Material (3) | 0.25 | 0.50 | 1.00 | 0.50 |
| Competitiveness and Innovation (4) | 0.50 | 0.50 | 2.00 | 1.00 |

| Environmental Comparison | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Material (1) | 1.00 | 0.33 | 2.00 | 3.00 | 2.00 |
| Water (2) | 3.00 | 1.00 | 3.00 | 4.00 | 3.00 |
| Indoor Environment (3) | 0.50 | 0.33 | 1.00 | 2.00 | 0.33 |
| Outdoor Environment (4) | 0.33 | 0.25 | 0.50 | 1.00 | 0.25 |
| Pollutions (Emissions to air, water, and soil) (5) | 0.50 | 0.33 | 3.00 | 4.00 | 1.00 |

| Social Comparison | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Hydrothermal Comfort (1) | 1.00 | 4.00 | 5.00 | 3.00 | 3.00 |
| Acoustic comfort (2) | 0.25 | 1.00 | 2.00 | 3.00 | 2.00 |
| Visual comfort (3) | 0.20 | 0.50 | 1.00 | 0.50 | 0.33 |
| Social and cultural aspects (4) | 0.33 | 0.33 | 2.00 | 1.00 | 0.33 |
| Accessibility and transportation (5) | 0.33 | 0.50 | 3.00 | 3.00 | 1.00 |

| Economic Comparison | (1) | (2) |
|---|---|---|
| Energy Consumption (Operational Costs) (1) | 1.00 | 2.00 |
| Financial (Initial Costs) (2) | 0.50 | 1.00 |

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