# Sustainable-Eco-Buildings Assessment Method SEBAM for Evaluation of Residential Areas in Hot-Dry Climate

Hind Abdelmoneim Khogali<sup>1</sup> & Saud Sadiq Hassan<sup>2</sup>

<sup>1</sup> Dar Al Uloom University, CADD-ARC, Riyadh City, Saudi Arabia

<sup>2</sup> Sudan University of Science and Technology, Sudan

Correspondence: Hind Abdelmoneim Khogali, Dar Al Uloom University, CADD-ARC, Riyadh City, Saudi Arabia. Tel: 966-1-1494-9123. E-mail: hind\_50abde@yahoo.com

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## Abstract

This research aimed to investigate the present situation regarding residential neighbourhood in hot-dry climates. The area of study comprised four urban classes in Greater Khartoum. The problems of residential buildings were examined, aiming to find a sustainable assessment method for evaluating residential areas and their services The methodology of the research began with a literature review for identifying passive and sustainable solutions suitable to hot-dry climates. This method employed eight main categories: sustainable sites, indoor environmental quality, outdoor thermal control, building forms, materials and resources, water supply, power supply systems, and environmental plan processes and CO<sub>2</sub> emisions. In addition, a points scale was used, based on ratings of 'Excellent', 'V. Good', 'Good', and 'Pass', with a total of 125 points to determine the evaluation result for a building. The study evaluated an urban sample in the Al Taief neighbourhood. A survey was initiated by identifying the standards for selecting the case study, the survey studied 48 cases in the residential areas, analysed the collected data, and then summarised it into tables and figures. The results presented indicated that 19% were Good, 25% were Pass, and 56% were considered 'weak'. The conclusions and recommendations regarding urban housing services can be applied to sustainable ecological neighbourhoods.

**Keywords:** passive solutions, sustainable eco-building, eco-neighbourhood principles, sustainable assessment methods, introduce assessment method, evaluation of residential areas in hot -dry climate

## 1. Introduction

This research was aimed at investigating the present situation regarding residential buildings in Greater Khartoum (the capital of Sudan), and specifically at evaluating those buildings using sustainable environmental parameters. The problems of residential buildings related to problems in the indoor and outdoor environments and services were investigated. The research also aimed to find a sustainable assessment method for evaluating residential areas and their services in Greater Khartoum. The location chosen for the case study was Greater Khartoum, which is classified into three towns: the capital Khartoum, Khartoum North, and Omdurman. The climate is described as a hot-dry climate, at a latitude of 15° 36' north and a longitude of 32° 3 east, with an altitude of 380 m above sea level. The temperature in summer ranges from 40 °C to 45 °C and drops to between 14 °C and 25 °C in winter. The rains range from 100 mm to 150 mm. The range of relative humidity is 40% to 60%. Greater Khartoum has been facing environmental and disaster such as floods, desertification, and rare earthquakes; nevertheless, there is a wide variety of natural vegetation in the lands around the River Nile.

## 1.1 Research Objectives

i. To introduce an assessment method for evaluating residential areas in the four urban classes (high income, medium income, low income, illegal areas) in the private sector in Greater Khartoum, based on sustainable principles.

ii. To study the infrastructure, energy and water utilities, and drainage systems for these neighbourhoods.

iii. To study the principles of sustainable design, environmental principles suitable for hot-dry climates, global environmental assessment methods for buildings, and conditions in Greater Khartoum.

iv. To present a methodology for evaluating the main categories and sub-issues.

v. To apply the research method to an urban sample in the El Taief Neighbourhood.

vi. To identify the fieldwork tools and procedures, method of documentation, method of analysis

vii. To present the results, in addition to appropriate criteria for selecting the case studies.

viii. To provide recommendations for sustainable ecological design in the areas of the study for Greater Khartoum, and to study the present situation and suggest modifications in regard to materials, water, energy, outdoor environments, site landscapes, and building forms.

#### 1.2. Literature Review

Passive solutions and environmental principles suitable to hot-dry climate

The research is defining sustainable-eco-building principles in relation to the environment; ultimately, we study all suitable solutions applicable to sustainable-eco-building and environmental comfort in hot-dry climates. The evaluations are based on a point scale, with a total of 125 points. As background, sustainable development started in 1992. Sustainable development is defined as development which meets the needs of the present, without compromising the ability of future generations to meet their own needs. The building design should be economical in regards to the costs of materials, building construction, maintenance, building equipment, and energy and water consumption, and there is a need to focus on socially connecting the building to the surrounding environment, e.g., by providing social services, recognising human health and safety needs, and improving the quality of life. In 2010, the Royal Institute of British Architects [1] considered the minimum key indicators for sustainability design and grouped them according to structures. The issues recommended for consideration were the land and ecology, community, health, materials, energy, and water [2]. Today, new concepts of architectural design have allowed us to greatly improve building energy performance, and to reduce the environmental impacts of materials used in buildings. The Leadership in Energy and Environment (LEED) group announced six main categories for sustainable design: sustainable site, indoor environmental quality, energy, water, materials, and innovation. In addition, there are many books discussing issues regarding sustainable design and eco-design principles. [3] also, discussed these issues in his book 'LEED Practices, Certification, and Accreditation Handbook'. [4] discussed the principles for designing eco-resorts, such as site selection and landscape, construction, energy management, water management, waste management, and climatic performance. Barrows (2009) discussed principles of sustainable design.

[5] and [6] discussed principles for ecological design, as follows: the solutions arise from the location; ecological accounting informs the design; the design is in accordance with nature; everyone is a designer; and nature should be made visible. [7] reviewed the literature on thermal comfort principles and design with reference to hot-dry climates. The author discussed basic thermal comfort principles, including the definition of thermal comfort, heat balances between humans and buildings, heat flows, time lags, human thermal balance, building thermal behaviors, building materials, and the importance of ceiling and wall insulation, along with six basic factors regarding thermal comfort. In their view, passive architectural design solutions were suitable for hot-dry climates, such as those based on urban planning control and spatial control, architectural element and component control, physical aspect control, and indoor/outdoor environment design control. They detailed three building components, and discussed the solutions, limitations, and risks of solar radiation and high air temperatures. [8] discussed landscaping and the implantation of traditional solutions such as passive cooling towers, courtyard systems, and controlled building forms, along with ventilation and orientation.

[9] used 'LEED-Neighbourhood Development', 'Building Research Establishment Environmental Assessment Method' BREEAM, and 'Comprehensive Assessment System for Built Environment Efficiency' systems for his study and discussed the social and economic needs of Greater Khartoum. He furthermore suggested including concepts such as energy, natural systems, materials, society, services, business, and creative design when evaluating sustainable projects in Greater Khartoum. [10] published a paper in the Journal of Sustainable Development comparing four global systems, and analysing the main categories of the global systems with corresponding weightings.[11] published a paper in an international conference regarding the built environment in London and discussed the low-cost housing in Greater Khartoum, New Deims, El Shabyia, the Al Iskan Project, and Elthora hara, based on comparisons in regards to size, area, design type, and house type. [12] published a paper entitled 'The Opportunities and Challenges for Sustainability in Old Neighbourhoods - A Case Study of Aburoof Neighbourhood in Sudan', showing the opportunities arising from sustainable communities. [13] discussed an urban sample in a Doha downtown neighbourhood, including discussions of mixed-use centres, mobility, land uses, and housing typologies. [14] PhD research discussed sustainable-eco buildings in Greater Khartoum. [15] The study was published as a book in 2019. [16] discussed sustainable eco neighbourhood in Greater Khartoum and introduce method of evaluation. [17] provide assessment method for livable, health and wellbeing community.[18]

discussed in his paper the case of Khartoum geography and environmental issues.[19] Dubai planning Center discussed Pearl assessment system for buildings and urban planning.[20] discussed in his paper Comparative Study on the Malaysian Sustainable Building Assessment Tools Among the criteria, energy, water, indoor and outdoor environmental qualities were given high priority with high credit and parameters allocation.

[21] A comparative analysis of sustainable building assessment methods. Sustainable Cities and Society, he results have shown that each of the methods separately does not assess all aspects of a sustainable building. Many assess energy and the quality of the interior environment, while few assess more recent social and economic aspects. [22] discussed Sustainable Building Assessment Tool in Slovakia; the study indicators respect Slovak standards and rules. Percentage weight of fields and indicators are determined on the basic their significance, according to multi-criteria decision analysis.[23] Ministry of housing in Khartoum provides Structure Plan KPP5 it applied until 2030, showing the new urban areas that considered the green urban planning, new center for Khartoum city.

[24] Analysis of the International Sustainable Building Rating System for Sustainable Development with Special Focus on Green Building Index Malysia(GBI).

Research questions:

Why do we need to introduce a new assessment method for the assessment of eco-buildings in Greater Khartoum?

The current global assessment methods were designed for specific environments and cultures and the social and economic problems of those communities; thus, this research highlights the need to study the environmental, social, cultural, and economic needs specifically concerning Greater Khartoum.

What are the suitable principles that could be considered for hot-dry climates?

## 2. Materials and Methods

The methodology of this research was an intensive study of the available assessment methods, which led to the rationalisation of a new evaluation method for testing a case study according to the nature of residential buildings in Greater Khartoum. This method was applied to all levels of urban classes. The methodology consisted of several steps, as follows.

(1) A review of previous literature regarding environmentally sustainable development and principles of ecological design was conducted, along with a review of the passive solutions suitable for hot-dry climates, and of the nature of case studies in such environments. The architectural, spatial, and infrastructure conditions were reviewed, along with the historical backgrounds of residential areas in Greater Khartoum, and the problems faced by them. A general review was conducted on the environmental assessment methods, physical assessment methods, quantitative and qualitative assessment methods, and sustainable assessment methods adopted in 1992. In addition, a new assessment method for evaluating residential buildings in Greater Khartoum was explained. The method for assessment was presented, and the passive solutions suitable to hot-dry climate were investigated, along with the principles of sustainable eco-buildings.

(2) A comparison between four sustainable building assessment methods was conducted during the research, and the results were published.

The Main Categories	BREBREEAN	LEED 1 V4	Australia System	Green	Star	Rating ESTIDAMA	AGSAS
Sustainable Site	0	•	•			0	•
Indoor environmental quality	0	•	•			0	•
Energy and atmosphere	•	•	•			•	•
Water Efficiency	•	•	•			•	•
Material and resources	•	•	•			•	•
Innovation in design	•	•	•			•	•
Regional priority	0	•	0			0	0
Management and operation	0	0	•			0	•
Transportation	•	0	•			0	0
Land Ecology	•	0	•			0	0
Urban community	0	0	0			•	•
Culture and economic value	0	0	0			0	•
Integrated developmen	t						
process	0	0	0			•	0
Natural system	0	0	0			•	0
Pollution	•	0	0			0	0
Health	•	0	0			0	0
Waste	•	0	0			0	0

Table 1. Main categories of global building assessment methods

Source: Khogali, Hind, 2016.

(1) The five global systems demonstrate similarities regarding the following factors: sustainable site, indoor environmental quality, building materials, energy, and water.

(2) Additional diverse categories were added for countries to solve specific local environmental, social, and economic problems.

(3) Lastly, within the context of Khartoum residential buildings, categories such as the outdoor environment, land ecology, and health and integrated development processes were considered as significantly useful.

(4) From the comparison, the main topics regarding the principles of sustainability were highlighted, i.e., sustainable sites, indoor environmental quality, materials and resources, energy, and water efficiency.

Why do we need to add a new sustainable assessment method suitable to Greater Khartoum?

The global sustainable building assessment methods were introduced in specific countries to solve specific local environmental, cultural, economic, and social problems. For instance, Australia introduced management, transportation, and land ecology programs, the 'ESTIDAMA' methodology considered livable communities and integrated design processes, and the 'Global Sustainability Assessment System' considered social and cultural issues. It is evident that all these countries have their own sustainable evaluation methods; although they have similarities, there are also different categories for solving their local social, economic, and environmental problems.

Accordingly, there was a need to add more categories to address local environmental, social, and economic problems. Thus, this study added three additional categories, as follows.

(1) Outdoor Environmental Quality: This category was integrated for its social and environmental impacts, as people use the outdoor environment for sitting, welcoming their guests, celebrating, and sometimes sleeping during hot summers. In addition, the study added solutions such as the use of canopies, terraces, areas with shade, plants and trees, and fountains to cool the air surrounding the buildings.

(2) Building Form: This category was included for its economic and environmental impacts. studying a building form with a solar angle provides more shade to the building and cools the air around the building; for energy

efficiency, studding the windows, vertical and horizontal sunscreens, wind towers, and courtyard system was shown to be more effective.

(3) Environmental design process: This category was added for two reasons: to control the entire design process including the eight categories, and for educational reasons, i.e., to educate architects, engineers, and the community regarding sustainability.

• The method of assessment used in the study was presented according to the main categories, the sub-issues, and the scale of evaluation, and then the criteria were determined for selecting the case studies, fieldwork tools, documentation, and analyses, based on interviews with owners and specialists.

• The fieldwork was conducted, including a survey to evaluate 48 case studies in different areas in Greater Khartoum, and the collected data was documented, presented, and demonstrated in tables and figures; in addition, it was analysed using computer programmes.

• Discussions and analyses based on the study method of assessment were conducted for all areas considered in the study, and then the average results for the main categories of the case studies were analysed and discussed for all areas of the study in Khartoum, Khartoum North, and Omdurman. These were followed by a discussion aiming to arrive at conclusions.

• General conclusions applicable to residential buildings in Greater Khartoum were determined, and suggestions were provided for areas requiring further study, along with recommendations for future research.

## 3. The Results

Figure 1 and Table 2 provide the results of the research on sustainable eco-buildings in Greater Khartoum. The categories and their proportions are as follows: sustainable site at 40%, indoor environmental quality at 33%, outdoor environmental quality at 41%, building forms at 15%, materials and resources at 22%, drainage system and water supply system at 20%, power supply system at 7%, and environmental design process at 25%. The research outcomes show that the sustainable site, indoor environmental quality, and outdoor environmental quality categories show 'Pass' results, i.e., between 35–40 % points, and the other categories show 'Weak' results (less than 35%).

Figure 10. Average results for all categories in selected areas in Greater Khartoum.

									Average for	
Thae Main Category	El Taie	fKhartoum 2	Al Sahafa	Illegal Area	sKafoori	Al Shabia	Al Rouda	Al Mouradfa	Greater	Evaluation
									Khartoum	
Substaminale site	51	64.6	27	23	55	22	52	28	40	Pass
Indoor Environnemental	20	47.0	27	12	41	27	42	2(	22	n
Qualité	38	47.8	27	13	41	27	42	26	33	Pass
Outdoor Thermal	64	55 (	14	11	70	25	70	0	41	P
Control		64	55.0	14	11	/8	25	13	0	41
Building Form	14	24.8	16	13	18	13	13	13	15	Weak
Materials and Resources	28	29.6	15	12	36	15	30	13	22	Weak
Drainage System and	20	22.14	25	0	22	25	10	17	20	XX7 1
Water Supply System	29	23.14	25	0	23	25	19	17	20	weak
Power Supply	9	10.584	7	7	7	7	6	7	7	Weak
Environme-ntal										
Substamina-le Design	32	36	19	11	35	19	33	16	25	Weak
Process										

Table 2. Conclusions of the discussions of the average results for all categories on the selected areas of the study in Greater Khartoum

Source: adapted by the researcher.



Figure 1. The average results for all categories on the selected areas of the study in Greater Khartoum Source: Adapted by the researcher

#### 3.1 Water

The results for water show that the first- and second-class buildings in the El Taief neighbourhood obtain water from the National Grid, whereas the other locations (third and fourth class) obtain available underground water.





Source: adapted by the researcher

#### 3.2 Energy

The results show that energy is available from the National Grid for all urban classes, although limited solutions were found for solar energy systems.



Figure 3. The average results for the power supply category in the areas of the study in Greater Khartoum Source: adapted by the researcher.

### 3.3 Outdoor Environment

The El Taief neighbourhood has limited outdoor open spaces; there is an open space used for praying during Eid's vacations at the centre, near the large Al Swahli mosque.



Figure 4. The average results for the outdoor environmental quality category in the areas of the study in Greater Khartoum

Source: adapted by the researcher.

#### 3.4 Environmental Design Process

40%, building phase is applicable by construction companies, 40% is applied during the operation and the maintenance is applied during the post building phase by 20%.



Figure 5. The general conclusions of the average results for the environmental design process category in the areas of the study in Greater Khartoum

Source: Adapted by the researcher.

The results show that The results presented indicated that 19% were Good, 25% were Pass, and 56% were considered 'weak'. The conclusions and recommendations regarding urban housing services can be applied to sustainable ecological neighbourhoods.

The energy and water are applied from the National Grid, most of the buildings used the local building materials, used of natural ventilation ad passive solutions.

## 4. Discussion

## 4.1 Study Method of Assessment

This study reviewed different environmental assessment methods (including sustainable assessment methods) and identified five main principles for the study assessment method. The previously reviewed literature discussed passive solutions suitable to hot-dry climates, identified building forms, outdoor environment, and environmental design processes, and detailed the main principles of sustainable eco-buildings. In summary, the main categories for the study's method for assessment are sustainable site, indoor environmental quality, outdoor environment, water efficiency, energy efficiency, building materials and building form, and environmental design process. The method is explained more fully below.

## 4.2 Development of Study Method of Assessment

The assessment method of was developed using different methods, as follows:

(1) By conducting an intensive literature review in study, including on the principles of sustainable development, principles of environmental design in urban components, architectural components, spatial aspects, physical aspects, outdoor and indoor environments, as well as by studying previous assessment methods and critically analyzing them.

(2) Five global assessment methods for sustainable buildings were analyzed, and the main categories for the sustainable assessment methods were identified, such as sustainable sites, indoor environmental quality, materials, energy efficiency, and water efficiency.

(3) After studying the environmental conditions in Greater Khartoum, the study identified three categories suitable for the hot-dry climates: the building forms, outdoor environmental quality, and environmental design process.

(4) Some sub-issues were considered to support the research method for assessment in the field of sustainable buildings (see Appendix-6). These issues were the importance of the materials in roof, walls, floors, and décor, as

shown in the evaluation method; in addition, the use of air conditioning was considered as a negative (-1 point), because it has a negative impact on the environment.

(5) Some solutions were included when reviewing literature on traditional solutions, such as the use of courtyard systems, wind towers, domes, and vaults, as well as their effects on absorbing solar radiation.

(6) Other solutions were also included based on practical experience, such as the use of vertical and horizontal sunscreens, orientating buildings at 45°, and the use of wells and septic tanks in drainage systems.

(7) Both global and regional technological solutions were introduced; these use energy simulation programs to achieve energy efficiency and use IBM software to develop eco-building designs in computers.

(8) The local natural resources for wind energy, solar energy, and eco-building materials were studied and imposed in the research method.

*4.3 Scale of Evaluation* 

The scale shown in Table 2 was used to evaluate each issue regarding residential buildings in Greater Khartoum.

Table 3. Scale of evaluation used in this research. These points were incorporated according to the predicted mean vote and scale index.

#### Table 3. The scale of evaluation

The Mandatory	y Meaning	Points Given for Evaluation
Positive	Means it's applicable	From 1 to 2
	Positive impact on the environment	1
	More Positive impact on the environment	t 2
negative	Means it's not applicable	0
	Negative impact to the environment	-1
	Too negative impact to the environment	-2

Source: adapted by the researcher.

#### 4.4 Method of Evaluation

The suggested sustainable-eco-building evaluation method for hot-dry climates (such as the climate in Greater Khartoum) was applied in this research to eco-buildings for 48 case studies in Greater Khartoum.

The designed sustainable-eco-building evaluation method was suitable to the local environment in Greater Khartoum. It contained eight main categories: sustainable site, indoor environmental quality, building form, outdoor environment, materials and resources, drainage system and resources, water supply and drainage system, power supply system, and environmental plan process; the maximum number of points that could be scored was 125. The difference between this method and other approaches was that it included three other separate main categories, i.e., outdoor thermal control, building form, and environmental process. This method also considered five main evaluation ranges for points, as follows: < 40 Weak; 41–44 Pass; 45–59 Good; 60–75 Very Good; and 76–125 Excellent.

These levels of evaluation were included in the British standards of green buildings, i.e., BREEAM uses the same categories for evaluation (weak, pass, good, very good, and excellent).

The sustainable-eco-buildings assessment method (SEBAM) was applied to the 48 samples in different urban classes in Greater Khartoum, after a wide-ranging review of the environmental assessment methods and suitable passive solutions for hot-dry climates. The method combines the main sustainability categories and passive solutions, while considering the environmental, spatial, architectural, residential, and technological conditions of the case studies. Table 4 shows the main categories of the assessment method.

Item	Category	Symbol	No. of Points
1	Sustainable Site	SS	13 points
2	Indoor environmental control	IEQ	34 points
3	Outdoor thermal control	OTHC	9 points
4	Building form	BF	8 points
5	Materials and Resources	MR	34 points
6	Water supply and drainage system	(DS&WS)	16 points
7	Natural power supply	NPS	15points
8	Environmental design process	(EDP)	1 point

4.5 Main Categories of the Method of Assessmen	t
Table 4. Main categories of the assessment method	od

Source: Hind Khogali, 2019.

#### 4.5.1 Sustainable Site

The sustainable site category concerns issues outside the building, i.e., the land that is being developed, and the surrounding community. Appendix-5 shows the total points requirement for a sustainable site, i.e., 12 points, equal to 10% of the maximum 125 points. These 12 points are based on the main content of the sustainable site category, including its sub-issues. They are: site selection (1/12), equivalent to 0.083; construction system (3/12), equivalent to 0.25; controlling systems (3/12), equivalent to 0.25 and including parking control, construction activity control, and natural water features; alternative transportation (3/12), equivalent to 0.25 and including public transportation access, bicycle storage, and low-fuel emission; improved thermal environment (2/12), equivalent to 0.16 and including maximized open space and enhanced landscaping on site; and the study of the heat island effect (1/12), equivalent to 0.083. For the applied assessment method, each sub-issue scores one or two points according to its importance and positive impact on the environment.

#### 4.5.2 Indoor Environmental Quality

The indoor environmental quality category concerns the materials and systems inside the building that affect the health and comfort of the occupants and construction workers. The indoor environmental quality category comprises 7 sub-issues. Appendix-1 and Appendix-2 provide details on the assessment method, and Appendix-5 addresses the requirements and benchmarks for the main categories of the assessment method. The total points which should be achieved in this category are 30/125, which is equivalent to 24% of the overall total. These 30 points come from the detailed content of the main issues and sub-issues concerning indoor environmental quality. The first issue is the building orientation (4/30), equivalent to 0.13; it includes a building orientation to the northsouth direction (1/30), equivalent to 0.03, or to the east-west direction (2/30), equivalent to 0.06. The second issue controlling the building dimensions by applying surface volume ratios; these should be between 0.12 to 0.16, to avoid excessive solar radiation on the building (1/30). The third issue is the roof thermal control (5/30), equivalent to 16.6%; it includes the roof thermal insulation (1/30), white colours (1/30), double roofs (2/30), and green roofs (1/30). The fourth issue is the wall thermal control (12/30), equivalent to 0.40; it includes building materials (1), windows (5) equivalent to 0.16, shaded devices (4/30) equivalent to 0.13, wall paints and colours (1), and green walls (1). The fifth issue is the floor thermal control (1/30), i.e., choosing a floor finishing material from an ecofloor material manufactured from recycled construction building materials such as concrete, stones, bricks, or ceramics, as well as one that has long-term durability, is easy to clean and maintain, and is resistant to pressure, slipping, heat, and moisture. The recycled content is suitable for most residential buildings. The sixth issue is the design of the thermal comfort (4/30), equivalent to 0.13; it includes the individual thermal comfort (1/30), controlling the natural ventilation, e.g., by maximising the windows (1/30), using traditional solutions such as wind towers (1/30), and a courtyard system (1/30) that improves the air movement and temperatures in buildings. The seventh issue is supporting these solutions by mechanical means (3/30), equivalent to 0.10, such as by using fans, desert coolers or heating, ventilation, and air conditioning systems, which help in controlling the air temperature and humidity, and filtering dust from the air. These solutions vary in different residential areas. However, the use of air-conditioning systems is evaluated as -1 point, because it has a negative impact on the environment. Each sub-issue scores one or two points according to its importance and positive impact on the environment.

## 4.5.3 Outdoor Thermal Control

This study adds the outdoor thermal control category. The details of the sub-issues for the outdoor thermal control category are as follows. The total points achieved are 9/125 points (equivalent to 7%); this number arises from the detailed issues and sub-issues of the outdoor thermal control category. Each sub-issue scores 1/9 points (equivalent to 0.11) or 2/9 points (equivalent to 0.22), according to their importance and positive impact on the environment. People in Greater Khartoum are aware of the outdoor environment, as the climate is hot and dry. They spend part of their time in gardens, especially at night; these are also utilised during holidays and celebrations. The first issue concerns providing shade to the building in the north-south direction (2/9). The second issue concerns providing shade in the east-west direction (1/9). The third issue concerns providing shade using balconies (1/9). The fourth issue concerns building fences to protect the site from dust (1/9). The sixth issue concerns building swimming pools (1/9). The seventh issue concerns installing fountains to change the dry climate into a humid climate (1/9), and/or installing built outdoor terraces (1/9).

## 4.5.4 Building Form

The building forms category was added to the five main categories in this study, as it is important to study the relationship between the solar angle and building form; then, it is possible to choose the best solution for giving the most shade to the building. This helps in cooling the air surrounding the building. The total points to be achieved are eight. Each sub-issue scores one point, according to its importance and positive impact on the environment.

Although LEED V4 did not add building forms as a separate category, the United States Green Building Council (U. S. G. B) (2014) suggested as follows: 'provide shade from structures covered by solar panels that produce energy used to offset some non-renewable resource use[;] provide shade from architectural devices or structures that have a solar reflectance index SRI of at least 29[; and] implement a maintenance program that ensures these surfaces are cleaned at least every 2 years to maintain good reflectance'. This was added under the sustainable site category in LEED V4 and LEED V3. Further, the U. S. G. B. (2014) mentioned, 'naturally ventilated buildings must comply with a local standard that is equivalent to ASHRAE Standard 62.1–2007'.

There is no specific category or sub-issue addressing building forms. It is essential to investigate building forms to control the building shade and natural ventilation through the building orientation. The total points for building form are 8/125 points, equivalent to 6.4 %. These eight points come from the detailed sub-issues. The research draws on details such as the linear forms (1/8, equivalent to 0.125), U-shaped forms (1/8), L-shaped forms (1/8), cubic forms (1/8), circular forms (1/8), courtyard systems (1/8), use of vaults (1/8), and use of domes (1/8).

#### 4.5.5 Materials and Resources

The materials and resources category includes 13 sub-issues, with a total of 34 points, equivalent to 27% of the overall total. Each sub-issue scores one or two points, according to its importance and positive impact on the environment. In particular, 34 points come from the detailed issues and sub-issues of the building materials category. The first issue is the material used in the base, e.g., bricks, cement, gravel, and stone (6/34), equivalent to 0.176. The second issue is the material used in the walls, e.g., bricks and stone (9/34), equivalent to 0.264. The third issue is the material used in the roof, e.g., cement, bricks, and wood (3/34), equivalent to 0.088. The fourth issue is the materials used in finishing, e.g., wood and carpet (5/34), equivalent to 0.147. The fifth issue is the vall claddings (1/34), equivalent to 0.029. The seventh issue is the indoor décor (3/34), equivalent to 0.088. The eighth issue is construction waste management (1/34), equivalent to 0.029. The ninth issue is calculating the embodied energy (1/34), equivalent to 0.029. The tenth issue is a life cycle analysis (1/34), equivalent to 0.029. The eleventh issue is adopting technologies (1/34), equivalent to 0.029. The twelfth issue is applying regional materials such as wood and stones (1/34), equivalent to 0.029, and the thirteenth issue is low-emitting building materials (1/34), also equivalent to 0.029.

#### 4.5.6 Water Supply and Drainage System

The water supply and drainage system category have seven sub-issues. The total points that should be achieved are 16/125 points, equivalent to 12.8%. These 16 points come from the detailed issues and sub-issues of water supply and drainage system. Appendix-1 provides details on the sub-issues of the water supply and drainage system. Each sub-issue scores one or two points, according to its importance and positive impact on the environment.

The first issue is choosing the appropriate technology for the drainage system (5/16), equivalent to 0.312. The second issue is studying the water source (3/16), equivalent to 0.187. The third issue is the water efficiency (4/16), equivalent to 0.25. The fourth issue is the rainwater container (1/16), equivalent to 0.062. The fifth issue is the grey water recycled at the site location (1/16), equivalent to 0.062. The sixth issue is the reduction in water usage (1/16), equivalent to 0.062. The seventh issue is the use of 'water sense'-labelled products (1/16), equivalent to 0.062. Most urban areas of Khartoum use septic tank and well systems, because there is no net drainage system available in most of these new urban areas. Each system (well and septic tank) is connected to an artesian well, which is usually at a depth of approximately 50 m, or at the underground waterbed. This system needs regular cleaning to secure a continuous water flow and to avoid clogging. Considering the ever-present risk of floods during the rainy season, regular maintenance is essential to guaranteeing an efficient system.

#### 4.5.7 Power Supply System

The power supply system category has four sub-issues for a total of 15/125 points, equivalent to 12% of the overall points. These 15 points come from the detailed issues and sub-issues of the power system. Appendix-1 provides details on the sub-issues of the power supply system category. Each sub-issue earns one or two points according to its importance and positive impact on the environment.

The first issue is studying the source of energy, i.e., an eco-building should provide natural resources such as solar energy and wind energy (6/15); this issue is equivalent to 0.4. The second issue is energy efficiency (1/15), equivalent to 0.06. The third issue is studying the applications (5/15), equivalent to 0.33; in Khartoum, sunshine is adequate year-round, and can be utilised as a source of power in all buildings for various activities, including lighting, cooking, heating, cooling, and storing energy in batteries. The fourth issue is adaptive technologies such as photovoltaic technologies, using simulations and energy smart panels (3/15), equivalent to 0.20. All these together total 15 points.

## 4.5.8 Environmental Design Process and the Emissions

The main scope of the design is to apply the sustainable categories to the entire design process. The term 'holism' has been used to describe the view that a whole system must be considered rather than simply its individual components, as shown in Figure 1. The Vales team addressed this point in their book 'Green Architecture' and suggested that a building should attempt to address all of the principles of green design in a holistic manner (Hide, 2008). Architects should consider the eight categories of this study's method of assessment for application to the design process at all design levels. The total points in this category is one (1/125), equivalent to 0.008.

(1) Pre-building phase: The pre-building phase is the design phase for the primary, developed, and final designs, and is based on adopting sustainable eco-building categories as its main goals. Apply solutions to minimize the  $CO_2$  emissions inside the buildings and in the neighbourhood.

(2) Building phase: The building phase is for the construction and system operations. The level concerns contractors and suppliers, applying appropriate technologies in mechanical systems, waste disposal, and noise control.

(3) Post building phase: This phase concerns the users after the construction of the building. The building should be maintained regularly to guarantee a long life and durability. The building should be evaluated using appropriate methods of assessment. These levels can be identified after a review of the previous methods, such as in BREEAM (2014), where < 40 points indicates 'weak', 40–44 indicates 'pass', 45–59 indicates 'good', 60–75 pts indicates 'very good', and 76–132 indicates 'excellent'. The more points, the higher the building's eco-sustainability.



Figure 6. The environmental design process on the level of eco-building

Source: adapted by the researcher.

The research method was applied to eight neighbourhoods in Greater Khartoum. The research focused on the El Taief neighbourhood based on analysing the physical aspects, accessibility, services and mixed-used centres, and housing types.

## 4.5.9 Fieldwork

This section explains the procedure adopted for the fieldwork in the selected areas of the case studies representing different areas in Greater Khartoum. The duration of the study was from 2015 to 2017. The fieldwork results are presented, starting with a presentation of the case studies and selected samples, and then the application of the sustainable-eco-building assessment method of this research (see Appendix-2) to the 48 case studies. Subsequently, a general summary of the information for each case study is given. The results are presented in figures, tables, pie diagrams, and photos.

The survey was conducted in the following residential areas in Greater Khartoum: Eltaief in Khartoum (eight case studies), Al Sahafa middle (eight case studies), Khartoum Two (five case studies), as well as in the illegal areas in West Sarya (three case studies); Kafoori, Khartoum North (five case studies), and Al Shabia (seven case studies); in Omdurman in Al Rouda (five case studies), and in Al Mourada (seven case studies). Thus, the total number of case studies was 48. The method of presentation of these samples was in photos, and short notes and documents regarding each house were written, including information regarding the name of the owner, plot size, built-up area, construction starting date, and construction ending date. Documentation was generated regarding the main categories of sustainable design identified in chapter two and discussed in chapter six, i.e., concerning the energy used, water, material, indoor environment, outdoor environment, and infrastructure. This was followed by summarising the information regarding these specific main categories in tables and figures for each house of the case studies. Figure 2 shows the locations of the case studies in Greater Khartoum. Figure 2: Satellite photographs showing general layout of the selected neighbourhoods (Source: Google maps).



a. Greater Khartoum



d. Al Sahafa /Khartoum



g. Al Rouda/Omdurman



#### Samples' Random Selection Techniques

(1) The case studies were divided into four groups, according to their date of origin (see Table 5).

(2) Group one covered the period from 1992 to 2017 in El Taief in Khartoum, Kafoori in Khartoum North, and Al Rouda in Omdurman, with a plot area variation from 400 m2 to 600 m2.

(3) Group two covered the period from 1951 to 1992 in Khartoum, with plot areas from 800 m2 to 400 m2.

(4) Group three covered the period from 1953 to 1963 in Al Sahafa middle, Al Shabia, and Al Mourada.

(5) Group four covered the illegal residential areas in West Sarya that have been extending over time; these are unplanned areas.

(6) The samples covered different building types, e.g., villas, apartments, and single houses.

(7) They were designed by specialists or consultant architects and were built by sub-contractors.

(8) They were attractive solutions, owing to their ventilation, orientation, and window design; this study investigated in greater detail, by applying the SEBAM.

(9) Samples were selected for the following purposes:

Studying the indoor environment, e.g., windows, ceilings, walls, floors, ventilation, and lighting.



b.El Taief /Khartoum



e. Kafoori /Khartoum North





c. Khartoum two/Khartoum



f. Al Shabia/Khartoum North



I. Illegal areas in Khartoum

h. Al Mawrada/Omdurman Figure 7. Satellite photographs showing general layout of the selected neighbourhoods (a-i)

- Studying the outdoor environment, e.g., parking, gardens, fountains, swimming pools, fences, and terraces.
- Studying technical solutions for services such as water supply, waste management, and drainage.
- Studying the building materials, including recycled and eco-building materials.

Table 5 shows the total number of houses in each neighbourhood and sample size. Note that the total number of houses was counted from Google Earth, 2019

Table 5. Total number of houses in each neighbourhood and sample size, as counted from Google Earth, 2019

Croups	Town	Name of the	Number of	Number of Houses in	Sample	Sample
Groups	TOWI	Area	the Samples	Each Neighbourhood	Size	Size %
	1.1 Khartoum	El Taief	8	1000	0.008	0.8%
	1.2 Khartoum	Khartoum 2	5	1000	0.008	0.8%
1.Khartoum	1.3 Khartoum	Al Sahafa Wasat	8	2000	0.004	0.4%
	1.4 Khartoum	Illegal, East and West Sarya	3	300	0.01	1.0%
2.Khartoum North	2.1 Khartoum North	Kafoori	5	500	0.01	1.0%
	2.2 Khartoum North	Al Shabiya	7	1000	0.007	0.7%
3.Om- Durman	3.1 Omdurman	Al Rouda	5	500	0.01	1%
	32 Omdurman	Al Mawrada	7	500	0.01	1%
			48	6800 sample house	0.007	0.7 %

Source: Hind Khogali, 2019.

Sample size = number of selected samples /Total number of houses

=48/6800

= 0.7 %

This sample size does not meet the 95% confidence level statistically; more than 200 samples are required for that achievement. The limitations of the sample size are addressed below.

Limitations of sample size

The limitations of the sample size are owing to several reasons, as follows.

(a) The samples of this study include different types of residential buildings including houses, villas and apartments from different areas in Greater Khartoum, including first-class, second-class, and third-class areas, along with illegal areas.

(b) Larger sample sizes provide more accurate and meaningful results and give more power to the study.

(c) However, in this the research, there are some reasons for the limitations of the sample size, as follows.

(1) The economic reason, i.e., the larger sample size of the survey, the greater the costs for transportation and analysis.

(2) It is difficult to enter the illegal areas alone, because it is not safe, owing to conflicts.

(3) Owing to the limited solutions for the SEBAM, the same results were found for the same groups, i.e., the buildings in the first group obtained results between 40 to 50, whereas buildings in the third group obtained results between 20 to 30, and the illegal areas obtained results between 16 and 17. In contrast, Scott, 2016 stated that 'the mean value of a continuous outcome variable in one group differs significantly from that in another group from that in another group'. (Scott, 2016).

(4) Logistical reasons, e.g., large surveys are usually conducted by teams, not individuals.

## Samples from the Case Studies

One house considered in this study was constructed during the period 2002–2007 in the El Taief neighbourhood. Abdall Mohammed Mualla designed the house using glass and aluminium mixed with the traditional Islamic style (e.g., Mashrabia and arches). The architect used a linear form, and the building was oriented towards the north-south direction. The architect used a solar heating system. There are many elements representing shade; for example, there are balconies oriented to the north, and to an east-south direction. Ventilation is maintained through large windows directed towards the north-south direction, whereas the other small windows are oriented towards the east-west direction. The outdoor environment is well-designed and includes a large garden, in addition to high fences, shaded and isolated car parking, and large terraces (see Figure 8).



Figure 8. Sample 5, plot 910, block 22, El Taief. Table (a), Figure (b), Pl (c), Pl (d), Pl.(f) and Pie (e) show the results of sample 5

Source: adapted by the researcher.

#### El Taief Neighbourhood

For all study purposes, eight samples were selected from El Taief neighbourhood. These areas were located in the middle of squares 23 and 22 in Khartoum, and three samples were located on the Abdella El Taieb Street. (See Figure 8.). The area shows a shortage in water supply, and the water is sourced from the 'National Grid'. The majority of people living in this neighbourhood use water recycling, and present high-water efficiency. The drainage systems are private, consisting of septic tanks and wells. The area sources its energy from the National Grid. The area has maximised outdoor spaces, so as to provide sufficient space for gardens. A wide range of

building materials is used in building construction, such as bricks, gravel, sand, and cement. Ceramic tiles, marble, and porcelain tiles are used to finish floors. Cement tiles for the outdoors, and wood for roll-up window shutters are also evident. The buildings are constructed with reinforced concrete. Figure 9 shows the urban sample for the El Taief Neighbourhood in Khartoum.



Figure 9. Shows the urban sample El Taief Neighbourhood in Khartoum

#### 1. Historical background

Figure 10 depicts the developments in the population, urban classes, and master plan in Greater Khartoum, as follows:

a: shows that the population in the El Taief neighbourhood is approximately 2000 > 4000 (Eltayeb, 2001)

b: shows the urban classes in Khartoum; the El Taief neighbourhood is classified as third-class, according to a Ministry of Housing survey in 1999 (Eltayeb, 2001); and

c: shows the fifth and last Greater Khartoum master plan in 2010, including the El Taief neighbourhood housing area (Ministry, 2010). Figure 5: Developments in population, urban classes, and master plan in Greater Khartoum.



Figure 10. The development in population, urban classes, and master plan in Greater Khartoum

## 2. Analysing physical aspects of El Taief neighbourhood

The Al Taief neighbourhood is a new urban community that has existed since 1990. From the physical visualization Figure 11, one can see a specialised hospital, Cambridge schools, the Al Swahli mosque, the Al Swaidi community hospital, the Djibouti Embassy, the Marshal Natural Reserve, and a mixed-use centre for everyday requirements near the Al Swahli Mosque.



Figure 11. Physical aspects of El Taief neighbourhood

#### 3. Social aspects

• Various housing typologies are proposed, based on the study of the demographic structures of the neighbourhood. People are from different places in El Taief Neighbourhood.

• Limited outdoor open spaces are available for people, as there are no green parks or green outdoor spaces in the El Taif neighbourhood; people often travel for 500 m to A Riyadh park.

• There is one large open space at the middle near the large Al Swahli mosque; it is used for praying during Eid's vacations.

• Building typologies are provided that meet the future vision of the neighbourhood, such as residential compounds.

4. Mixed-use centres and services

The mixed-use centre is used for everyday requirements like shops (e.g., for vegetables and fruits), pharmacies, mosques, and hospital centres, and pays water and electricity bills; in addition, there is open space used for praying during Eid's vacations. The energy and water services are provided from the respective parts of the National Grid,

and waste management is provided by a local service in the El Taief neighbourhood. Figure 7: Mixed-use centre in the El Taief neighbourhood near the Al Swahli mosque.



Figure 12. The mix use centre in Eltaief neighbourhood near Al Swawli mosque

#### 5. Mobility

The cluster pattern is a rectilinear pattern with squares and rectangular shapes with perpendicular angles, and with a plot area of 500 m2–800 m2. The main streets surrounding El Taief neighbourhood are shown in red in Figure 8. The main streets are 30-m wide, and there is an intermediate Al Nekheel street for services (20 m wide). All internal roads are walkable streets, and cars can move on the narrow 10-m wide roads. There is no pedestrian pavement on the streets and roads. Figure 8: El Taief street pattern.



Figure 13. Shows Al Taief streets pattern

#### 6. Building Types

Housing diversity is a significant social parameter for investigating land use dynamics, and refers to a mix of housing that supports socially cohesive communities, while enabling efficient urban operation. Housing diversity is often viewed in terms of income level and age. Different building types are used in the El Taief neighbourhood, including: (a) a high-rise building with seven floors, where the ground floor is used for shops facing the main street; (b) a building with four floors building used for medium-income flats; and (c) a medium-rise building in which the walls are covered by aluminium sheets, and the ground floor is used for shops facing the main road. In addition, types (d), (e), and (f) are private villa types with one or two floors. Most of buildings in El Taief are

private villas, comprising approximately 70% of the housing, and the other 30% are the high-rise buildings facing the main streets (for commercial reasons). Figure 14. shows Different types of buildings in El Taief neighbourhood.



Figure 14. Shows different types of buildings in El Taief neighbourhood

## 6. Conclusions and Recommendations

## 6.1 Recommendations Regarding the Proposed Evaluation Method

This research recommends that the proposed evaluation method should be reviewed and developed by industry academics and professionals; with their approval, it could be implemented by the Ministry of Housing and Urban Planning. Consequently, the advantages and benefits from the application of this research method for assessment could be apparent from the application of all recommended solutions, as suggested in the SEBAM studies on the 48 samples (See Appendix-1 and Appendix-5). Moreover, when leveraging this assessment method proposed in the study, the architectural field can immensely benefit, e.g., by providing sustainable and ecological building, and by constructing healthy, economical houses.

The research recommends that architects and professionals propose recommendations for a larger survey on the building materials, energy efficiency, water efficiency, building form, site, and indoor and outdoor environment.

#### 6.2 Recommendations for Applying Sustainable Eco-buildings and Eco-neighbourhoods in Greater Khartoum

For accessibility, all plot areas should be near a public transportation axis. The site should provide protocols, construction activity control, noise prevention, and waste management. The site should also have good landscape management, e.g., solar lighting control for all streets, and/or pedestrian pavement for walking and bicycles.

The heat island effect should be studied in the context of the strategic positioning of plant trees and the use of light colours.

The open spaces at the house unit level should be provided with controlling shades, cantilevers, and canopies. The number of outdoor spaces at the middle of each cluster should be increased, and parks should be provided for families and children within a walkable distance in the El Taief neighbourhood.

Water features should be added, e.g., a humidifier could be built to humidify the air surrounding the building.

Tree and vegetation cover should be maintained in all areas of the study, i.e., to improve the air conditions from dry to humid.

The environmental design process should be applied in the three design phases, to provide educational value.

Minimize the  $CO_2$  emission in the neighbourhood by applying more trees encourage people to use bicycles, minimize the use of cars.

Insulation should be used in the in the roof and walls.

Construction materials for buildings should be provided from the local environment.

Recycled materials should be used whenever possible, especially for outdoor areas. Ecological carpets and suspended ceilings are recommended in the indoor environments.

The water efficiency should be increased by adopting the standards of the World Health Organisation.

A distribution network should be adopted for the sewerage systems in all residential areas. In addition, the use of septic tanks and wells should be minimised (and the existing ones should be properly maintained), as they are contamination threats to underground water.

Relevant solutions should be applied for sustainable ecological buildings, such as the recycling of grey water and rainwater collection.

Natural energy resources (such as solar energy) should be applied in different applications, such as for solar heating, solar cooking, and solar photovoltaic technology.

It is strongly recommended to add educational value to increase the knowledge of the community and teach students, architects, designers, and people regarding sustainable and ecological building, e.g., through lectures, workshops, conferences, and courses corresponding to the main categories.

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