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# GREEN BUILDING ASSESSMENT PERFORMANCE INDICATORS: USING ANALYTICAL NETWORK PROCESS

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**الملخص العربى :**

**تقييم الأداء مفيد لمقارنة أداء المشروع المقاس والمتوقع من حيث الفعالية والكفاءة وجودة المنتج. ركزت الأبحاث السابقة على انظمه تقييم المباني الخضراء والاعتمادات المتعارف عليها ، وركزت على أدوات القياس التقليدية مثل الوقت والتكلفة والجودة. وافتقرت الأدبيات السابقة نموذج محدد للتنبؤ وقياس الاداء للمشاريع الخضراءو توضيح العلاقة بين مؤشرات الأداء. علاوة على ذلك، ركزت غالبية الدراسات على البحث بدلا من التطبيق والممارسة.تعتمدهذه الدراسه على دمج أبعاد الاستدامة مع إدارة المشروع لضمان نجاح المشروع على أساس لتقييم أداء للمشاريع (ANP) الترابط والاعتمادية لمؤشرات الأداء المحدده. تم استخدام نهج الشبكة التحليلية عن طريق حساب أوزان الأولوية لمقاييس الأداء والتي تكون مترابطة المباني الخضراء يمكن استخدام النموذج المقترح لمشاريع المباني الخضراء لأن جميع المشاريع، بغض النظر عن حجمها أو نوعها، تتبع نمطا متطابقا نسبيا من التطوير**

# Abstract:

Performance assessment useful for comparing measured and forecasted project performance in terms of effectiveness, efficiency, and craftsmanship and product quality. Previous research concentrated on green building rating tools and credit, concentrate on traditional measurement tools like time, cost, and quality. Previous literature lacked: a specific model for predicting green projects, as well as an explanation of the relationship between performance indicators. Furthermore, the majority of the studies focused on research rather than application and practice. Integrating sustainability dimensions with project management to ensure project success based on the interdependence and dependability of performance indicators. Performance assessment is commonly used in construction projects to measure the performance of project operations. The Analytical Network Process (ANP) approach is used to assess the performance of green buildings (GB) projects. The priority weights for the performance metrics, which are interdependent by nature, are calculated using an ANP-based methodology. Finally, the model's proposed structure is depicted, and the performance of GB projects is quantified. The proposed model can be used for any project in the GB industry because all projects, regardless of size or type, follow a relatively identical pattern of development. The model focuses on the GB project's construction phase and anticipated operation performance.

**Keywords:** sustainability, green building, performance assessment, analytical process network.

## 1. Introduction

In comparison to conventional buildings, green buildings (GBs) are projected to perform better. This, however, does not occur in actual life. GBs don't perform as well as they should [Demanuele et al., 2010; Bordass et al., 2011]. The disparity between expected and actual performance of GBs has become all too common in recent years, raising serious concerns in the construction industry. The construction industry is under greater pressure to acknowledge the significance of closing the so-called "performance gap," which designers and builders face in meeting clients' expectations, as a result of the enormous challenges posed by environmental issues, rising energy prices, health effects, and protection of the environment [De Wilde, 2014]. The ability to accurately and consistently estimate green project performance is crucial to the success of both green construction projects and businesses. This type of forecasting aids in gaining early warnings of prospective difficulties. In the meantime, a change in one performance index may have an impact on other indices. The dynamic nature of such indices makes determining interdependencies between performance measurements more difficult. On the other hand, often employed performance forecasting techniques do not take into consideration these interactions or clarify the connection between performance indices. Because of this, they are unable to give reliable information on the actual impact of performance modifications. The green construction industry still needs realistic models for measuring, evaluating, and forecasting the performance of green projects that are comprehensive and take into consideration the natural interdependency between the multi-dimensional indicators that make up such performance.

## 2. Literature Review

The first Sustainability Assessment Method for Buildings, BREEAM, was published in 1990. Rick Fedrizzi, David Gottfried, and Mike Italiano founded the first Green Building Council (GBC) in the world in 1993, in collaboration with the USGBC. Their goal was to advance sustainable building ideas and advocate for practices that focus on sustainability in the building and construction sector. The USGBC created the LEED (Leadership in Energy and Environmental Design) green building rating system in 1998. For assessing the "green degree" of GB projects and boosting the effectiveness of GB operations [Li et al. 2020]. The assessment of a building's performance takes into account aesthetic, cultural, social, and psychological factors in addition to health, safety, security, operation, validation, and workflow [Aghili et al. 2016]. By implementing the appropriate set of key performance indicators (KPIs), the sustainability dimensions can be integrated into strategic planning to gain a competitive advantage and produce sustainability value [Hristov and Chirico 2019]. The process of choosing project team members, determining their developmental needs, predicting the project's performance level before it starts, and helping businesses decide on their strategic stance on the project may all benefit from the assessment of KPI [Toor and Ogunlana 2009]. The following KPIs were listed, according to Kylili et al. [2016]: time, quality, disagreements, economy, social, ecological, and technological factors. In order to guarantee the success of green projects based on the interdependence and dependability of performance indicators, this study aims to integrate the dimensions of sustainability with project management.

Some of the performance indicators for GBs that have been derived from earlier studies are compiled in Table 1.

**Table 1** KPIs for green project initiatives

| KPI | Reference |
|---|---|
| Site selection, Water monitoring, Water saving index, Waste management, Energy performance, Environmental, Innovation, Quality, Health and safety, Cost performance, Profit performance, Time index, Client. | Kylili et al. 2016 |
| Site planning and design, Water efficiency, Selection of material, Resource reuse, Energy efficiency, Indoor environmental quality, Innovation, Financial performance, Schedule performance. | Atanda and Öztürk 2020, Lwin and Panuwatwanich 2021 |
| Actual service of building, Cost performance, Schedule performance. | Raouf and Al-Ghamdi 2020 |
| Site development, Water saving index, Energy performance, Health and safety, Schedule performance, Client, Team. | Onubi et al. 2021, Darko and Chan 2016 |
| User satisfaction | Syahroni et al.2019 |
| Site selection, Selection of material, Rework, Designs, Productivity, Technological, Schedule performance, Team. | Hwang et al. 2016 |

## 3. Research Methodology

**3.1 Determine the performance indicators:** The technique of Delphi was used to help the respondents come to an agreement. Twelve professionals in green construction were interviewed two-round in semi-structured interviews. A list of fifteen KPIs were created as shown in Fig.1

.

**3.2 Identifying Causal Relation:** To study the dependencies and impacts among the proposed performance indicators, a second comprehensive assessment of the literature was conducted. As a result, a list of inter-performance indices impacts was created. The goal of this review of literature is to: Gather data on the interdependence of the performance indices for the construction and operation phases; and Assist in the formulation of quantitative and qualitative correlations between performance measures and related variables.

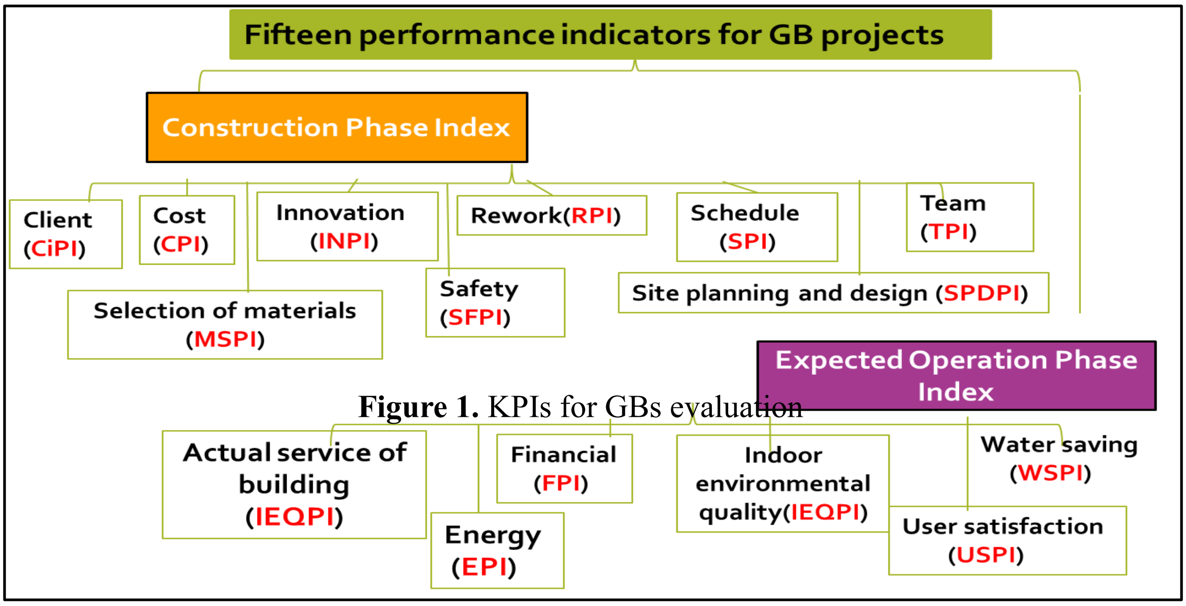


**Figure 1.** KPIs for GBs evaluation

**3.3 Model Development using the Analytical Network Process**: A multi-attribute utility function of GB projects performance indicators was designed to evaluate the overall construction and operation performance of GB projects. The analytical network process (ANP) approach is used to normalize the performance indices and evaluate the relative weights among the interdependent performance metrics. The ANP model has numerous steps, including elicitation of pairwise comparison matrices, normalization, and eigenvector calculation. The eigenvalue and consistency ratio are calculated, the super matrix is formed, and the limit super matrix is solved. The ANP model was implemented using Super Decision software. Finally, GB projects' success is assessed statistically.

## 4. Analytical Network Process (ANP)

The ANP relies on ratio scales to record all interactions, generate precise projections, and assist in decision-making. It has so far succeeded in predicting economic movements, commercial, social, and political happenings when supplemented with expert knowledge. The ANP enables us to systematically address all forms of dependency and responses. Its success is due to the manner in which it collects opinions and employs measurement to create ratio scales. This study provided a model for evaluating GB projects' performance using the ANP. The priority weights for the connected performance metrics are determined and the complete project's performance is quantified [Saaty and Sodenkamp, 2010; Saaty and Vargas, 2013; Saaty, 2004b].

### 4.1 Interdependence of Performance Indicators

Two clusters, performance and indices, make up the proposed ANP network, and they are utilized to determine priority weights and relative relevance among the interdependent performance indices of GB projects. The performance cluster represents the project's overall performance, and the fifteen performance indices are organized into cluster designated indices and used two models: one to evaluate overall construction performance and another to evaluate expected overall operation performance. On the other hand, the multi-dimensional performance indicators have varying degrees of interdependence. The looped arc represents the inner reliance among the indices in the same cluster [Saaty, 2008]. The interdependencies/influences among the proposed performance indices are indicated based on the literature review. The direct influences among the performance indices are shown in Table (2).

## 5. The ANP Model

## 5.1Problem-Solving Arrangement

This phase's task is to determine the evaluation aim then, to identify criteria (clusters/nodes) and alternatives once the aim has been determined. Furthermore, during the creation of the network, the relationships that occur among the elements must be discovered. The network structure can be obtained using a variety of methods, including focus groups and brainstorming [Saaty, 2004a]. The suggested ANP-based decision model for both the construction and operation stage are depicted in Figures (2) and (3), respectively. The arrow between each two indices goes from the influenced index to the influencing index to show the interdependence among the proposed indices.

**Table 2.** Direct effects of the proposed construction performance indicators

| Impacting index | Impacted index | Reference |
|---|---|---|
| Client | Team, Innovation, Material Selection | Frey et al. [2013], Elforgani and Rahmat [2012] |
| Cost | Client | Nalewaik, and Venters [2010] |
| Innovation | Cost, Material Selection, Site planning and design | Suprun et al. [2018], Patel [2021], Sahlol et al. [2020], Ismaeel et al. [2021] |
| Material selection | Cost | Sahlol et al. [2020] |
| Rework | Schedule, Cost, Client | Love et al. [2008], Love, 2002a, 2002b, Hwang et al. [2013] |
| Health and Safety | Team, Schedule, Cost, Client | Tam et al. [2006], Pearce and Kleiner [2013], Ahmed et al. [2021], Okoye, [2021], Berawi et al. [2020] |
| Site planning and design | Schedule, Health and Safety | Wang et al. [2019], Huo et al. [2019] |
| Schedule | Financial, Client | Vandevoorde and Vanhoucke [2006], Hawang et al. [2013], [2016], Al Ameri& Nasaruddin [2020] |
| Team | Rework | Samari et al. [2013] |
| Actual service of building | Client, User satisfaction | Geng et al. [2019], Abdulmalek and Ahamat [2022], |
| Energy | Financial, Indoor Environmental quality, Actual service of building | Abu Bakar et al. [2015], Assad et al. [2013], Raouf and Al-Ghamdi, [2020] |
| Financial | Client performance, Actual service of building performance | Okoye [2021], Raouf and Al-Ghamdi [2019], Abdulmalek and Ahamat [2022] |
| Indoor Environmental quality | Actual service of building, User satisfaction | Mujan et al. [2021] |

| | | |
|---|---|---|
| Expected cost | Financial | Dwaikata ana Ali [2018] |
| Expected schedule | Financial | Raouf and Al-Ghamdi, [2019] |
| Innovation | Energy, Indoor Environmental quality, Water Saving | Suprun et al. [2018], Mujan et al. [2021], Karamanos et al. [2007] Das et al. [2015] |
| Material selection | Indoor Environmental quality, Energy | Sahlol et al. [2020] |
| Site planning and design | Energy, Indoor Environmental quality | Wang et al. [2019], Mujan et al. [2019] |
| User satisfaction | Client | Mamalougka et al. [2013] |
| Water Saving | Energy, financial, Actual service of building | Cheng et al. [2016], Das et al. [2015], Raouf and Al-Ghamdi [2020] |

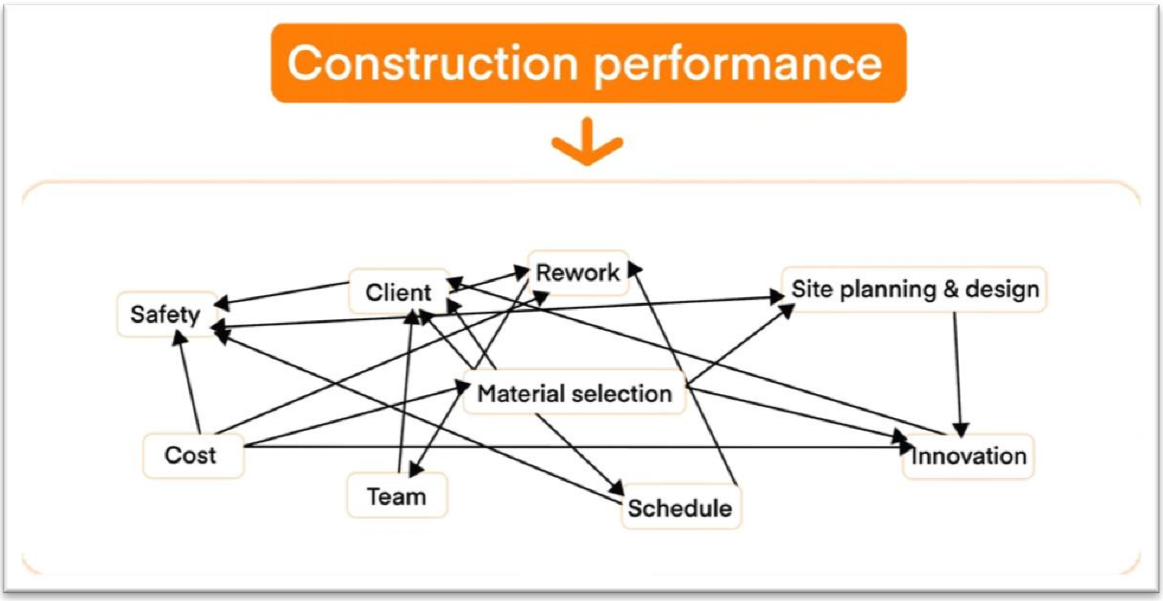


**Figure 2.** The suggested ANP-based decision model construction stage

## 5.2. Pairwise Comparison

Pairwise comparison is used in ANP to compare items and determine their preferences. For both clusters and nodes, the distinct priorities are discovered using pairwise comparison and judgement. Clusters are weighted based on their individual roles and influence, as well as their mutual reliance. The Saaty nine-point scale is used to assess the relative aspects' importance shown in Table (3) [Bottero et al. 2020]. Comparing a pair of elements on a single property without regard for other attributes or elements is an efficient technique to concentrate judgement. Decision-makers are asked to reply to a series of pairwise comparisons of two elements, with the goal of determining which element has a higher impact on the parent element. Pairs of performance indicators will be evaluated with respect to which indicator is considered more essential for the parent indicator, depending on the existing dependencies.

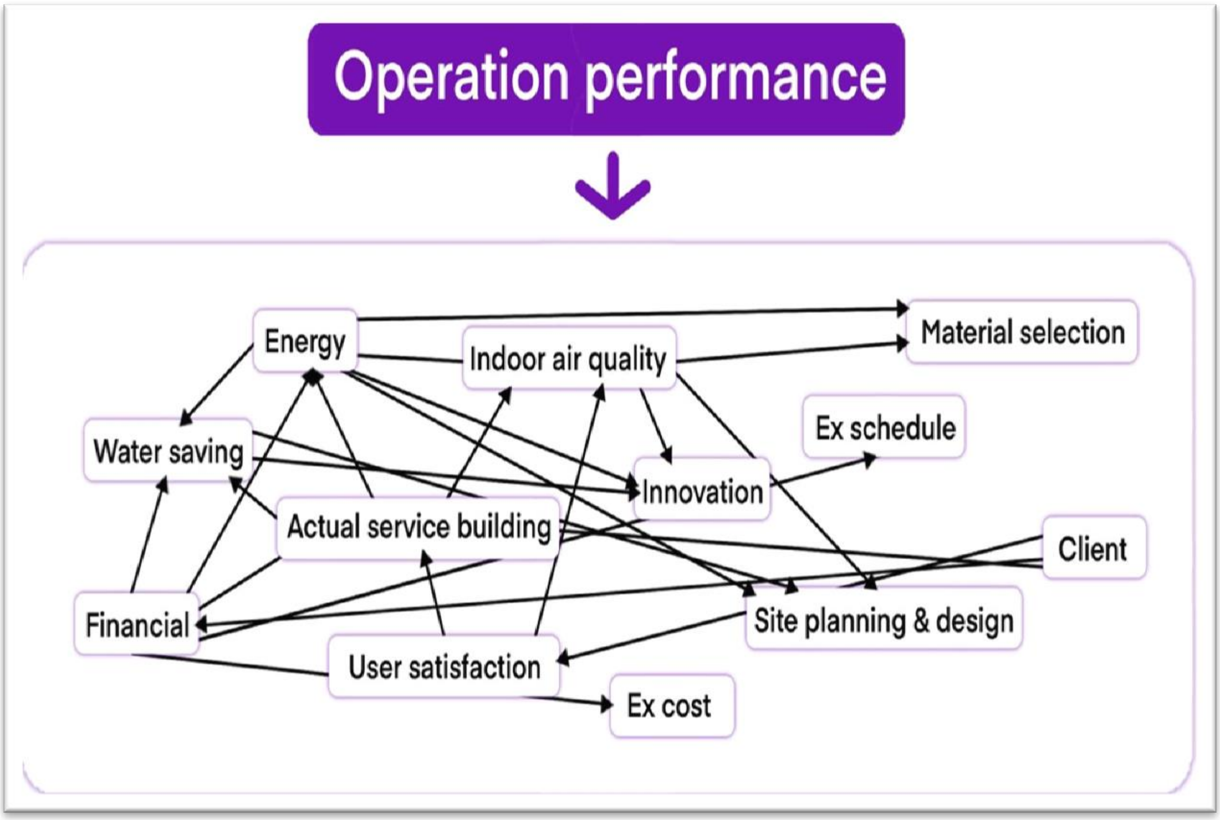


**Table 3.** ANP nine-point scale

| Degree of importance | Definition | Explanation |
|---|---|---|
| 1 | Equal Important | The two indices both equally contribute to the goal. |
| 2 | Weak | |
| 3 | Moderate Important | One measure somewhat outperforms the other based on experience and judgement. |
| 4 | Moderate Plus | |
| 5 | Strong Important | One index is clearly preferred over another based-on experience and judgement. |
| 6 | Strong Plus | |
| 7 | Very Strong or Demonstrated Importance | One index is very strongly preferred over another, and its dominance is shown in action. |
| 8 | Very, Very Strong | |
| 9 | Extreme Important | The strongest kind of affirmation is used to support the preference of one index over another. |
| Reciprocals of the above | When compared to index j, if index I has one of the non-zero integers listed above assigned to it, then index j has the reciprocal value. | The larger element can be calculated as a multiple of the smaller element by utilizing it as the unit. |

The score of the $a_{ij}$ symbolizes the element's relative weight of the index in row ($i$) over the index in column ($j$).

$$a_{ij} = wi/w_j \quad \text{Eq. (1)}$$

Where, $wi$ =the weight of index in row (i), $wj$ =the weight of index in column (j). When an index (D) is compared with index (E), then the index (E) has the value of reciprocity when compared with index (D).

Using the ANP technique to decide how to weight the GB performance indicators by the two experts were asked to react to several pairwise comparisons of two performance indicators in order to assess their significance (i.e., influence) on the overall GB project performance index. Additionally, paired analyses were done to look at interdependencies between the performance metrics in the construction and operation phases. The pairwise comparison matrices for overall GB construction performance are shown in Tables (4) and (5) , and operation performance, Tables (6) through (10) present the geometric mean of the pairwise comparison matrices with respect to CiPI, CPI, MSPI, SPI, and TPI, respectively, based on construction phase, while the geometric mean of the matrices of pairwise comparisons concerning ASBPI, CiPI, EPI, FPI, IEQPI, USPI, WSPI, are presented in Table (11) through

Table (17) respectively according to operation phase.

**Table 4.** The Pairwise Comparisons Matrices with Respect to Overall GB Construction Performance

| GBCPI | CiPI | CPI | INPI | MSPI | RPI | SFPI | SPI | SPDPI | TPI |
|---|---|---|---|---|---|---|---|---|---|
| CiPI | 1 | 1 | 3 | 3 | 0.5 | 2 | 1 | 2 | 1 |
| CPI | 1 | 1 | 4 | 3 | 1 | 3 | 2 | 4 | 4 |
| INPI | 0.333 | 0.25 | 1 | 0.333 | 0.333 | 0.333 | 0.25 | 1 | 0.333 |
| MSPI | 0.333 | 0.333 | 3.00 | 1 | 0.333 | 0.5 | 0.5 | 2 | 3 |
| RPI | 2 | 1 | 3.00 | 3.00 | 1 | 2 | 3 | 3 | 2 |
| SFPI | 0.5 | 0.333 | 3.00 | 2 | 0.5 | 1 | 1 | 0.333 | 1 |
| SPI | 1 | 0.5 | 4 | 2 | 0.333 | 1 | 1 | 2 | 2 |
| SPDPI | 0.5 | 0.25 | 1 | 0.5 | 0.333 | 3.00 | 0.5 | 1 | 4 |
| TPI | 1 | 0.25 | 3.00 | 0.333 | 0.5 | 1 | 0.5 | 0.25 | 1 |

**Table 5.** The Pairwise Comparisons Matrices with Respect to Overall GB Operation Performance

| GBOPI | ASBPI | CiPI | EPI | CPPR | SPPR | FPI | IEQPI | INPI | MSPI | SPDPI | USPI | WSPI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ASBPI | 1 | 1 | 2 | 3 | 4 | 0.333 | 3 | 3 | 3 | 3 | 1 | 3 |
| CiPI | 1 | 1 | 3 | 2 | 3 | 2 | 0.5 | 2 | 0.333 | 2 | 1 | 0.5 |
| EPI | 0.5 | 0.333 | 1 | 2 | 3 | 2 | 2 | 3 | 2 | 4 | 1 | 1 |
| CPPR | 0.333 | 0.5 | 0.5 | 1 | 2 | 0.333 | 0.333 | 0.5 | 0.333 | 3 | 0.333 | 0.5 |
| SPPR | 0.25 | 0.333 | 0.333 | 0.5 | 1 | 0.333 | 0.333 | 0.5 | 0.5 | 0.5 | 0.333 | 0.25 |
| FPI | 3.00 | 0.5 | 0.5 | 3.00 | 3.00 | 1 | 2 | 3 | 0.5 | 3 | 1 | 3 |
| IEQPI | 0.333 | 2 | 0.5 | 3.00 | 3.00 | 0.5 | 1 | 2 | 2 | 3 | 1 | 1 |
| INPI | 0.333 | 0.5 | 0.333 | 2 | 2 | 0.333 | 0.5 | 1 | 0.333 | 0.333 | 0.333 | 0.33 |
| MSPI | 0.333 | 3.00 | 0.5 | 3.00 | 2 | 2 | 0.5 | 3.00 | 1 | 3 | 0.5 | 1 |
| SPDPI | 0.333 | 0.5 | 0.25 | 0.333 | 2 | 0.333 | 0.333 | 3.00 | 0.333 | 1 | 0.333 | 0.5 |
| USPI | 1 | 1 | 1 | 3.00 | 3.00 | 1 | 1 | 3.00 | 2 | 3.00 | 1 | 2 |
| WSPI | 0.333 | 2 | 1 | 2 | 4 | 0.333 | 1 | 3.00 | 1 | 2 | 0.5 | 1 |

**Tables 6 to 10,** The pairwise comparison matrices with respect to CiPI, CPI, MSPI, SPI and TPI consecutively (Construction Phase)

| CiPI | CPI | RPI | SFPI | SPI |
|---|---|---|---|---|
| CPI | 1 | 1 | 2 | 2 |
| RPI | 1 | 1 | 4 | 3 |
| SFPI | 0.5 | 0.25 | 1 | 1 |
| SPI | 0.5 | 0.333 | 1 | 1 |

**(6) CiPI**

| CPI | INPI | MSPI | RPI | SFPI | SPI | TPI |
|---|---|---|---|---|---|---|
| INPI | 1 | 0.333 | 0.25 | 0.333 | 0.25 | 0.333 |
| MSPI | 3.00 | 1 | 0.333 | 1 | 0.333 | 3 |
| RPI | 4 | 3.00 | 1 | 3 | 3 | 4 |
| SFPI | 3.00 | 1 | 0.333 | 1 | 1 | 3 |
| SPI | 4 | 3.00 | 0.333 | 1 | 1 | 3 |
| TPI | 3.00 | 0.333 | 0.25 | 0.333 | 0.333 | 1 |

| MSPI | CiPI | INPI | SPDPI |
|---|---|---|---|
| CiPI | 1 | 0.333 | 1 |
| INPI | 1 | 1 | 2 |
| SPDPI | 3 | 0.5 | 1 |

| SPI | RPI | SFPI | SPDPI | TPI |
|---|---|---|---|---|
| RPI | 1 | 4 | 4 | 3 |
| SFPI | 0.25 | 1 | 2 | 2 |
| SPDPI | 0.25 | 0.5 | 1 | 1 |
| TPI | 0.333 | 0.5 | 1 | 1 |

**(8) MSPI**

**(9) SPI**

| TPI | CiPI | SFPI |
|---|---|---|
| CiPI | 1 | 2 |
| SFPI | 0.5 | 1 |

**(10) TPI**

**Tables 11 to 17** The pairwise comparison matrices with respect to, ASBPI, CiPI, EPI, FPI, IEQPI, USPI, and WSPI consecutively (Operation Phase)

| ASBPI | EPI | FPI | IEQPI | WSPI |
|---|---|---|---|---|
| EPI | 1 | 3 | 0.5 | 3 |
| FPI | 0.333 | 1 | 0.333 | 1 |
| IEQPI | 2 | 3 | 1 | 3 |
| WSPI | 0.333 | 1 | 0.333 | 1 |

**(11) ASBPI**

| CiPI | ASBPI | FPI | USPI |
|---|---|---|---|
| ASBPI | 1 | 0.333 | 0.25 |
| FPI | 3 | 1 | 1 |
| USPI | 4 | 1 | 1 |

**(12) CiPI**

| EPI | INPI | MSPI | SPDPI | WSPI |
|---|---|---|---|---|
| INPI | 1 | 0.333 | 0.333 | 0.25 |
| MSPI | 3 | 1 | 2 | 1 |
| SPDPI | 3 | 0.5 | 1 | 0.5 |
| WSPI | 4 | 1 | 2 | 1 |

**(13) EPI**

| FPI | CPI | EPI | SPI | WSPI |
|---|---|---|---|---|
| CPI | 1 | 1 | 2 | 3 |
| EPI | 1 | 1 | 3 | 2 |
| SPI | 0.5 | 0.333 | 1 | 0.5 |
| WSPI | 0.333 | 0.5 | 2 | 1 |

**(14) FPI**

| IEQPI | EPI | INPI | MSPI | SPDPI |
|---|---|---|---|---|
| EPI | 1 | 2 | 3 | 1 |
| INPI | 0.5 | 1 | 0.5 | 0.333 |
| MSPI | 0.333 | 2 | 1 | 1 |
| SPDPI | 1 | 3.00 | 1 | 1 |

**(15) IEQPI**

| USPI | ASBPI | IEQPI |
|---|---|---|
| ASBPI | 1 | 3 |
| IEQPI | 0.333 | 1 |

**(16) USPI**

| WSPI | INPI | SPDPI |
|---|---|---|
| INPI | 1 | 0.333 |
| SPDPI | 3.00 | 1 |

**(17) WSPI**

**Note:** When a group of experts participates in the judgement process, they may have discussions and come to an agreement on priorities. On the other hand, if they disagree, we can take into account the geometric mean of their assessments [Saaty and Vargas, 2013].

## 5.3. Normalization

4 $Y_j = \frac{n_{ij}}{\sum_{i=1}^{n} n_{ij}} =$

$$\begin{bmatrix} 5\ Y_{11} & 6\ Y_{12} & 7\ \cdots & 8\ \cdots & 9\ Y_{1n} \\ 11\ Y_{21} & 12\ Y_{22} & 13\ \cdots & 14\ \cdots & 15\ Y_{2n} \\ 16\ \vdots & 17\ \vdots & 18\ \vdots & 19\ \vdots & 20\ \vdots \\ 21\ \vdots & 22\ \vdots & 23\ \vdots & 24\ \vdots & 25\ \vdots \\ 26\ Y_{n1} & 27\ Y_{n2} & 28\ \cdots & 29\ \cdots & 30\ Y_{nn} \end{bmatrix} \quad 10$$

Eq. (2)

The pairwise matrix's sum of the values in each column is calculated. A normalized pairwise matrix is obtained by dividing each element of the matrix by the sum of its columns [Kumar and Biswas, 2013].The total number of rows in the normalized matrix is divided by the number of criteria (n) the weighted matrix. being used to create $P_{ij} = \frac{\sum_{j=1}^{n} Y_{ij}}{n} = \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_n \end{bmatrix}$ Eq. (3)

**Tables 18 to 23** Normalized Pairwise Comparison Matrix GBCPI, CiPI, CPI, MSPI, SPI, and TPI Consecutively (Construction Phase)

| GBCPI | CiPI | CPI | INPI | MSPI | RPI | SFPI | SPI | SPDPI | TPI |
|---|---|---|---|---|---|---|---|---|---|
| CiPI | 0.130412 | 0.203335 | 0.12 | 0.197785 | 0.103391 | 0.144571 | 0.102564 | 0.128337 | 0.054543 |
| CPI | 0.130412 | 0.203335 | 0.16 | 0.197785 | 0.206782 | 0.216857 | 0.205128 | 0.256674 | 0.218174 |
| INPI | 0.043558 | 0.050834 | 0.04 | 0.02202 | 0.069065 | 0.024143 | 0.025641 | 0.064168 | 0.018218 |
| MSPI | 0.043558 | 0.067914 | 0.12 | 0.065928 | 0.069065 | 0.036143 | 0.051282 | 0.128337 | 0.16363 |
| RPI | 0.260824 | 0.203335 | 0.12 | 0.197785 | 0.206782 | 0.144571 | 0.307692 | 0.192505 | 0.109087 |
| SFPI | 0.065206 | 0.067914 | 0.12 | 0.131857 | 0.103391 | 0.072286 | 0.102564 | 0.021432 | 0.054543 |
| SPI | 0.130412 | 0.101667 | 0.16 | 0.131857 | 0.069065 | 0.072286 | 0.102564 | 0.128337 | 0.109087 |
| SPDPI | 0.065206 | 0.050834 | 0.04 | 0.032964 | 0.069065 | 0.216857 | 0.051282 | 0.064168 | 0.218174 |
| TPI | 0.130412 | 0.050834 | 0.12 | 0.02202 | 0.103391 | 0.072286 | 0.051282 | 0.016042 | 0.054543 |

**(18) GBCPI**

| CiPI | CPI | RPI | SFPI | SPI |
|---|---|---|---|---|
| CPI | 0.333333 | 0.387147 | 0.25 | 0.2857 |
| RPI | 0.333333 | 0.387147 | 0.5 | 0.4285 |
| SFPI | 0.166667 | 0.096787 | 0.125 | 0.1428 |
| SPI | 0.166667 | 0.12892 | 0.125 | 0.1428 |

**(19) CiPI**

| CPI | INPI | MSPI | RPI | SFPI | SPI | TPI |
|---|---|---|---|---|---|---|
| INPI | 0.05555 | 0.03842 | 0.10004 | 0.04995 | 0.04225 | 0.02323 |
| MSPI | 0.16666 | 0.11539 | 0.13325 | 0.15001 | 0.05628 | 0.20930 |
| RPI | 0.22222 | 0.34618 | 0.40016 | 0.45004 | 0.50709 | 0.27907 |
| SFPI | 0.16666 | 0.11539 | 0.13325 | 0.15001 | 0.16903 | 0.20930 |
| SPI | 0.22222 | 0.34618 | 0.13325 | 0.15001 | 0.16903 | 0.20930 |
| TPI | 0.16666 | 0.03842 | 0.10004 | 0.04995 | 0.05628 | 0.06976 |

**(20) CPI**

| 31 SPI | 32 CiPI | 33 INPI | 34 SPDPI |
|---|---|---|---|
| 35 CiPI | 36 0.2 | 37 0.181669 | 38 0.25 |
| 39 INPI | 40 0.2 | 41 0.545554 | 42 0.5 |
| 43 SPDPI | 44 0.6 | 45 0.272777 | 46 0.25 |

**(21) MSPI**

| SPI | RPI | SFPI | SPDPI | TPI |
|---|---|---|---|---|
| RPI | 0.545554 | 0.666667 | 0.5 | 0.428571 |
| SFPI | 0.136388 | 0.166667 | 0.25 | 0.285714 |
| SPDPI | 0.136388 | 0.083333 | 0.125 | 0.142857 |
| TPI | 0.181669 | 0.083333 | 0.125 | 0.142857 |

**(22) SPI**

| TPI | CiPI | SFPI |
|---|---|---|
| CiPI | 0.666667 | 0.666667 |
| SFPI | 0.333333 | 0.333333 |

**(23) TPI**

**Tables 24 to 31.** Normalized Pairwise Comparison Matrix ASBPI, CiPI, EPI, FPI, IEQPI, USPI, and WSPI Consecutively (Operation Phase)

| GBOPI | ASBPI | CiPI | EPI | CPPR | SPPR | FPI | IEQPI | INPI | MSPI | SPDPI | USPI | WSPI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ASBPI | 0.1143 | 0.0789 | 0.1832 | 0.1208 | 0.125 | 0.0317 | 0.24 | 0.1111 | 0.225 | 0.1077 | 0.12 | 0.213 |
| CiPI | 0.1143 | 0.0789 | 0.2748 | 0.0805 | 0.0937 | 0.1904 | 0.04 | 0.0740 | 0.025 | 0.0718 | 0.12 | 0.0355 |
| EPI | 0.0571 | 0.0263 | 0.0916 | 0.0805 | 0.0937 | 0.1904 | 0.16 | 0.1111 | 0.15 | 0.1437 | 0.12 | 0.071 |
| CPPR | 0.0381 | 0.0395 | 0.0458 | 0.0403 | 0.0625 | 0.0317 | 0.0267 | 0.0185 | 0.025 | 0.1077 | 0.04 | 0.0355 |
| SPPR | 0.0286 | 0.0263 | 0.0305 | 0.0201 | 0.0312 | 0.0952 | 0.0267 | 0.0185 | 0.0375 | 0.0179 | 0.04 | 0.0177 |
| FPI | 0.3428 | 0.0395 | 0.0458 | 0.1208 | 0.0937 | 0.0476 | 0.16 | 0.1111 | 0.0375 | 0.1077 | 0.12 | 0.213 |
| IEQPI | 0.0381 | 0.1579 | 0.0458 | 0.1208 | 0.0937 | 0.0317 | 0.08 | 0.0740 | 0.15 | 0.1077 | 0.12 | 0.0710 |
| INPI | 0.0381 | 0.0395 | 0.0305 | 0.0805 | 0.0625 | 0.0317 | 0.04 | 0.0370 | 0.025 | 0.0119 | 0.04 | 0.0236 |
| MSPI | 0.0381 | 0.2368 | 0.0458 | 0.1208 | 0.0625 | 0.1904 | 0.04 | 0.1111 | 0.075 | 0.1077 | 0.06 | 0.071 |
| SPDPI | 0.0381 | 0.0395 | 0.0229 | 0.0134 | 0.0625 | 0.0317 | 0.0267 | 0.1111 | 0.025 | 0.0359 | 0.04 | 0.0355 |
| USPI | 0.1142 | 0.0789 | 0.0916 | 0.1208 | 0.0937 | 0.0952 | 0.08 | 0.1111 | 0.15 | 0.1077 | 0.12 | 0.142 |
| WSPI | 0.0381 | 0.1579 | 0.0916 | 0.0805 | 0.125 | 0.0317 | 0.08 | 0.1111 | 0.075 | 0.0718 | 0.06 | 0.071 |

**(24) GBOPI**

| ASBPI | EPI | FPI | IEQPI | WSPI |
|---|---|---|---|---|
| EPI | 0.272777 | 0.375 | 0.23084 | 0.375 |
| FPI | 0.090835 | 0.125 | 0.15374 | 0.125 |
| IEQPI | 0.545554 | 0.375 | 0.461681 | 0.375 |
| WSPI | 0.090835 | 0.125 | 0.15374 | 0.125 |

**(25) ASBPI**

| CiPI | ASBPI | FPI | USPI |
|---|---|---|---|
| ASBPI | 0.125 | 0.142735 | 0.111111 |
| FPI | 0.375 | 0.428633 | 0.444444 |
| USPI | 0.5 | 0.428633 | 0.444444 |

**(26) CiPI**

| EPI | INPI | MSPI | SPDPI | WSPI |
|---|---|---|---|---|
| INPI | 0.090909 | 0.117543 | 0.062441 | 0.090909 |
| MSPI | 0.272727 | 0.352983 | 0.375023 | 0.363636 |
| SPDPI | 0.272727 | 0.176491 | 0.187512 | 0.181818 |
| WSPI | 0.363636 | 0.352983 | 0.375023 | 0.363636 |

**(27) EPI**

| FPI | CPI | EPI | SPI | WSPI |
|---|---|---|---|---|
| CPI | 0.352983 | 0.352983 | 0.25 | 0.461538 |
| EPI | 0.352983 | 0.352983 | 0.375 | 0.307692 |
| SPI | 0.176491 | 0.117543 | 0.125 | 0.076923 |
| WSPI | 0.117543 | 0.176491 | 0.25 | 0.153846 |

**(28) FPI**

| IEQPI | EPI | INPI | MSPI | SPDPI |
|---|---|---|---|---|
| EPI | 0.352983 | 0.25 | 0.545455 | 0.30003 |
| INPI | 0.176491 | 0.125 | 0.090909 | 0.09991 |
| MSPI | 0.117543 | 0.25 | 0.181818 | 0.30003 |
| SPDPI | 0.352983 | 0.375 | 0.181818 | 0.30003 |

**(29) IEQPI**

| USPI | ASBPI | IEQPI |
|---|---|---|
| ASBPI | 0.750188 | 0.75 |
| IEQPI | 0.249812 | 0.25 |

**(30) USPI**

| WSPI | INPI | SPDPI |
|---|---|---|
| INPI | 0.25 | 0.249812 |
| SPDPI | 0.75 | 0.750188 |

**(31) WSPI**

## 5.4. Analyzing Consistency

When comparing different indices with interdependencies among each other throughout the human judgement process, inconsistency can arise. As a result, before obtaining the priority vector, an inconsistency test for the comparison matrices is required. By dividing the total number of rows in the normalized matrix by the number of criteria being used, the weighted matrix is produced. [Saaty and Vargas, 2013]. The positive entries in the pairwise comparison matrix A = *(aij), aij = pi/pj, i.j* =1, 2, ..., n. *pij = 1/ pij* it's known as a reciprocal matrix. When this matrix is multiplied by the column vectors (p1, p2, ..., pn), the result is a vector (np). $P_{jk} = n_{ik}/n_{ij}$, Where, i, j, k= 1, 2, 3, ...., n. Eq. (4) $AP = nP$ Eq. (5). According to Saaty [1990], the largest Eigen value ($\lambda$ max) must match the size of the comparison matrix for the equation AP=nP to have a non-zero solution for the consistent reciprocal matrix (n). $\lambda max = n$ (Eq. 6). A local priority vector can be created by calculating the equation below as an estimation of the relative importance connected with the indices under comparison: $Ap = \lambda max$ p (Eq. 7). Where, $\lambda max$ = The principal eigenvalue of comparison matrix A. P= The eigenvector, $\lambda$ max is calculated by averaging the value of the consistency vector. $\lambda max = 1/p_i \sum_{j=1}^{n} n_{ij} p_j$ (Eq. 8). Where, in which i, j = 1, 2, 3,..., n, n is the matrix's number of indices. The consistency index (CI) can be used to calculate the deviation of the obtained relative weights. $CI = \frac{\lambda_{max} - n}{n-1}$ (Eq. 9). By dividing the consistency index (CI) by the random consistency index (RI) for the same size comparison matrix, the consistency ratio (CR) for a group of judgments is obtained: $CR = CI/RI$ (Eq. 10). The matrix size (i.e., number of elements) is used to determine the random consistency index (RI), as stated in Table 32.

**Table 32.** Random consistency index [Saaty and Vargas, 2013]

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 47 Num. | 48 2 | 49 3 | 50 4 | 51 5 | 52 6 | 53 7 | 54 8 | 55 9 | 56 10 | 57 11 | 58 12 | 59 13 | 60 14 | 61 15 |
| 62 RI | 63 0.0 | 64 0.58 | 65 0.90 | 66 1.12 | 67 1.24 | 68 1.32 | 69 1.41 | 70 1.45 | 71 1.49 | 72 1.51 | 73 1.54 | 74 1.56 | 75 1.57 | 76 1.59 |

In general, a CR score of less than 0.1 implies that the judgements were satisfied. Perfect uniformity is difficult to achieve. In order to obtain accurate findings for the decision-making process, judgments must be consistent.

## 5.5 Expert Judgment Consistency Check

For the expert assessment regarding the overall GB construction performance and operation performance consistency ratios are calculated as 0.088, 0.089. While the consistency ratios for the expert judgement about the CiPI, CPI, MSPI, SPI and TPI have been determined to be 0.017, 0.06, 0.017, 0.00, 0.036, and 0.0 respectively. While the consistency ratios for the expert judgement about the ASBPI, CiPI, EPI, FPI, IEQPI, USPI and WSPI have been determined to be 0.02 0.008, 0.017, 0.038, 0.00 and 0.00 respectively. The judgments are acceptable because the consistency ratios in science are fewer than 0.1.

**Table 33.** Priority Weights of Influential Indicator

| 77 | 78 P1 | 79 P2 | 80 P3 | 81 P4 | 82 P5 | 83 P6 | 84 P7 | 85 P8 | 86 P9 |
|---|---|---|---|---|---|---|---|---|---|
| **90 GBCPI** | **91 CPI** | **92 CiPI** | **93 INPI** | **94 MSPI** | **95 RPI** | **96 SFPI** | **97 SPI** | **98 SPDPI** | **99 TPI** |
| 103 Influential indicator 104 (weighted) | 105 0.202 | 106 0.132 | 107 0.04 | 108 0.085 | 109 0.192 | 110 0.08 | 111 0.112 | 112 0.09 | 113 0.067 |
| 117 | **118 P1** | **119 P2** | **120 P3** | **121 P4** | **122 P5** | **123 P6** | **124 P7** | **125 P8** | **126 P9** |
| **130 EX GBOPI** | **131 ASBPI** | **132 CiPI** | **133 EPI** | **134 CPPR** | **135 SPPR** | **136 FPI** | **137 IEQPI** | **138 INPI** | **139 MSPI** |
| 143 Influential indicator 144 (weighted) | 145 0.14 | 146 0.1 | 147 0.11 | 148 0.04 | 149 0.03 | 150 0.11 | 151 0.1 | 152 0.04 | 153 0.1 |

## 6. Analytical Case Study

The proposed model is used in a case study to evaluate the effectiveness of the indicators and the degree of project success. The project under study is an administrative building in Egypt, located in the new administrative capital. After 20 months of development, data for the project was gathered from sustainability design reports and on-site consultations with the project manager.

### 6.1Performance Assessment

The GB project performance hierarchy depicted in Figure 4 serves as the structural foundation for the formal, quantified GB performance evaluation approach described in this study. Table 34 shows the assessment of performance indicators.

**Table 34.** Performance Indicators Assessment

| Indicator | Amount of Indicator | Indicator | Amount of Indicator |
|---|---|---|---|
| **CPI** | 1.5 | ASBPI | 7 |
| **CiPI** | 6.958 | EPI | 1.46 |
| **INPI** | 5 | CPPR | 0.9 |
| **MSPI** | 1.42 | SPPR | 0.8 |
| **RPI** | 0.15 | FPI | 2.2 |
| **SFPI** | 0.8 | IEQPI | 1.6 |
| **SPI** | 1.3 | USPI | 1.08 |
| **SPDPI** | 0.8 | WSPI | 1.6 |
| **TPI** | 7 | | |

## 6.2 Evaluating GB Success

The construction performance index and expected operation performance index for GB project can be expressed as an equation in a form of:

$\text{GB}C\text{ PI} = \sum_{i=1}^{9} P_i \times L_i$ (Eq. 11), $\text{EX GB}O\text{ PI} = \sum_{i=1}^{12} P_i \times L_i$ (Eq. 12)

Where, $P_i =$ Relative weights for the normalized performance indices, and $\sum_{i=1}^{9} P_i = 1$.

$L_i =$ The normalized performance indices. The weights proposed will illustrate how sensitive the overall GBCPI, EX GBOPI is to each of the performance metrics. Furthermore, these weights will influence the decision-making process and the various forms of corrective action required during the project. Table (35) depicts the schematic classification limits of overall GBPI.

**Table 35.** GB Performance-Rating Table

| Range | Range | Rating |
|---|---|---|
| 2.2 ≤ GBCPI | 2.2 ≤ EX GBOPI | Outstanding Performance |
| 1.6≤ GBCPI<2.2 | 1.6≤ EX GBOPI<2.2 | Performance up Target |
| 1.2≤ GBCPI<1.6 | 1.2≤ EX GBOPI<1.6 | Performance in Target |
| 0.80≤ GBCPI<1.2 | 0.80≤ EX GBOPI<1.2 | Performance Below Target |
| GBCPI< 0.80 | EX GBOPI< 0.80 | Poor Performance |

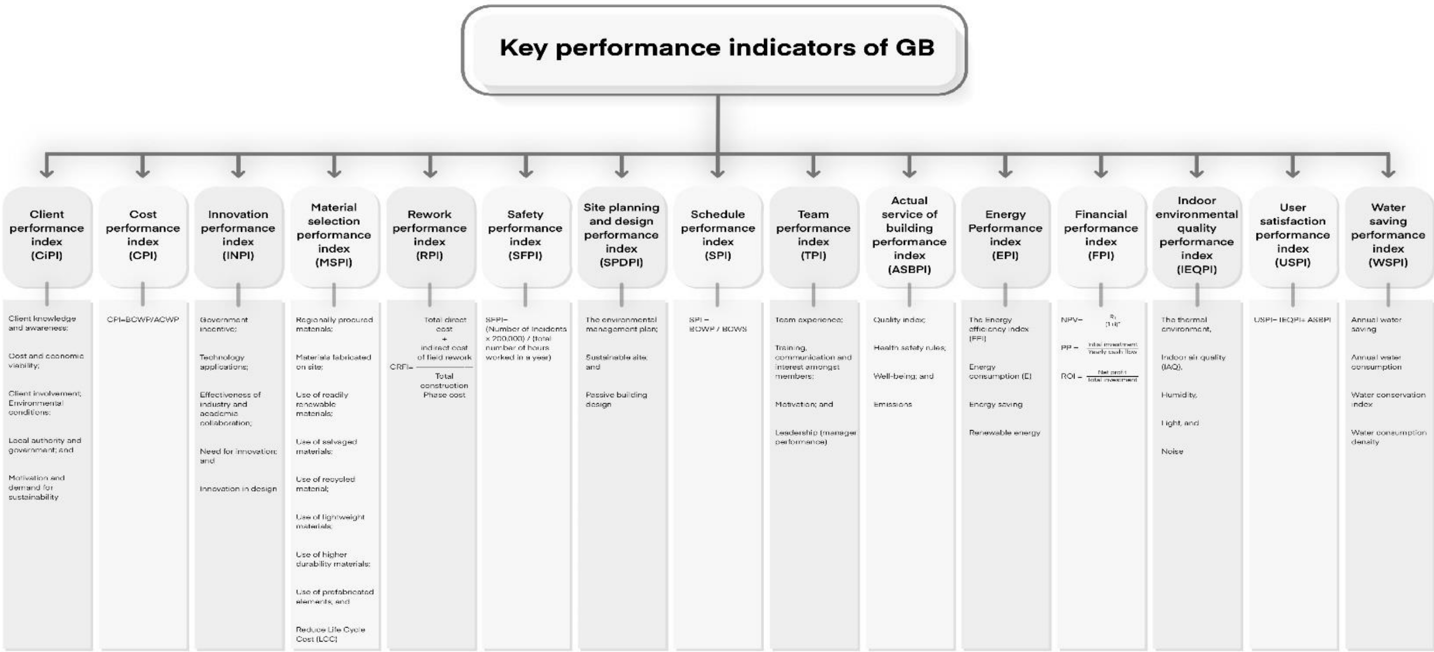


**Figure 4. GB Project Performance Hierarchy Design**

GBCPI = (P1*CPI, P2*CiPI, P3*INPI, P4*MSPI, P5*RPI, P6*SFPI, P7*SPI, P8*SPDPI, and

P9*TPI), (Eq. 13)

GBCPI= (0.202×1.5) + (0.0132×1.11) + (0.04×0.8) + (0.085×1.42) + (0.192×0.5) + (0.08×0.8) + (0.112×1.3) + (0.09×0.8) + (0.067×0.912) = 1.15 (The project's performance falls short of expectations).

Equation 14 gives an expression for the expected operation performance of the entire GB project (EX GBOPI) as a function of the twelve project success criteria.

EX GBOPI equals (P1*ASBPI, P2*CPPR, P3*CiPI, P4*EPI, P5*FPI, P6*IEQPI, P7*INPI, P8*MSPI, P9*SPPR, P10*SPDPI, P11*USPI, and P12*WSPI) (Eq. 14). The project performance that meets expectations where, EX GBOPI = (0.141.12) + (0.040.9) + (0.11.11) + (0.111.46) + (0.112.2) +(0.11.612) + (0.040.8) + (0.11.42) + (0.030.85) + (0.040.8) + (0.111.08) + (0.081.6) = 1.51.

## 7. Conclusion

Early GB project effectiveness estimation is a crucial and challenging problem. Prior studies mainly focused on GB rating instruments, credit, and conventional measurement instruments like time, cost, and quality. A specific model for estimating the performance of green projects and an explanation of the correlation between performance indicators were lacking in earlier literature. Project will be successful if sustainability dimensions are integrated with project management and are based on the interdependence and dependability of performance indicators. Due to the discussion that has gone before, the goal of this research is to close the knowledge gap by creating an integrated model that uses multidimensional performance indicators to assess the success of green initiatives. The selection of 15 appropriate qualitative and quantitative performance measures was based on a review of the literature and discussions with subject matter experts. While promoting environmental awareness, appropriate design that complies with contemporary technology techniques and effective building trend planning help to reduce energy and water use. Additionally, innovations and education work to develop and build institutions that produce skilled workers with knowledge of green building technology, producing ideal financial, schedule, and growing productivity to appease stakeholders. Utilizing renewable energy, environmentally friendly materials, and increasing energy efficiency reduces emissions, fosters a work- and social-environment, and improves public convenience and productivity.

## 8. Recommendations and Future Work

Using systems dynamics to simulate many scenarios to improve project performance, predict changes between performance indicators, and ensure their success. Contract types should be integrated and added as a performance indicator to guarantee the success of the green project. focusing on identifying key elements, breaking new ground in innovation, and the role of government and education in spreading knowledge of sustainable construction. creating a model to predict the precise performance of the GB project through pre-planning simulations during the planning and design phase.

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