COMPOSITE INDICATORS FOR ASSESSING THE CARBON EMISSION REDUCTION ON BIO-ECO-RESILIENCE OF RESIDENTIAL BUILDINGS

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ABSTRACT
In the 21st century, extreme precipitation and temperature are expected due to climate change. This climate change is induced by carbon emissions, in which residential buildings contribute significantly. We propose a kinetic green façade with a double frame. The first frame is an outdoor frame of bio-vegetation, while the second frame is built of green construction materials with isolated glass. This kinetic skin is intended to mitigate extreme temperature and use extreme precipitation. This system integrates three state-of-the-art approaches: biophilic, ecological and resilience to compact climate changes hazards. In this paper, we established bio-eco-resilience composite indicators (BER-CIs) to assess this modification for existing residential building in the New Borg Al-Arab City (NBC), Egypt in five different scenarios. We find that scenario 5 where the highest vegetation footprints in which all the harmful and unhealthy exposure was utilized sustainably, and carbon sequestration is higher than carbon emissions with BER-CIs of 21.64.
Keywords: green façade, carbon emission, carbon sequestration, composite indicator, RIVET, GIS.

1 INTRODUCTION

Greenhouse gas emissions form residential units strengthening the greenhouse effect, causing climate change [1], and the residential development have not yet peaked. Recently, cities embodied 80% Cities of carbon emissions [2] mainly due to residential building energy consumption [3]. In Egypt, carbon emissions are 73% of total greenhouse gas emissions, in which 44% is due to residential building energy consumption [4]. The European Union (EU) targets to reduce gas emission from 55% in 2030 to nearly zero in 2050 to achieve climate neutrality. Moreover, United Nations Sustainable Development Goals (UNSCD) targets to replace traditional energy by clean renewable energy in 2030 [1] by creating buildings with high-energy efficiency and passive design [5], [6].

Since 2013, Rockefeller foundation "100 resilient city" has organized by gathering difference disciplines such as architecture, urban design, civil engineering, and social sciences. These efforts are held to convert 100 cities to resilience cities able to adapt to climate changes and other issues. A resilient city is expected to be able to reduce the impact of the natural disasters and recover quickly [7], [8]. In this context, "Resilience" is defined as the ability to absorb, adapt, and transform after affect to harmful events, stress and shock [9]. Thus, climate resilience requires the reduction of greenhouse emissions [10] and promoting a healthy coherent system [11].

The socio-ecological system can be described as the dynamic of the city to link the society and human wellbeing to ecosystem service [2]. This system is promoting the sense of place [12], and is regenerating the built environment [13] by linking the engineering resilience with nature to adapt the climate changes [14]. Urban ecosystem has positive influence on people and environment [15]. Recent research efforts discussed socio-ecological system and its impact on the society based on improving urban green infrastructure (UGI) are promoting the sense of place and biodiversity conservation. UGI elements are in macro-scale gardens,

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parks, blue footprints, and micro-scale green spaces, green roofs, green/living walls. UGI was suggested to mitigate climate change either socially [16]–[21] or economically [22]–[27]. Additionally green filtration process within micro-scale UGI is described as Natural Base Solution (NBS). In 2021, researchers suggested that adding new technologies to NBS can establish climate change resilient cities through phytoremediation [28], [29].We believe that these new technologies can be bio-inspired (Biophilic) through covering residential units with multi-bio-functional dynamic skin. These multi-bio-functions combine vegetation, renewable energy, and green building materials. This skin consists of subdivision kinetic units, adapting to environmental changes. In this skin, the vegetation collects, absorbs, and filtrates rain, and reduces the urban heat island. Also, we will utilize renewable energy and green building materials to reduce the overall carbon footprint of the residential units. Thus, this Biophilic approach helps creating a resilient city [30] through achieving the following seven qualities: (1) Reflectiveness by ability to make future decisions based on skin kinetic measurements; (2) Resourcefulness by employing available cost-effective green building materials; (3) Robustness by complying with design building codes and regulations, and testing safety periodically; (4) Redundancy by absorbing, transforming and accepting climate changes; (5) Flexibility by modular design to enable easy implementation of any future technology; (6) Inclusive by enhancing ownership and personal vision of the residents, not exclusively the engineers; and (7) Integration by bring together interdisciplinary designs and technologies. Thus, our proposed system integrates of three aforementioned approaches: Biophilic, ecological and resilience approaches.

In our research, we analysis the predictive weather scenarios at the New Borg Al-Arab City (NBC), Egypt. NBC combines coastal and desert land features [31]. This analysis includes the temperature and precipitation. The temperature and precipitation are anticipated to increase at coastal regions [4]. Then we establish bio-eco-resilience composite indicators (BER-CIs) to measure three parameters: (1) energy consumption; (2) carbon emission; and (3) water conversion. We computational simulated BER-CIs by Revit Autodesk plugins (dynamo, green building studio and BIM), Esri-estimation (ArcGIS) and IBMM SPSS statistics. CIs (composite indicators) are performed from combining of specific indicators into a single index that enable the measurement of multi-dimensions [32]. These single indicators can be classified to key indicators and extensive indicators. Key indicators (KIs) are defined as indicators that can be measured and easy to collect. Extensive indicators (EIs) complete the results of the key indicators to achieve detailed indicator [33].

2 BIO-ECO-RESILIENCE COMPOSITE INDICATORS

Our study proposes adapting to climate change by accepting, absorbing, and transforming extreme temperatures and perceptions to reduce the impact of natural disasters. BER-CIs (bio-eco-resilience composite indicators) measure three parameters: (1) energy consumption; (2) carbon sequestration; and (3) water conversion. BER-CIs have three CIs, eight KIs, and 15 EIs, as shown in Table 1.

CIs 1, 2, and 3 focuses on promoting nearly zero energy, carbon, and water, respectively. CIs 1 is established by combining four KIs (from 1 to 4) and seven EIs (from 1 to 7), CIs 2 is established by combining two KIs (5 and 6) and four EIs (from 8 to 11), and CIs 3 is established by combining two KIs (7 and 8) and four EIs (from 12 to 15). In this paper, we solely classify, evaluate and measure CIs 2. Bio-eco-resilience with nearly zero carbon (CIs 2: BER-nearly zero carbon) is defined as the total amount of carbon sequestration from healthy bio-vegetation lying in BER-residential units. The best-case scenario when CIs value increases, indicating reduction of the greenhouse gas emissions to approximately zero.

Table 1: Bio-eco-resilience composite indicators (BER-CIs) classification.

BER-CIs			**Best-case scenario**	**Multi-dimensions**
CIs.1		**BER-nearly zero energy**	**Low value is better**	
KI.1		BER-EC ($MJ/m^2/Yr.$)	Low value is better	Residential units (shelters) and built environment
	EI.1	EU ($MJ/m^2/Yr.$)	Low value is better	
	EI.2	REP ($MJ/m^2/Yr.$)	High value is better	
KI.2		BER-Elec. C ($MJ/m^2/Yr.$)	Low value is better	
	EI.3	Elec. C ($MJ/m^2/Yr.$)	Low value is better	
	EI.4	NVEES ($MJ/m^2/Yr.$)	High value is better	
	EI.5	SEES ($MJ/m^2/Yr.$)	High value is better	
KI.3		BER-EEI ($MJ/m^2/Yr.$)	Low value is better	
KI.4		BER-Elec. C Cost ($)	Low value is better	Economy
	EI.6	Elec. C Cost ($)	Low value is better	
	EI.7	NVEES. Cost ($)	High value is better	
CIs.2		**BER-nearly zero carbon**	**High value is better**	
KI.5		BER-CSS (Kg. $C/m^2/Yr.$)	High value is better	Residential units (shelters) and built environment
	EI.8	EC (Kg. $C/m^2/Yr.$)	Low value is better	
	EI.9	CS (Kg. $C/m^2/Yr.$)	High value is better	
KI.6		BER-Vegetation (%)	High value is better	Built environment and economy
	EI.10	VVF (m^2).	High value is better	
	EI.11	HVF (m^2).	High value is better	
CIs.3		**BER-nearly zero water**	**High value is better**	
KI.7		BER-WSI (L/Yr.)	High value is better	Residential units (shelters) and built environment
	EI.12	RRWHS (L/Yr.)	High value is better	
	EI.13	NVWS (L/Yr.)	High value is better	
KI.8		BER-WCS ($)	High value is better	Economy
	EI.14	RRWHCS ($)	High value is better	
	EI.15	NVIWCS ($)	High value is better	

KI 5 (kg. $C/m^2/Yr.$) is calculated by subtracting EI 9 from EI 8. EI 9 measures carbon sequestration (CS). CS is defined as the total amount of carbon sequestration in BER-units due to vegetation and green building materials. While EI 8 measures embodied carbon (EC). EC is defined as the total amount of carbon embodied during the construction process. KI 6 (%) is calculated by adding EI 10 and EI 11 as a percentage of total residential unit area. EI 10 and EI 11 (m^2) measures vertical (VVF) and horizontal (HVF) vegetation footprint, respectively. We used EC coefficients from the Inventory of Carbon and Energy (ICE) database [34], [35] for EI 8, CS coefficients from Arodudu et al. [36] for EI 9. Then the collected coefficients were applied and simulated into material mass of the BER-residential unit using Revit Autodesk building information modelling (BIM) plugin. Then we employ IBM SPSS software to perform statistical analysis to find CIs 2 value. This statistical analysis was performed by checking reliability, then defining normalization and estimating weight coefficient of various KIs and EIs. After that the CIs sensitivity and correlation was checked. This quantitative methodology of CIs construction is well-explained in details in Nardo et al. [32].

3 CASE STUDY: A RESIDENTIAL BUILDING AT NBC, EGYPT.

We propose a kinetic skin with a double frame. The first frame is an outdoor frame of bio-vegetation, while the second frame is built of green construction materials with isolated glass. In this section, we will apply five scenarios on a residential building. We generated five scenarios by varying skin normalize curve parameter (NCP) using ladybug dynamo plugin in Autodesk Revit. The proposed skin divided into regular parametric units. Each parametric has a triangle shape with unique dimensions. These dimensions are proportional to the skin surface area. NCP varies from 0.1 to 0.9. The parametric units are fully exposed to sunlight at NCP 0.1. Healthy natural sunlight exposure for residents at NCP ≥ 0.5. So, we varied NCP values from 0.1 to 0.5 with 0.1 increment for maximum exposure of the kinetic skin.

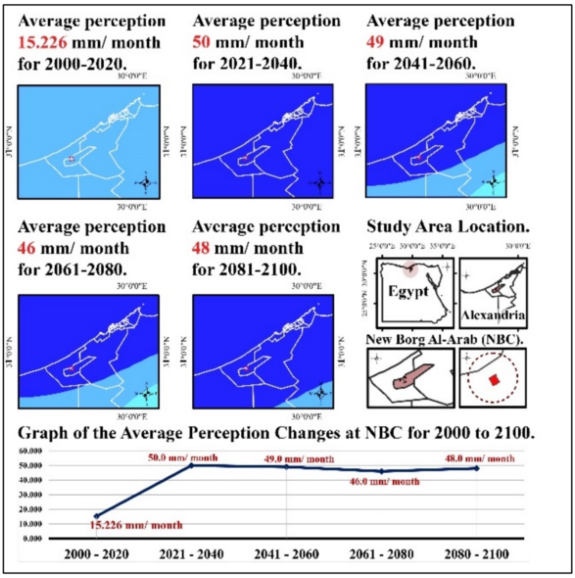
The New Borg Al-Arab City (NBC) is new residential and industrial development city with coastal and desert land features [31]. National aeronautics and space administration (NASA) is predicting NBC to suffer increasing in both perception and temperature due to climate change, each is an exclusive predicament of coastal and desert land as shown in Fig. 1(a) and (b), respectively. We generated Fig. 1 by kriging analysis method using ArcGIS for five periods: 2000 to 2020, 2021to 2040, 2041 to 2060, 2061 to 2080, and 2081 to 2100. NBC has two residential units' prototypes. These prototypes are covered with non-thermally insulated brick walls, non-thermally insulated windows, and non-insulated concrete tile roofs [31]. Thus, these units lack thermal comfort. We selected a 320 m^2 residential unit located in in the centre of the first neighbourhood at a south-east direction latitude of 30°52`30`` north and longitude 29°34`30`` east at NBC. The study area covered an area of approximately 391.97 km^2, of which ≈ 45.72 km^2 (11.66%) built-up including ≈ 34.34 km^2 (8.76%) residential clusters, and ≈ 11.38 km^2 (2.90%) public buildings. There are two residential clusters, each with a different prototype. The first cluster consists of 57 units, each unit is 320 m^2. While the second cluster consists of 23 units, each unit is 700 m^2. This data is analysed by Arc GIS as shown in Fig. 2. We estimated current EC and CS and for the selected 320 m^2 unit to be 102 and 0 Kg. C/m^2/Yr. for EI 8 and 9, respectively. Also, the unit has zero vegetation for KI 6.

We simulated the potential solar estimation for the modified unit with kinetic skin. Then we applied 5 aforementioned scenarios to find CIs 2. The maximum sun exposure occurred on 22 July 2021 at 12:00 pm for 45 minutes in NBC area of study. The simulation process is divided into following phases: solar time preparation, simulation, and testing. Sun exposure footprint is simulated and calculated using ladybug dynamo plugin in Autodesk Revit. Fig. 3 shows that ≈ 44% of skin footprint is exposed to the maximum exposure (NCP = 0.1) while only ≈ 2% at minimum exposure (NCP ≥ 0.9). And ≈ 9% can be classified as a healthy natural sunlight exposure for residents (0.6 ≤ NCP ≤ 0.9).

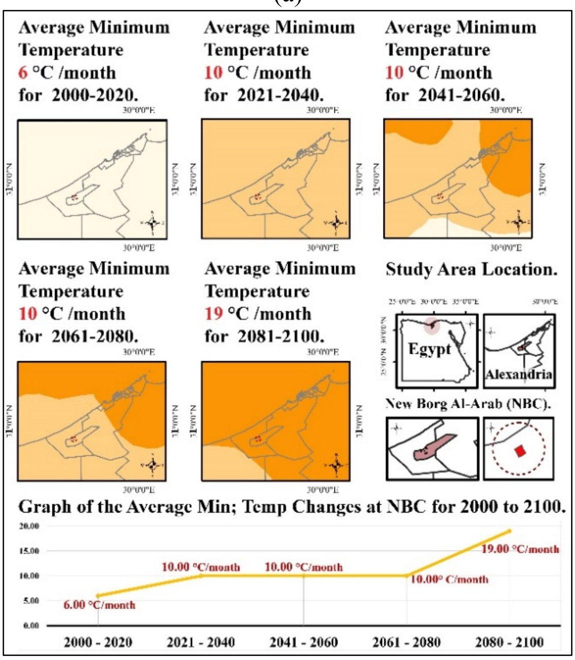
We find potential solar radiation is 44, 57, 71, 82, and 88%, respectively for the 5 scenarios, corresponding to bio-vegetation footprint. Thus, we suggest 56, 43, 29, 18 and 12%, respectively for the kinetic opening for the proposed skin as shown in Fig. 3.

4 RESULT AND DISSUSSION

This section evaluates CIs 2 for 320 m^2 residential unit for 5 scenarios. Table 2 shows the values of KIs and EIs for the 5 scenarios. We evaluate CIs 2 statistically in four stages. First



(a)



(b)

Figure 1: The climate change kriging geo-statistics analysis of Alexandria metropolitan area (includes NBC to the west) from 2000 to 2100. (a) Perception has already risen from 15.226 to 50 mm, starting from 2021 and will stayed relatively stable till 2100, increasing the vulnerability to extreme storms; while (b) Minimum temperature has stayed relatively stable at 10°C from 2021 to 2080, but will rise to 19°C in 2081.

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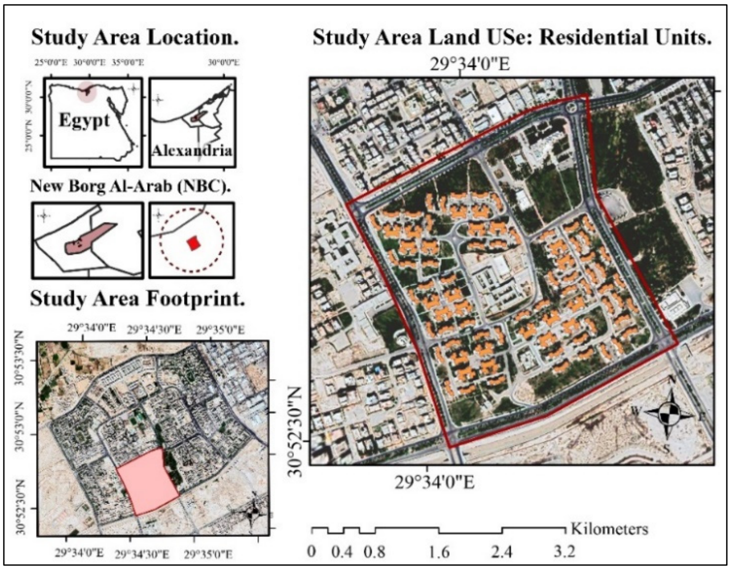

Figure 2: Study area at New Borg Al-Arab City (NBC) location.

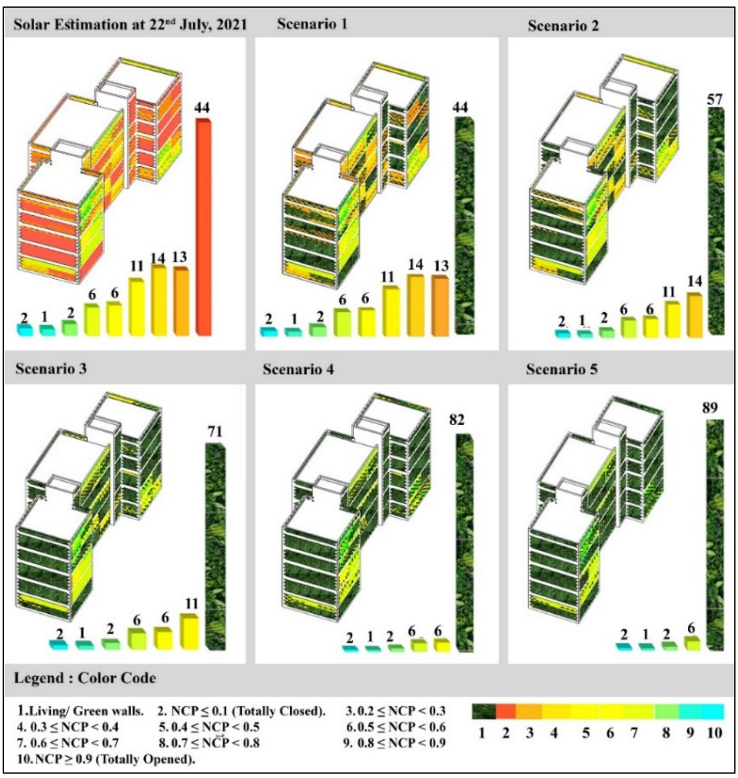

Figure 3: The solar radiation and applying the five scenarios.

stage, we check the reliability statistics between KIs 5, 6, and EIs 8 to 11. An acceptance reliability statistic has been reported: α ≈ 0.796, and the standard accept value > 0.6 [32]. Then we normalized KI 5 and 6, and EI 8 to 11 using the rescale method with the following equation at the second stage:

$$\frac{In - In_{min}}{In_{max} - In_{min}},$$

where, *In* is a KI or an EI.

Table 2: The measurement of KIs and EIs at the case study for CIs.

BER-KIs/EIs (Unit area ≈ 320 m²)			**Scenarios**				
			1	**2**	**3**	**4**	**5**
KI.5		BER-CS (Kg. C/m²/Yr.)	2.77	9.6	16.86	22.75	26.06
	EI.8	EC (Kg. C/m²/Yr.)	30.82	27.05	23.32	20.34	18.66
	EI.9	CS (Kg. C/m²/Yr.)	33.59	36.65	40.21	43.09	44.71
KI.6		BER-Vegetation (%)	49.34	61.50	74.03	83.66	88.83
	EI.10	VVF (m²).	1172	1308	1466.4	1594.1	1666.4
	EI.11	HVF (m²).	300	300	300	300	300

The rescale normalization was calculated as 0, 0.0034, 0.0071, 0.10, and 0.117 for KI 5, 0.081, 0.063, 0.046, 0.032, and 0.025 for EI 8, 0.007, 0.017, 0.027, 0.036, and 0.041 for EI 9, 0, 0.1426, 0.2851, 0.4995, and 0.7856. K 10, 0, 0.0009, 0.0019, 0.0027 and 0.0031 for EI 10 respectively for each of the five scenarios. While E 11 is zero for all scenarios. Then we estimated the weight coefficient values for KIs 5, 6, and EIs 8 by principal component analysis to be 13.9, 15.5, 16.017, 15.683, 15.767 and 15.817 at the third stage. In the fourth stage, we aggregated the KIs and EIs by summing of the multiplication of rescale normalized and weight coefficient to find CIs 2. And CIs 2 is 0.14, 2.42, 4.71, 8.12 and 12.64, respectively for each of the five scenarios.

The data identifies the difference occurs for a 320 m² residential unit after converting un-thermal un-insulation walls and windows to bio-vegetation kinetic openings in NBC. Fig. 4 shows that embodied carbon (EC) was reduced from 102 to 30.82, 27.05, 23.32, 20.34, and 18.66 Kg. C/m²/Yr. due to converting the un-thermal insulation brick walls and insulation glass windows into green construction materials, insulation glass, and bio-vegetation walls. Furthermore, carbon sequestration (CS) rises from 0 to 33.59 in scenario 1 then enhanced to

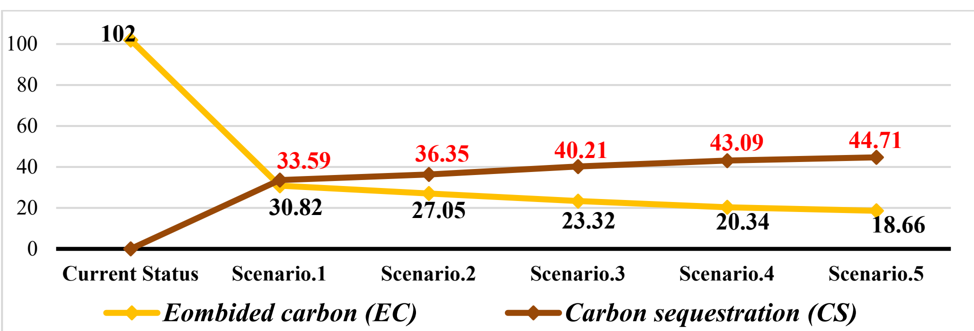

Figure 4: The graph of the impact of five Scenarios at BER-CIs.

be 44.71 in scenario 5 due that vegetation footprints increased from 0 to 49.34 then 88.83, respectively. EC and CS values are shown in Fig. 4.

5 CONCLUSION

Scenario 5 shows the highest vegetation footprints where all the harmful and unhealthy exposure was utilized sustainably. This scenario raises carbon sequestration, decreases the embodied carbon. Thus, this scenario provides the highest BER-CS with nearly zero carbon with CIs of 12.64 compared to 26.06 for the scenario 1. We presented CIs 2 of 3 BER-CSs to assist a proposed kinetic skin to enhance a residential unit at the New Borg Al-Arab city, a city that combined two climate features: the Mediterranean coast and desert land. This research is a part of the efforts to mitigate climate changes in emerging development communities in which extreme temperatures and precipitation is expected.

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