Developing a Green Building Assessment Tool for Ethiopia

Mekonnen Abebe Anshebo,*, Wubishet Jekale Mengesha, Daniel Lirebo Sokido

Addis Ababa Science and Technology University, College of Architecture and Civil Engineering, Department of Architecture, Ethiopia
Addis Ababa University, Ethiopian Institute of Architecture, Building Construction and City Development, Chair of Construction Management, Ethiopia
Ethiopian Civil Service University, College of Urban Development, Ethiopia

HIGHLIGHTS

- The study identified eight assessment categories and sixty-seven criteria.
- The assessment categories have a CR of 0.07 and 0.1 and are considered consistent.
- The Ethio-SBAT was developed after considering the local context.
- The award points for the buildings that will be examined have been determined.

ARTICLE INFO

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ABSTRACT

Sustainable/green building rating systems are utilized by both developed and developing countries based on their local context. This paper aims to develop an assessment tool that considers the triple bottom line sustainability of buildings. In Ethiopia, buildings of various types and purposes are constructed at an alarming rate with inadequate resources and wasteful uses, so this tool is in urgent need. Developing such a tool is highly appreciated due to the diversified and complicated ecological and socio-economic issues in the building construction sector. This research has developed new green building assessment categories and criteria depending upon consensus reached with 93 experienced experts working on the construction sectors. This research reviewed a total of 10 widely and repeatedly used tools that were critically studied, for instance, Leadership in Energy and Environmental Design, Building Research Establishment Environmental Assessment Method, Comprehensive Assessment System for Building Environmental Efficiency, Deutsche Gesellschaft für Nachhaltiges Bauen, Sustainable Building Tool, and so on. The Analytic Hierarchy Process technique was applied for weighting and prioritizing after selecting these assessment categories and criteria. The outcomes of the research with the relative priority values were materials and resources (18.66%), sustainable sites and ecology (16.92%), energy efficiency (16.78%), indoor environmental quality (12.60%), economic aspects (10.41%), management (10.30%), water efficiency (8.06%) and location and transportation (6.27%). Thus the proposed sustainable building assessment tool that best suits Ethiopian settings was developed.

1. Introduction

Green building philosophy is derived from the term “Arcology” which stands for a combination of architecture and ecology [1]. It addresses environmental and health problems as well as minimizes the effects of the construction sector on the natural habitat and individuals. Green buildings are also more energy-efficient so that the adverse effect of building on the environment and inhabitants is reduced.

The built environment, including building, operating, and management normally require enormous amounts of energy, water, and raw materials, generating large quantities of waste and causing air and water pollution. The only solution is to develop greener and more resource-efficient construction, renewal, operations, and maintenance strategies [2].

The application of the theory of high-performance buildings in the construction sector is indispensable as it prioritizes environmentally responsible and efficient resource allocation to the building's whole lifecycle. Green buildings can save 36% of total energy consumption, 65% of electricity consumption, 30% of greenhouse gas emissions, 30% of raw material consumption, 30% of waste output, and 12% of potable water consumption [3].

* Corresponding author.
E-mail address: mekonnen.abebe@aastu.edu.et (M.A. Anshebo).

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Presently, several assessment techniques exist worldwide and are utilized both by developed and developing countries depending on their local contexts for the evaluation and certification of these buildings. Some of these tools are CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) and BREEAM (Building Research Establishment Environmental Assessment Method), LEED (Leadership in Energy and Environmental Design), SBTool (Sustainable Building Tool), etc. The concern of standardization to the built environment has also improved, as noted under [4, 5, 6, 7, 8].

Ethiopia’s buildings are not critically assessed and evaluated from a sustainability perspective because there are no such types of studies conducted so far. No institution is responsible to evaluate and certify the buildings (both new and existing) but still, they are being constructed at an increasing rate.

Ethiopia is in urgent need of using green design practices for enhancing the environmental, social, and economic performances of both existing and new buildings. Preparing an evaluation techniques intended for the Ethiopian context is indispensable; such a tool is urgently needed. Therefore; this study has prepared the proposed allocated points and awards for the buildings to be assessed were < 40 points: Certificate with Not Green rank; 40–59 points: Certificate with Green rank; 60–79 points: Certificate with Very Green rank; ≥ 80 points: Certificate with Extreme Green rank. The newly developed evaluation technique for Ethiopia is the Ethiopian-Sustainable Building Assessment Tool (Ethio-SBAT).

1.1. The rationale for developing a new sustainable building assessment tool/method

Ethiopia’s construction sector is rapidly expanding, with buildings being built by private sectors, real estate developers, the government, individuals, and cooperatives. These buildings are used for residences, commercials, institutions, services, and others.

The construction of new buildings should be synchronized with the natural environment by conserving and preserving it. This can be achieved by depending more on the availability of renewable resources, water, and other resources. We are also observing limits in the exploitation of non-renewable resources and understanding the threats to nature as well as the surroundings.

There are no evaluation techniques, categories and criteria so far. There is a need of creating novel methods and practices by considering the philosophy and applications of the perception of high-performance building for the success of development in the construction industry of Ethiopia. The main assumption of this study is that developing sustainable building assessment tool must be depending upon reviewing and examining the most widely and commonly used practices of the industrialized nations; the developed tool must be suitable to the Ethiopian context, directed toward the residential buildings only and implemented from the initial stages of design.

The existing environmental assessment methods like BREEAM, LEED, SBTool, and CASBEE were developed for different local purposes and are not fully applicable to all regions [9]. Consideration of agreement among the Ethiopian experienced experts on applicable sustainability categories and criteria will be the best solution.

2. Literature review

Sustainable/green buildings have a long history, dating back to cave dwellers who used environmentally friendly materials and built their homes to fit into the landscape [10]. Assessment tools for sustainable/green buildings, often known as certification, are used to evaluate and acknowledge structures that meet specified green requirements or standards. Companies and organizations that create and maintain sustainable/green buildings are recognized and rewarded using assessment systems, which are typically voluntary. This encourages and incentivizes them to push the frontiers of sustainability. Assessment tools can be used during the planning and design, construction, operation and maintenance, renovation, and destruction phases of a sustainable or green building. Specific tools or subsets of tools are utilized for different building kinds such as homes, office buildings, commercial buildings, or even entire communities, and assessment techniques might differ in the types of buildings they are applied to. Green building research has lately emerged as one of the most important areas of construction management [11]. Academic institutions have begun to incorporate green construction components into their programs of study in order to raise awareness of this subject [12].

The WorldGBC recognizes the importance of evaluation tools (CASBEE, LEED, BREEAM, DGNB, Green Star SA, SBTool) in improving building sustainability and strongly encourages their use. Furthermore, it is acknowledged that each evaluation instrument is unique and that the member Green Building Council in a given nation is in the greatest position to develop or adopt a rating method that is most suited to their market. As a result, WorldGBC takes a neutral stance on individual assessment tools and does not recommend one over the other. With the extensive usage of assessment tools around the world, WorldGBC thinks that each sustainable/green building evaluation tool should meet quality requirements [13]. The Quality Assurance Guide for Green Building Assessment Tools, issued by WorldGBC in 2015, is a step-by-step guide for operators of new, developing, and established assessment tools to guarantee that their creation and implementation are resilient, transparent, and of high quality. By adopting all of them [14], the researchers [15] identified a total of 57 sustainable building evaluation tools, which show the region, nation name, owner/management, year, type of technique, and references. Africa has two assessment tools, Asia has fourteen assessment tools, Europe has 45 assessment tools, North America has seven assessment tools, Oceania has three assessment tools, and South America has three assessment tools. All of these assessment tools, such as the Comprehensive Assessment System for Built Environment Efficiency (CASBEE), Leadership in Energy and Environmental Design (LEED), and Building Research Establishment Environmental Assessment Methodology (BREEAM), have their own assessment categories and criteria that were developed according to their own local context. They may adapt directly from well-known assessment tools and also be extensively modified for relevance to their actual contexts, such as the Comprehensive Assessment System for Built Environment Efficiency (CASBEE), Leadership in Energy and Environmental Design (LEED), and may adapt directly from different countries, such as the Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) in Austria, Thailand, China, Bulgaria, Czech Republic, Denmark, Germany, Greece, Hungary, Poland, Russia, Spain, Switzerland, Ukraine, and Turkey, utilize the same assessment tools. According to the researchers [15], the BREEAM is made up of ten (10) categories that describe sustainability using fifty-one (51) criteria in total. Each category is given a percentage-weighting factor, and the total number of 112 available credits is proportionally assigned. Under the two categories, the CASBEE has six assessment criteria [16], whereas the LEED has eight (8) categories and sixty-seven (67) criteria [17]. The SBTools contains nine (9) categories and twenty-six (26) criteria, whereas the DGNB assessment tool has five (5) categories and forty-three (43) criteria [18]. For example, the Green Star-South Africa assessment tools have eight (8) categories and ninety-four (94) criteria [19]. The Hong Kong-based Comprehensive Environmental Performance Assessment Scheme (CEPAS) is made up of eight (8) categories and twenty (20) criteria [20]. Based on their local environment, all other sustainable building assessment methods have their own assessment categories and criteria. As indicated by [15] in Table 1, different types of sustainable building assessment tools are utilized in different regions of the world based on their local environment.

3. Methodology

3.1. The study design

Research is a systematic investigation to find answers to a problem plus procedures for collecting, analyzing, and interpreting information. Research can be theory-based (deductive) or problem-based (inductive) [9].
| Region | Country   | Name                        | Owner/Management                                   | Year | Type of Method | References                                      |
|--------|-----------|-----------------------------|---------------------------------------------------|------|----------------|------------------------------------------------|
| Africa | South Africa | Green Star SA | South Africa GBC | 2008 | MCDM           | (GCB, 2015) and (Loftness, V. and D. Haase, 2013) |
|        |           | SBAT                     | CSIR                                              | 2002 | MCDM           | (CSIR, 2015) and (Gibbert, J., 2008)            |
| Asia   | China     | GHEM                      | China Real Estate Chamber of Commerce             | N/A  | MCDM           | (Loftness, V. and D. Haase, 2013)               |
|        |           | GOBAS                     | Ministry of Science & Technology                  | 2003 | MCDM           | (Loftness, V. and D. Haase, 2013), and (Borong, L., et al., 2015) |
|        |           | DGNB                      | DGNB China                                        | 2009 | MCDM           | (Loftness, V. and D. Haase, 2013) and (DGNB, 2015) |
|        |           | ESGB                      | Ministry of Housing and Urban-Rural Construction  | 2006 | MCDM           | (Loftness, V. and D. Haase, 2013) and (Wang, Z.Q. and Q. Hu, 2012) |
|        | Hong Kong | BEAM Plus                 | HK-BEAM Society                                   | 1996 | MCDM           | (Loftness, V. and D. Haase, 2013) and (HKGBC, 2015) |
|        |           | CEPAS                     | HK Building Department                            | 2002 | MCDM           | (Loftness, V. and D. Haase, 2013)               |
|        |           | TERI-GRHA                 | TERI (The Energy & Research Institute)             | 2007 | MCDM           | (Loftness, V. and D. Haase, 2013) and (Korkmaz, S., et al., 2009) |
|        |           | LEED®-India               | Indian GBC                                        | 2011 | MCDM           | (Loftness, V. and D. Haase, 2013), (Korkmaz, S., et al., 2009), and (IGBC, 2014) |
|        | Japan     | CASBEE                    | Japan Sustainable Building Consort.               | 2004 | MCDM           | (CASBEE, 2015) and (Aotake, N., et al., 2005)   |
|        | Korea     | GBCC                      | Korean Korea Institute of Energy Research         | 1997 | MCDM           | (KGBCC, 2015)                                   |
|        | Malaysia  | GBI                       | PAM (Pertubuhan Arkitek Malaysia/Malaysian Institute of Architects) and AGEM (the Association of Consulting Engineers Malaysia) | 2008 | -              | (A.Y. Bahaudin, E.M. Elias, A.M. Saifudin, 2014) |
|        | Singapore | Green Mark                | Singapore Building & Construction Authority (BCA) | 2005 | MCDM           | (BCA, 2015)                                     |
|        | Taiwan    | EEWH                      | ABRI (Architecture & Building Research Institute)  | 1999 | MCDM           | (EEWH, 2015)                                    |
|        | Thailand  | DGNB                      | ARGF - Archimedes Facility-Management GmbH, Bad Oeynhausen & RE/ECC | 2010 | MCDM           | (DGNB, 2015)                                    |
|        | Vietnam   | LOTUS                     | Vietnam GBC                                        | 2007 | MCDM           | (CEC, 2015)                                     |
| Europe | Austria   | BREEAM AT                 | DfNIN                                             | N/A  | MCDM           | (BREEAM, 2015)                                 |
|        |           | DGNB                      | ÖGNI                                              | 2009 | MCDM           | (DGNB, 2015)                                    |
|        | Belgium   | LEnSE                    | Belgian Building Research Institute               | 2008 | MCDM           | (Loftness, V. and D. Haase, 2013)               |
|        | Bulgaria  | DGNB                      | Bulgarian GBC                                     | 2009 | MCDM           | (DGNB, 2015)                                    |
|        | Czech Republic | DGNB      | DfNIN                                             | 2011 | MCDM           | (DGNB, 2015)                                    |
|        |           | SBToolCZ                  | iiSBE International, CIDEAS                       | 2010 | MCDM           | (SBToolCZ, 2015)                                |
|        | Denmark   | BEAT 2002                 | SBI                                               | 2002 | MCDM           | (Haapio, A. and P. Viitaniemi, 2008) and (Fornberg, A. and F. von Malmberg, 2004) |
|        |           | DGNB                      | Denmark GBC                                       | 2011 | MCDM           | (DGNB, 2015)                                    |
|        | Finland   | PromisE                   | VTT                                               | 2006 | MCDM           | (Loftness, V. and D. Haase, 2013)               |
|        |           | BeCost                    | VTT                                               | N/A  | MCDM           | (Haapio, A. and P. Viitaniemi, 2008)            |
|        | France    | HQE™ Method               | HQE™                                              | 1997 | MCDM           | (Loftness, V. and D. Haase, 2013)               |
|        |           | ELODIE                    | CSTB’s Environment Division                       | 2006 | LCA            | (Loftness, V. and D. Haase, 2013)               |
|        |           | TEAM®                     | Ecobilan                                          | 1995 | LCA            | (Haapio, A. and P. Viitaniemi, 2008) and (Nibel, S. and A. Rialhe, 2000) |
|        | Germany   | DGNB                      | German Sustainable Building Council               | 2008 | MCDM           | (DGNB, 2015)                                    |
|        |           | BREEAM DE                 | DfNIN                                             | 2011 | MCDM           | (BREEAM, 2015)                                  |
|        | Greece    | DGNB                      | DfNIN                                             | 2010 | MCDM           | (DGNB, 2015)                                    |
|        | Hungary   | DGNB                      | DfNIN                                             | 2010 | MCDM           | (DGNB, 2015)                                    |
|        | Italy     | LEED®                     | Italy GBC                                         | 2006 | MCDM           | (GBC, 2015)                                     |

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For the study design, Ethiopia’s Ministry of Construction, Addis Ababa City Administration Housing Development Corporation, Industry, and Academia are key stakeholders. The researcher takes key expertise that is directly or indirectly resourceful with the topic to form the basis to the population under study population and as a source of data. A researcher’s research is judged to be of high quality if controlled, rigorous and systematic, valid and reliable, empirical and critical, and its application, objectives, and type of information utilized by the researcher (i.e. validity, validity, reproducibility, accessibility, applicability, relevance, practicality, power, and impact). The following (Figure 1) shows the research methodological framework.

### 3.2. Data collection technique

For the collection of the data, the key existing evaluation techniques were explored by considering the best inclusive and methodological tools developed to examine sustainability issues, is mainly targeted to identify the frequently and regularly employed categories and criteria of the

| Region | Country | Name | Type of Method | References |
|--------|---------|------|---------------|------------|
| Luxembourg | Protocollo | ITACA iSBE Italia | MCDM | (Loftness, V. and D. Haase, 2013) |
| | BREEAM LU | DIFNI | MCDM | (BREEAM, 2015) |
| Netherlands | BREEAM-NL | Dutch GBC | MCDM | (Loftness, V. and D. Haase, 2013), (BREEAM, 2015) and (BREEAM-NL, 2015) |
| | SIMAPRO | Pre Consultants | LCA | (M. Castro, J.A. Remmerswaal, and M.A. Reuter, 2003) |
| Eco-Quantum | IVAM | MCDM | (Haapio, A. and P. Viitaniemi, 2008) |
| Norway | BREEAM-NOR | Norwegian GBC | MCDM | (Haapio, A. and P. Viitaniemi, 2008) and (BREEAM, 2015) |
| | BREEAM CH | DIFNI | MCDM | (BREEAM, 2015) |
| | DGNB | SGNI | MCDM | (DGNB, 2015) |
| Russia | DGNB | DGNB International | MCDM | (DGNB, 2015) |
| Spain | VERDE | Spanish GBC | MCDM | (Loftness, V. and D. Haase, 2013) |
| | DGNB | N/A | MCDM | (DGNB, 2015) |
| | BREEAM ES | Fundacion Instituto Tecnologico de Galicia | MCDM | (BREEAM, 2015) |
| Sweden | EcoEffect | Royal Institute of Technology | LCA | (Haapio, A. and P. Viitaniemi, 2008), (Loftness, V. and D. Haase, 2013) and (Forsberg, A. and F. von Malmberg, 2004) |
| | BREEAM SE | Swedish GBC | MCDM | (BREEAM, 2015) |
| Switzerland | BREEAM CH | DIFNI | N/A | MCDM | (BREEAM, 2015) |
| | DGNB | SGNI | MCDM | (DGNB, 2015) |
| Turkey | DGNB | - | MCDM | (DGNB, 2015) |
| | DGNB International | | MCDM | (DGNB, 2015) and (EGS—plan) |
| United Kingdom | BREEAM | BRE | MCDM | (Haapio, A. and P. Viitaniemi, 2008), (BREEAM, 2015) and (Grace, M., 2000) |
| | Envest 2 | BRE | MCDM | (Haapio, A. and P. Viitaniemi, 2008), and (DOE, 2015) |
| North America | Canada | LEED®-Canada | Canada GBC | MCDM | (Loftness, V. and D. Haase, 2013) and (CAGBC, 2015) |
| | | GreenGlobes | ECD Canada | MCDM | (Loftness, V. and D. Haase, 2013) and (GreenGlobes, 2015) |
| | | ATHENA™ | ATHENA Sustainable Material Institute | MCDM | (Haapio, A. and P. Viitaniemi, 2008), (DOE, 2015) and (Meil, J.K., 1995) |
| Mexico | SICEC | Mexico GBC | MCDM | (Loftness, V. and D. Haase, 2013) |
| United States | LEED® | United States GBC | MCDM | (Haapio, A. and P. Viitaniemi, 2008), (Loftness, V. and D. Haase, 2013) and (Trusty, B.W. and S. Horst, 2003) |
| | BEES 4.0 | NIST | MCDM | (Loftness, V. and D. Haase, 2013) and (GreenGlobes, 2015) |
| | GreenGlobes | Green Building Initiative | MCDM | (Loftness, V. and D. Haase, 2013) and (GreenGlobes, 2015) |
| Oceania | Australia | Green Star | Australian GBC | MCDM | (GBCA, 2015) and (Roderick, Y., et al., 2009) |
| | NABERS | NSW Office of Environment and Heritage | MCDM | (NABERS, 2015) and (Cole, R.J., et al., 2005) |
| New Zealand | Green Star NZ | New Zealand GBC | MCDM | (NZGBC, 2015) and (Byrd, H. and P. Leardini, 2011) |
| South America | Argentina | LEED®-Argentina | Argentina GBC | MCDM | (GRC, A., 2015), and (Laresson,N.K. and R.I. Cole, 2001) |
| Brazil | LEED®-Brazil | Brazil GBC | MCDM | (USBG, 2014) and (GBCB, 2015) |
| | HQE™ | Fundación Vanzolini | MCDM | (HQE™, A., 2015) |

Source: Elena Bernardi, Salvatore Carlucci, and Cristina Cornaro, (2017).
selected ten (10) SBATs, and then identifying the best categories and criteria suitable to the Ethiopian context by considering the environmental, socio-economic, plus physical conditions.

An interview with experts from various segments like government offices, industries, and academia was taken into account as an appropriate method to collect data. This technique allows each expert for replying to a question by asking questions and sharing ideas as per their know-how. For this, a survey questionnaire format was utilized which contains both closed-ended and open-ended questions. It is composed of eight (8) categories and sixty-seven (67) criteria of evaluation techniques that suit to the Ethiopian context, which was identified by experts/participants in a common understanding process, and they were asked whether the questionnaire was valid or not and to apply any required modifications regarding these categories and criteria.

Table 2. Scales for the importance of criteria.

| Important scale | Definition of Important Scale |
|----------------|-------------------------------|
| 1              | Equally Important             |
| 2              | Moderately Important          |
| 3              | Strongly Important            |
| 4              | Very Strongly Important       |
| 5              | Extremely Important           |

A pairwise scale was employed, which represents the best criteria that utilized the scale ranges from 1 to 5 as shown in Table 2 below where each number represents importance of every criterion to the other criteria.
In each part, the participant had to allocate a scale for each question of the categories and criteria and to weight and rank the measures according to their importance in establishing a sustainable building assessment tool for Ethiopia. The investigator created clear roles of responding by the respondents while conducting an interview.

### 3.3. The sampling process

Ethiopia’s Ministry of Construction, Construction Works and Regulatory Authority, industry, senior experts (reputable professionals), and academia are being surveyed to prepare evaluation/assessment technique. A researcher is conducting survey questionnaires for the experts from various organizations in Addis Ababa. 100 professionals from different disciplines, such as architects, engineers, designers, planners, and construction managers, were selected purposely for conducting the study because they have a good working experiences as well as actively engaged in the construction sectors like design preparation; construction of the buildings; teaching and learning about the designing and construction of buildings; consulting in the design, supervision, regulating and evaluation of the overall building construction processes. The investigation was conducted with contestants in the form of questionnaires. The survey questionnaires included closed-ended and open-ended questions. Out of the 100 participants, 93 (Architects, 23 (24.7%), Designers, 2 (2.2%), Planners 6 (6.5%), Engineers 48 (51.5%), and Construction Managers 14 (15.1%) responded to the questionnaires as shown in Table 3 below. The response rate was 93%.

### 3.4. Ethical approval and informed consent

This study paper was ethically approved by the Addis Ababa Science and Technology University Ethical Review Board with a member of five committees named as Dr. Abera Belay (Chairperson), Ato Tariku Arena (Secretary), Dr. Mesfin Tafesse (Member), W/ro Amrote Seifu (Member) and W/ro Selamawit Dejen (Member). For this study, a written informed consent was obtained from all participants before collecting a primary data (Survey Questionnaire). The Ethical Approval Letter, Full names of the Ethical Approving Committee and a sample of the Written Informed Consent from the participants were delivered as a Supplementary Materials.

### 3.5. Categories and criteria for evaluation/ratings

A thorough discussion was made that resulted in the applicable and relevant categories and criteria and cover eight (8) categories and sixty-seven (67) criteria, as illustrated Table 4 below. They depend upon evaluating the foremost characteristics of numerous evaluation/rating techniques across various nations plus reviewing their original settings too.

### 3.6. AHP

AHP is a decision-making tool that gives the weights and prioritizes and ranks the credits of categories plus criteria depending upon its

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### Table 3. Responses for the questionnaires by the participants by professions.

| Respondents’ Professions | Frequency | Percent |
|--------------------------|-----------|---------|
| 1                        | Architect | 23      | 24.7    |
| 2                        | Urban Designer | 2      | 2.2     |
| 3                        | Urban Planner   | 6      | 6.5     |
| 4                        | Engineers      | 48     | 51.5    |
| 5                        | Construction Manager | 14 | 15.1    |
| Total                    | 93         | 100     |

### Table 4. The categories and criteria for evaluation/ratings.

| Category                      | Criteria                                                                 |
|-------------------------------|--------------------------------------------------------------------------|
| Resources and Materials       | Use of locally available materials                                      |
|                               | Material efficiency over its life cycle                                  |
|                               | Use of materials with recycled content                                  |
|                               | Use of finishing materials                                             |
|                               | Reuse of structural frame materials                                     |
|                               | Use of materials of low environmental impact                            |
|                               | Use of non-renewable-virgin materials                                   |
| Ecology and Sustainable Sites | Existence of open space, green area, playground area, plus civic place  |
|                               | Protecting or Restoring Open Space                                      |
|                               | Site selection and protection                                            |
|                               | Use of local/indigenous plants/flora                                    |
|                               | Ecological/Land Value                                                   |
|                               | Enhance site Ecology                                                    |
|                               | Reclaimed Contaminated Land                                             |
|                               | Reuse of Land                                                           |
| Interior ecological quality (IEQ) | Interior Air Quality                                         |
|                               | Existence of natural ventilation                                        |
|                               | Thermal comfort concerning Cooling control and comfort                  |
|                               | Lighting & Illumination concerning Lighting Controllability             |
|                               | Sound absorption                                                        |
|                               | Availability of Ventilation system                                      |
|                               | Lighting & Illumination concerning Glare measure and control            |
|                               | Thermal comfort concerning Heating control and comfort                  |
|                               | Sound insulation                                                        |
|                               | Lighting & Illumination concerning View out                            |
|                               | Air purification- supply of fresh air                                   |
|                               | Noise level                                                             |
|                               | Thermal comfort concerning Humidity control and comfort                 |
|                               | Visual Comfort                                                          |
| Energy Efficiency             | Use of energy-efficient equipment                                       |
|                               | Use of energy monitoring/management system                              |
|                               | Energy savings                                                          |
| Economic Aspects             | Energy for internal lighting                                            |
|                               | Energy for external lighting                                            |
|                               | Utilizing Renewable Energy                                              |
|                               | HVAC Systems                                                            |
|                               | Use of Hot Water/Steam                                                  |
| Management                   | Building’s affordability concerning the distance of getting Health services |
|                               | Building’s affordability concerning the distance of getting Education Services |
|                               | Construction cost                                                       |
|                               | Costs of buildings life cycle                                           |
|                               | Investment risk                                                         |
|                               | Building’s affordability concerning the distance of getting Shops/marketplaces |
|                               | Costs for maintenance and operation                                      |
|                               | Building’s affordability concerning the distance of facilities of Transportation |
|                               | Building’s affordability concerning rental for residential              |
|                               | Building’s affordability concerning the distance of the workplace        |
|                               | Consultation                                                            |
|                               | The construction process for the overall administration                 |

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other researchers [25] have stated. However, because hierarchy structure despite the qualities themselves being unchanged, other researchers [24].

"cally known truth that when the order of a matrix climbs to more than comparison the worst approach for weighting [23].

main steps required to devise the AHP framework, which comprises hi-

technique as described by [20]. In their descriptions, there were four

ments, while the increased time and effort it entails necessitates a greater

require actual data sets as described by [22].

The AHP method has drawbacks such as a high computational

requirement even for small problems, as well as its subjective nature and the fact that it relies on emotions being translated into numerical judg-
ments, which the increased time and effort it entails necessitates a greater number of pair comparisons, as [23] points out. Another problem is that criterion's values might fluctuate over time and space, making pairwise comparison the worst approach for weighting [23]. "It is a mathemati-
cally known truth that when the order of a matrix climbs to more than three, the inconsistency issue begins and escalates exponentially as the number of criteria and alternatives grows," the researchers [23] added. "One of AHP's weak points is the difficulty in working with huge issues, that is, situations with many hierarchy levels (above 4)," according to the other researchers [24].

"The AHP has several limitations, including confusing questions, set measuring scales, and variable outcomes, depending on the style of hierarchy structure despite the qualities themselves being unchanged," the other researchers [25] have stated. However, because "AHP is not flawless but can be a very powerful tool if you can utilize it appropriately, "as emphasized by [23], adopting the AHP approach in decision making should not be eschewed completely.

Despite the drawbacks, employing the AHP technique in decision-
making is critical since "intuitive conclusions are not supported by facts and documentation and may appear arbitrary," according to [26].

3.6.1. Hierarchy construction

It is a top-down process and comprises several levels, starting with the proposed evaluation techniques designed for the Ethiopian context, the categories, plus the criteria. There is no specialized method for creating a hierarchy, and AHP only has three levels, as shown in (Figure 2). Level one is the suggested sustainable building assessment instrument, level two is the eight categories, and level three is the criteria within each category. The elements of hierarchical levels are controlled in such a way that they are on the same scale and magnitude, and they must be associated with the other relevant factors of the structure, as the researchers have explicitly defined [27].

3.6.2. “Pair-wise” compare matrix for criteria

The AHP can prioritize (or “pair-wise” compare) both category and criterion and distinguish the more important factors from the less important factors [28, 29, 30]. Through a test of consistency, AHP is can solicit consistent subjective expert's judgment. It is an essential stage and also a backbone for the system called AHP which is an approach to analyzing weightings, rankings, and prioritizing the selected evaluation category and criterion prepared from the responses to a survey questionnaire.

The outcomes were converted into the numbers 1, 2, 3, 4, and 5 and 1/2, 1/3, 1/4, and 1/5 depending upon the categories' relevance for another criteria, plus pair-wise matrix established designed for catego-

ries as shown in Table 5 below. This comparison matrix was created using the respondents' comparative judgments and displays the weight of the criteria in relation to one another as well as their relative importance. It's vital to note that the matrix's diagonal values are all 1, indicating that the weight of criteria in relation to itself is always 1, as seen in red cells. Furthermore, the pink cells' comparing judgments demonstrated that both the row and column criteria are seen as equally relevant.

3.6.3. Deriving relative weights/relative priority (normalization)

For every selected category and criteria, it is required to evaluate the relative weights.

Normalization of the resulting matrix of categories (from Table 2) has to be done. This involves calculating every criterion's urgency according to its contribution to the expected goal. Normalization processes were employed for establishing the normalized pair-wise comparison, in which each criterion was divided by total values in each column, and the resulting weight was considered the weight [1, 31]. Normalization of the resulting matrix of categories (from Table 5) has to be done. This involves calculating every criterion's urgency according to its contribution to the expected goal. According to the researchers [32], the normalization techniques were applied in two steps:

i. The total of the values in each column of the pairwise comparison matrix.

ii. The Weight was calculated by dividing each criterion in the pairwise comparison matrix by the sum of the values in each column.

A normalized pairwise comparison matrix was created as a conse-

quence. The Sum, Weight, Relative Priority (percentage), and Rank of each category are shown in Table 6.

3.6.4. Testing consistency index (CI) and consistency ratio (CR)

The measure of “Consistency Ratio” (CR) is an important part of AHP technique, and consistency analysis was used in this study to guarantee

| Category | Criteria |
|----------|----------|
| Facility Management | Waste Management during construction and operation |
| Security | Commissioning |
| Water efficiency (WE) | Use of rain Water Harvesting |
| | Regular water Usage Monitoring |
| | Use of water Efficient Fittings and equipment |
| | Water consumption |
| | Recycling of wastewater |
| | Recharge of groundwater |
| | Regular water leak detection and monitoring |
| Location and Transportation (LT) | Availability of alternative modes of transportations |
| | (Buses, Taxi, Bicycle, Pedestrian/Foot, Light Rail Transport (LRT)) |
| | Accessibility to public transportation |
| | Surrounding density and diverse uses |
| | Density Development location |
| | Sensitive land protection |
| | Community/Local Connectivity |
| | Provision of the car parking area and parking capacity |

importance [29]. Survey questionnaires were created aimed at analyzing the AHP analysis. A pairwise scale as mentioned in Table 2 is utilized to represent the significance of each criterion like 1 = Equally Important, 2 = Moderately Important, 3 = Strongly Important, 4 = Very Strongly Important, and 5 = Extremely Important. A final checklist for the new evaluation technique intended for present building was established with their credits and their corresponding weights.

For the development of the new scheme of sustainable building assessment tool for Ethiopian context, the researcher has used the AHP technique as described by [20]. In their descriptions, there were four main steps required to devise the AHP framework, which comprises hi-

erarchy construction, pairwise comparisons, deriving relative weights, consistency checking, and synthesizing results. Therefore; this technique was highly preferable to investigate weightings, relative priority values (%), and the rankings of categories and criteria as described by [21].

The AHP approach is a dependable strategy for quality decision making and is used for assessing and prioritizing goals as well as multi-
criteria decision making. Furthermore, the AHP addresses both qualita-
tive and quantitative components of a decision-making challenge, such as usability; it is a straightforwardly reasonable approach; it deconstructs a complex problem by breaking it down into smaller parts; and it does not require actual data sets as described by [22].

The AHP method has drawbacks such as a high computational require-
ment even for small problems, as well as its subjective nature and the fact that it relies on emotions being translated into numerical judg-
ments, while the increased time and effort it entails necessitates a greater number of pair comparisons, as [23] points out. Another problem is that criterion's values might fluctuate over time and space, making pairwise comparison the worst approach for weighting [23]. "It is a mathemati-
cally known truth that when the order of a matrix climbs to more than three, the inconsistency issue begins and escalates exponentially as the number of criteria and alternatives grows," the researchers [23] added. "One of AHP’s weak points is the difficulty in working with huge issues, that is, situations with many hierarchy levels (above 4)," according to the other researchers [24].

“The AHP has several limitations, including confusing questions, set measuring scales, and variable outcomes, depending on the style of hierarchy structure despite the qualities themselves being unchanged,” the other researchers [25] have stated. However, because “AHP is not
that original preference ratings were consistent, and a consistency ratio was generated and its value checked. The researchers [21] went on to say that an index was created to measure the consistency of weights in order to calculate the consistency ratio. The acceptable CR range should be less than or equal to 0.10. If CR is more than this threshold value, a pairwise comparison must be revised, as stated by [21]. The researchers [33] recommended that the following steps be followed for determining the consistency ratio:

Table 5. The Eight Category of AHP Comparison -Paired Matrix.

| Category | EA | EE | WE | LT | ES | IEQ | RM | MAN |
|----------|----|----|----|----|----|-----|----|-----|
| EA       | 1.00 | 0.50 | 2.00 | 2.00 | 0.33 | 0.50 | 1.00 | 1.00 |
| EE       | 2.00 | 1.00 | 2.00 | 2.00 | 0.50 | 0.50 | 1.00 | 1.00 |
| WE       | 0.50 | 0.50 | 1.00 | 2.00 | 0.50 | 0.50 | 0.50 | 1.00 |
| LT       | 0.50 | 0.50 | 0.50 | 1.00 | 0.33 | 1.00 | 0.33 | 0.50 |
| ES       | 3.00 | 2.00 | 2.00 | 3.00 | 1.00 | 0.50 | 1.00 | 1.00 |
| IEQ      | 2.00 | 2.00 | 2.00 | 1.00 | 2.00 | 1.00 | 0.33 | 2.00 |
| RM       | 1.00 | 1.00 | 2.00 | 3.00 | 1.00 | 3.00 | 1.00 | 2.00 |
| MAN      | 1.00 | 1.00 | 1.00 | 2.00 | 1.00 | 0.50 | 0.50 | 1.00 |
| SUM      | 11.00 | 8.50 | 12.50 | 16.00 | 6.67 | 7.50 | 5.67 | 9.50 |

Source: Researcher's calculation by using MS-Excel, (September, 2021).
N.B: EA = Economic Aspects, EE = Energy Efficiency, WE = Water Efficiency, LT = Location and Transportation, ES = Ecology and Sustainable Sites, IEQ = Interior ecological quality (IEQ), RM = Resources and Materials, MAN = Management.

Table 6. AHP normalization of the eight categories.

| Category | EA | EE | WE | LT | SE | IEQ | RM | MAN | Sum | Weight | Relative Priority (%) | RANK |
|----------|----|----|----|----|----|-----|----|-----|-----|--------|-----------------------|------|
| EA       | 0.09 | 0.06 | 0.16 | 0.13 | 0.05 | 0.07 | 0.18 | 0.11 | 0.83 | 0.1041 | 10.41 | 5 |
| EE       | 0.18 | 0.12 | 0.16 | 0.13 | 0.08 | 0.07 | 0.18 | 0.11 | 1.01 | 0.1260 | 12.60 | 4 |
| WE       | 0.05 | 0.06 | 0.08 | 0.13 | 0.08 | 0.07 | 0.09 | 0.11 | 0.64 | 0.0806 | 8.06 | 7 |
| LT       | 0.05 | 0.06 | 0.04 | 0.06 | 0.05 | 0.13 | 0.06 | 0.05 | 0.05 | 0.0627 | 6.27 | 8 |
| SE       | 0.27 | 0.24 | 0.16 | 0.19 | 0.15 | 0.07 | 0.18 | 0.11 | 1.35 | 0.1692 | 16.92 | 2 |
| IEQ      | 0.18 | 0.24 | 0.16 | 0.06 | 0.30 | 0.13 | 0.06 | 0.21 | 1.34 | 0.1678 | 16.78 | 3 |
| RM       | 0.09 | 0.12 | 0.16 | 0.19 | 0.15 | 0.40 | 0.18 | 0.21 | 1.49 | 0.1866 | 18.66 | 1 |
| MAN      | 0.09 | 0.12 | 0.08 | 0.13 | 0.15 | 0.07 | 0.09 | 0.11 | 0.82 | 0.1030 | 10.30 | 6 |

Source: Researcher's calculation by using MS-Excel, (September, 2021).
Table 7. The Eight Categories of AHP’s CI as well as CR.

| Category     | EA   | EE   | WE   | LT   | ES   | IEQ  | RM   | MAN  | Weighted Sum | Weighted Sum/Weight |
|--------------|------|------|------|------|------|------|------|------|--------------|---------------------|
| EA           | 0.104| 0.063| 0.161| 0.125| 0.056| 0.084| 0.187| 0.103| 0.884        | 8.48402             |
| EE           | 0.208| 0.126| 0.161| 0.125| 0.085| 0.084| 0.187| 0.103| 1.079        | 8.56368             |
| WE           | 0.052| 0.063| 0.081| 0.125| 0.085| 0.084| 0.093| 0.103| 0.686        | 8.51345             |
| LT           | 0.052| 0.063| 0.040| 0.063| 0.056| 0.168| 0.062| 0.051| 0.556        | 8.86709             |
| ES           | 0.312| 0.252| 0.161| 0.188| 0.169| 0.084| 0.187| 0.103| 1.456        | 8.60505             |
| IEQ          | 0.208| 0.126| 0.161| 0.125| 0.085| 0.084| 0.187| 0.103| 1.458        | 8.69236             |
| RM           | 0.104| 0.126| 0.161| 0.188| 0.169| 0.503| 0.187| 0.206| 1.644        | 8.8114              |
| MAN          | 0.104| 0.126| 0.081| 0.125| 0.169| 0.084| 0.093| 0.103| 0.885        | 8.59987             |
| SUM          |       |      |      |      |      |      |      |      | 69.14        |                     |

Source: Researcher’s calculation by using MS-Excel, (September, 2021).

i. The first column’s each value was multiplied by the prominence of the first item; the same was done to the remained columns (Table 7).

ii. Values across rows were summed to get a vector of values called “Weighted Sum”.

iii. The Weighted Sums of every element were divided using each equivalent prioritized criteria to get a Weighted Sum/Weight.

iv. The average of the values in Weighted Sum/Weight was calculated and expressed as $\lambda_{\text{max}}$.

v. Then CI was calculated as shown in equation (1).

$$CI = \frac{(\lambda_{\text{max}} - n)}{(n - 1)}$$ (1)

where n is the number of items (criteria) being compared.

CI is consistency index, and $\lambda_{\text{max}}$ is the sum of weighted sum divided by number of items

$$CR = \frac{CI}{RI}$$ (2)

where CR is consistency ratio as shown in equation [2], CI is consistency index, and RI is the random inconsistency index.

Note that for the Random Inconsistency Index (RI) for n = 1, 2, 3,..., 15, is displayed in Table 8 below.

For this eight (8) categories.

• $\lambda_{\text{max}}$ = Sum of Weighted Sum/Weight divided by criteria’s number = 69.14/8 = 8.64
• Consistency Index $CI = \frac{(\lambda_{\text{max}} - n)}{(n - 1)} = \frac{(8.64 - 8)}{(8 - 1)} = 0.09$
• Consistency Ratio $CR = \frac{CI}{RI} = \frac{0.09}{0.10} = 0.9$

CR = 0.07 ≤ 0.1.hol Consistent

Judges have been rated on their reliability and consistency with an index below that recommended by [28]. 0.07 is the outcome of CR, meaning conclusions are drawn which is reliable and ensures a good level of consistency with a given category.

For the assessment criteria found under every eight categories, the same process was undertaken for checking CR and CI. The following Tables (Table 9 and Table 10) show the CI and CRs for the categories of Energy Efficiency (EE) and Recourses and Materials (MR).

N.B: EE_1 = Utilizing a monitoring/management system, EE_2 = Energy for internal lighting, EE_3 = Energy for external lighting, EE_4 = Use of energy-efficient equipment, EE_5 = Utilizing Renewable Energy, EE_6 = Use of Hot Water/Steam, EE_7 = HVAC Systems, and EE_8 = Energy savings.

For this category (Energy Efficiency).

• $\lambda_{\text{max}}$ = Sum of Weighted Sum/Weight divided by Number of criteria = 69.14/8 = 8.64
• Consistency Index $CI = \frac{(\lambda_{\text{max}} - n)}{(n - 1)} = \frac{(8.64 - 8)}{(8 - 1)} = 0.10$
• Consistency Ratio $CR = \frac{CI}{RI} = \frac{0.10}{0.10} = 1$

CR = 0.07 ≤ 0.1.hol Consistent

For this matrix, the CR value is 0.07. Because this ratio is less than 0.1, the matrix is regarded consistent, and the judgments are considered reliable and consistent. With an index below the recommended, the validity of the selected criteria is confirmed.

N.B: MR_1 = Use of materials of low environmental impact, MR_2 = Use of non-renewable-virgin materials, MR_3 = Reuse of structural frame materials, MR_4 = Use of locally available materials, MR_5 = Use of materials with recycled content, MR_6 = Use of finishing materials, and MR_7 = Material efficiency over its life cycle.

For this category (Materials and Resources) as shown in Table 10 above.

• $\lambda_{\text{max}}$ = Sum of Weighted Sum/Weight divided by Number of criteria = 53.48/7 = 7.64
• Consistency Index $CI = \frac{(\lambda_{\text{max}} - n)}{(n - 1)} = \frac{(7.64 - 7)}{(7 - 1)} = 0.10$
• Consistency Ratio $CR = \frac{CI}{RI} = \frac{0.10}{0.10} = 1$

CR = 0.08 ≤ 0.1.hol Consistent

Because this ratio is less than 0.1, the matrix is regarded consistent, and the judgments are considered reliable. With an index below the recommended, the validity of the selected criterion is confirmed.

Table 11 shows every criterion’s weighting, relative priority (%), and ranking results under their respective category that suits to Ethiopian Context.

4. Results and discussion

The technique for evaluating the building has to consider the dimensions of sustainability—environmental, social, and economic. For the category, displayed (Table 8) above, a comparative verdict does not imply that an individual criterion is chosen with reference to others in a numerical amount. The rankings used for prioritizing the utmost preferable and relevant assessment criteria under the specified category to

Table 8. Random Inconsistency Index (RI) for n = 1, 2, 3,..., 15.

| n  | RI  |
|----|-----|
| 1  | 0   |
| 2  | 0.6 |
| 3  | 0.9 |
| 4  | 1.12|
| 5  | 1.24|
| 6  | 1.32|
| 7  | 1.41|
| 8  | 1.45|
| 9  | 1.49|
| 10 | 1.51|
| 11 | 1.48|
| 12 | 1.56|
| 13 | 1.57|
| 14 | 1.59|
| 15 |     |
establish evaluation techniques for the Ethiopian context can be simply identified from this tabulation. Table 11 above shows that open space, green areas, playground areas, plus civic places are the key criteria under the ecology and sustainable sites category. It has the 1st ranking in overall rankings with a relative priority value of 28.76%, and the next are utilizing energy-efficient apparatus under the energy-efficiency category with a relative priority value of 28.66%, plus employing the rainwater harvesting under the water efficiency category with a relative priority value of 28.04%. The first criterion (open space, green areas, playground areas, and civic places) is essential for the built environment to be alive and well, meaning that sustainability has been attained. Because Ethiopia is rich in renewable energy sources such as wind, hydropower, geothermal, and solar, energy-efficient equipment is essential for harnessing these resources to satisfy the energy demands of buildings and industries, resulting in the country’s economic success. Rainwater harvesting from these buildings is also highly suggested for usage in a variety of applications such as gardening, washing, urban agriculture, and watering vegetation and various types of trees, which aids climate management and lowers energy needs.

Table 9: The criteria of the energy-efficiency category of AHPs' CI and CR.

| Criteria | EE_1 | EE_2 | EE_3 | EE_4 | EE_5 | EE_6 | EE_7 | EE_8 | Weighted Sum | Weighted Sum/Weight |
|----------|------|------|------|------|------|------|------|------|--------------|---------------------|
| EE_1     | 0.18 | 0.31 | 0.31 | 0.14 | 0.26 | 0.15 | 0.16 | 0.15 | 1.66         | 9.00                |
| EE_2     | 0.06 | 0.10 | 0.10 | 0.07 | 0.26 | 0.11 | 0.16 | 0.07 | 0.94         | 8.95                |
| EE_3     | 0.06 | 0.10 | 0.10 | 0.07 | 0.26 | 0.11 | 0.16 | 0.07 | 0.94         | 8.95                |
| EE_4     | 0.37 | 0.42 | 0.42 | 0.29 | 0.26 | 0.15 | 0.21 | 0.44 | 2.54         | 8.86                |
| EE_5     | 0.06 | 0.03 | 0.03 | 0.10 | 0.09 | 0.11 | 0.16 | 0.15 | 0.72         | 8.48                |
| EE_6     | 0.05 | 0.03 | 0.03 | 0.07 | 0.03 | 0.04 | 0.02 | 0.04 | 0.31         | 8.42                |
| EE_7     | 0.06 | 0.03 | 0.03 | 0.07 | 0.03 | 0.11 | 0.05 | 0.04 | 0.43         | 8.23                |
| EE_8     | 0.18 | 0.21 | 0.21 | 0.10 | 0.09 | 0.15 | 0.21 | 0.15 | 1.28         | 8.80                |
| SUM      |      |      |      |      |      |      |      |      | 69.69        |                     |

Source: Calculated by the researcher by using MS-Excel, (September, 2021).

Table 10: The criteria of the materials and resources category of AHPs’ CI and CR.

| Criteria | MR_1 | MR_2 | MR_3 | MR_4 | MR_5 | MR_6 | MR_7 | Weighted Sum | Weighted Sum/Weight |
|----------|------|------|------|------|------|------|------|--------------|---------------------|
| MR_1     | 0.083| 0.153| 0.032| 0.08 | 0.14 | 0.04 | 0.08 | 0.62         | 7.4913               |
| MR_2     | 0.021| 0.038| 0.032| 0.06 | 0.03 | 0.03 | 0.06 | 0.28         | 7.2946               |
| MR_3     | 0.25 | 0.115| 0.097| 0.08 | 0.07 | 0.04 | 0.08 | 0.75         | 7.6706               |
| MR_4     | 0.25 | 0.153| 0.292| 0.25 | 0.43 | 0.4  | 0.25 | 2.03         | 7.9997               |
| MR_5     | 0.083| 0.192| 0.032| 0.08 | 0.14 | 0.4  | 0.08 | 1.01         | 7.1027               |
| MR_6     | 0.25 | 0.153| 0.292| 0.08 | 0.05 | 0.13 | 0.08 | 1.04         | 7.9248               |
| MR_7     | 0.25 | 0.153| 0.292| 0.25 | 0.43 | 0.4  | 0.25 | 2.03         | 7.9997               |
| SUM      |      |      |      |      |      |      |      | 53.48        |                     |

Source: Calculated by the researcher by using MS-Excel, (September, 2021).

The applicable and pertinent appraisal criteria plus categories selected for the Ethiopian context are agreed upon by experts. Occasionally the inclusion of international codes and guidelines is highly recommended for buildings that are needed and awarded credits. Table 11 shows every evaluation category has its criteria aimed at appraising the sustainability level of the nation depending upon socioeconomic, cultural, plus ecological settings. This tool allows the decision-maker to judge how well the chosen criteria can succeed in meeting overall sustainable building assessment goals.
Table 11. The Weighting, Relative Priority (%) and Ranking results evaluation technique of every category that suits to Ethiopian Context.

| Criteria | Weight  | Relative Priority (%) | Rank by Category | Overall Rank |
|----------|---------|-----------------------|------------------|--------------|
| 1. Economic Aspects (EA) |         |                       |                  |              |
| Building's affordability concerning the distance of facilities of Transportation | 0.0528  | 5.28                  | 8                | 55           |
| Building's affordability concerning the distance of the workplace | 0.0412  | 4.12                  | 10               | 60           |
| Building's affordability concerning the distance of getting Health services | 0.1503  | 15.03                 | 1                | 14           |
| Building's affordability concerning the distance of getting Education Services | 0.1481  | 14.81                 | 2                | 15           |
| Building's affordability concerning the distance of getting Shops/market places | 0.1031  | 10.31                 | 6                | 28           |
| Building's affordability concerning rental for residential | 0.0431  | 4.31                  | 9                | 58           |
| Costs of operation and maintenance | 0.0583  | 5.83                  | 7                | 51           |
| Cost for building life cycle | 0.1328  | 13.28                 | 4                | 21           |
| Investment risk | 0.1283  | 12.83                 | 5                | 24           |
| Construction cost | 0.1420  | 14.20                 | 3                | 18           |
| 2. Energy Efficiency (EE) |         |                       |                  |              |
| Utilizing a monitoring/management system | 0.1844  | 18.44                 | 2                | 12           |
| Energy for internal lighting | 0.1046  | 10.46                 | 4                | 27           |
| Energy for external lighting | 0.1046  | 10.46                 | 4                | 27           |
| Use of energy-efficient equipment | 0.2866  | 28.66                 | 1                | 2            |
| utilizing Renewable Energy | 0.0853  | 8.53                  | 5                | 36           |
| Use of Hot Water/Steam | 0.0364  | 3.64                  | 7                | 62           |
| HVAC Systems | 0.0521  | 5.21                  | 6                | 56           |
| Energy savings | 0.1458  | 14.58                 | 3                | 16           |
| 3. Water efficiency (WE) |         |                       |                  |              |
| Water consumption | 0.0924  | 9.24                  | 4                | 33           |
| Regular water leak detection and monitoring | 0.0677  | 6.77                  | 7                | 42           |
| Employing rain Water Harvesting | 0.2804  | 28.04                 | 1                | 3            |
| Utilizing water fixtures as well as equipment | 0.1808  | 18.08                 | 3                | 13           |
| Regular water Usage Monitoring | 0.2105  | 21.05                 | 2                | 8            |
| Recycling of wastewater | 0.0842  | 8.42                  | 5                | 37           |
| Recharge of groundwater | 0.0840  | 8.40                  | 6                | 38           |
| 4. Location and Transportation (LT) |         |                       |                  |              |
| Availability of alternative modes of transportations (Buses, Taxi, Bicycle, Pedestrian/Foot, Light Rail Transport (LRT)) | 0.2630  | 26.30                 | 1                | 4            |
| Provision of the car parking area and parking capacity | 0.0583  | 5.83                  | 6                | 51           |
| Community/Local Connectivity | 0.0620  | 6.20                  | 5                | 48           |
| Density Development location | 0.1165  | 11.65                 | 3                | 25           |
| Sensitive land protection | 0.1018  | 10.18                 | 4                | 29           |
| Surrounding density and diverse uses | 0.1353  | 13.53                 | 2                | 19           |
| Accessibility to public transportation | 0.2630  | 26.30                 | 1                | 4            |
| 5. Ecology and Sustainable Sites (ES) |         |                       |                  |              |
| Site selection and protection | 0.1339  | 13.39                 | 3                | 20           |
| Reuse of Land | 0.0419  | 4.19                  | 8                | 59           |
| Ecological/Land Value | 0.0961  | 9.61                  | 5                | 32           |
| Reclaimed Contaminated Land | 0.0488  | 4.88                  | 7                | 57           |
| Enhance site Ecology | 0.0556  | 5.56                  | 6                | 53           |
| Use of local/indigenous plants/flora | 0.1297  | 12.97                 | 4                | 23           |
| Protecting or Restoring Open Space | 0.2064  | 20.64                 | 2                | 9            |
| Existence of open space, green area, playground area, plus civic place | 0.2876  | 28.76                 | 1                | 1            |
| 6. Interior ecological quality (IEQ) |         |                       |                  |              |
| Noise level | 0.0617  | 6.17                  | 11               | 49           |
| Sound insulation | 0.0633  | 6.33                  | 8                | 45           |
| Sound absorption | 0.0683  | 6.83                  | 5                | 41           |
| Thermal comfort concerning Cooling control and comfort | 0.0868  | 8.68                  | 3                | 34           |
| Thermal comfort concerning Heating control and comfort | 0.0633  | 6.33                  | 8                | 45           |
| Thermal comfort concerning Humidity control and comfort | 0.0577  | 5.77                  | 12               | 52           |
| Lighting & Illumination concerning Lighting Controllability | 0.0702  | 7.02                  | 4                | 40           |
| Lighting & Illumination concerning View out | 0.0632  | 6.32                  | 9                | 46           |
| Lighting & Illumination concerning Glare measure and control | 0.0657  | 6.57                  | 7                | 44           |
| Interior Air Quality | 0.1160  | 11.60                 | 1                | 26           |
| Visual Comfort | 0.0553  | 5.53                  | 13               | 54           |

(continued on next page)
### Table 11 (continued)

| Criteria                                           | Weight | Relative Priority (%) | Rank by Category | Overall Rank |
|----------------------------------------------------|--------|-----------------------|------------------|--------------|
| Existence of natural ventilation                  | 0.0983 | 9.83                  | 2                | 30           |
| Availability of Ventilation system                | 0.0676 | 6.76                  | 6                | 43           |
| Air purification- supply of fresh air             | 0.0624 | 6.24                  | 10               | 47           |
| 7. Resources and Materials (RM)                   |        |                       |                  |              |
| Utilize low environmental impact materials         | 0.0834 | 8.34                  | 5                | 39           |
| Use of non-renewable-virgin materials             | 0.0383 | 3.83                  | 6                | 61           |
| Reuse of structural frame materials               | 0.0973 | 9.73                  | 4                | 31           |
| Use of locally available materials                | 0.2532 | 25.32                 | 1                | 5            |
| Use of recycled materials                         | 0.1428 | 14.28                 | 2                | 17           |
| Use of finishing materials                        | 0.1317 | 13.17                 | 3                | 22           |
| Material efficiency over its life cycle           | 0.2532 | 25.32                 | 1                | 5            |
| 8. Management (MAN)                               |        |                       |                  |              |
| Facility Management                               | 0.2046 | 20.46                 | 3                | 10           |
| Commissioning                                     | 0.0863 | 8.63                  | 5                | 25           |
| Consultation                                      | 0.2456 | 24.56                 | 1                | 6            |
| The construction process for the overall administration | 0.2111 | 21.11                 | 2                | 7            |
| Waste Management during construction and operation | 0.1927 | 19.27                 | 4                | 11           |
| Security                                           | 0.0596 | 5.96                  | 6                | 50           |

Source: Researcher’s calculation by using MS-Excel, (September 2021).

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### Table 12. The mean/average and score/point of the criteria according to the experts’ judgment.

| Category               | Criteria                                                                 | Mean/Average | Points |
|------------------------|---------------------------------------------------------------------------|--------------|--------|
| Economic Aspects       | Affordability of the building with respect to distance of facilities of Transportation | 4.2          | 3      |
|                        | Affordability of the building with respect to distance of work place       | 4.0          | 3      |
|                        | Affordability of the building with respect to distance of getting Health services | 3.8          | 2      |
|                        | Affordability of the building with respect to distance of getting Education Services | 3.9          | 2      |
|                        | Affordability of the building with respect to distance of getting Shops/market places | 4.0          | 3      |
|                        | Affordability of the building with respect to rental for residential       | 3.9          | 2      |
|                        | Operation and maintenance cost                                           | 3.9          | 2      |
|                        | Life cycle cost (LCC)                                                     | 3.8          | 2      |
|                        | Investment risk                                                           | 3.7          | 2      |
|                        | Construction cost                                                         | 4.0          | 3      |
| Energy Efficiency      | Use of energy monitoring/management system                                | 4.0          | 3      |
|                        | Energy for internal lighting                                              | 4.0          | 3      |
|                        | Energy for external lighting                                              | 4.0          | 3      |
|                        | Use of energy efficient equipment                                         | 3.9          | 2      |
|                        | Use of natural energy resources/Renewable Energy                          | 3.9          | 2      |
|                        | Use of Hot Water/Steam                                                    | 3.5          | 2      |
|                        | HVAC Systems                                                              | 3.7          | 2      |
|                        | Energy savings                                                            | 3.9          | 2      |
| Water Efficiency       | Water consumption                                                         | 4.2          | 3      |
|                        | Regular water leak detection and monitoring                                | 3.8          | 2      |
|                        | Use of rain Water Harvesting                                              | 3.6          | 2      |
|                        | Use of water Efficient Fittings and equipment                             | 3.9          | 2      |
|                        | Regular water Usage Monitoring                                            | 3.9          | 2      |
|                        | Recycling of waste water                                                  | 3.7          | 2      |
|                        | Recharge of ground water                                                  | 3.6          | 2      |
| Location and Transportation | Availability of alternative modes of transportations (Buses, Taxi, bicycle, Pedestrian/ Foot, Light Rail Transport (LRT)) | 4.2          | 3      |
|                        | Provision of car parking area and parking capacity                         | 4.0          | 3      |
|                        | Community/Local Connectivity                                              | 3.9          | 2      |
|                        | Density Development location                                              | 3.8          | 2      |
|                        | Sensitive land protection                                                 | 3.7          | 2      |
|                        | Surrounding density and diverse uses                                      | 3.7          | 2      |
|                        | Accessibility to public transportation                                     | 4.1          | 3      |

(continued on next page)
Table 12 (continued)

| Category                        | Criteria                                           | Mean/Average | Points |
|---------------------------------|----------------------------------------------------|--------------|--------|
| Ecology and Sustainable Sites   | Site selection and protection                      | 4.2          | 3      |
|                                 | Reuse of Land                                      | 3.8          | 2      |
|                                 | Ecological/Land Value                              | 4.0          | 3      |
|                                 | Reclaimed Contaminated Land                        | 3.7          | 2      |
|                                 | Enhance site Ecology                               | 3.9          | 2      |
|                                 | Use of local/indigenous plants/flora               | 3.8          | 2      |
|                                 | Protect or Restore Open Space                      | 4.0          | 3      |
|                                 | Existence of open space, green area, playground area and public space | 4.1          | 3      |
| Indoor Environmental Quality    | Noise level                                        | 4.0          | 3      |
|                                 | Sound insulation                                   | 3.9          | 2      |
|                                 | Sound absorption                                   | 3.7          | 2      |
|                                 | Thermal comfort with respect to Cooling control and comfort | 3.8          | 2      |
|                                 | Thermal comfort with respect to Heating control and comfort | 3.8          | 2      |
|                                 | Thermal comfort with respect to Humidity control and comfort | 3.6          | 2      |
|                                 | Lighting & Illumination with respect to Lighting Controllability | 3.9          | 2      |
|                                 | Lighting & Illumination with respect to View out   | 3.9          | 2      |
|                                 | Lighting & Illumination with respect to Glare measure and control | 3.8          | 2      |
|                                 | Indoor Air Quality                                 | 4.1          | 3      |
|                                 | Visual Comfort                                     | 4.1          | 3      |
|                                 | Existence of natural ventilation                   | 4.3          | 3      |
|                                 | Availability of Ventilation system                 | 3.9          | 2      |
|                                 | Air purification- supply of fresh air              | 3.7          | 2      |
| Materials and Resources         | Use of materials of low environmental impact        | 4.2          | 3      |
|                                 | Use of non-renewable-virgin materials              | 3.5          | 2      |
|                                 | Reuse of structural frame materials                | 3.7          | 2      |
|                                 | Use of locally available materials                 | 4.3          | 3      |
|                                 | Use of materials with recycled content             | 3.9          | 2      |
|                                 | Use of finishing materials                         | 4.1          | 3      |
|                                 | Material efficiency over its life cycle             | 4.0          | 3      |
| Management                      | Facility Management                                | 4.2          | 3      |
|                                 | Commissioning                                      | 3.9          | 2      |
|                                 | Consultation                                       | 4.0          | 3      |
|                                 | Construction process planning and management        | 4.2          | 3      |
|                                 | Waste Management during construction and operation | 4.0          | 3      |
|                                 | Security                                           | 4.1          | 3      |

Source: Calculated by the researcher by using MS-Excel, (September, 2021).

The CR in all pair-wise matrixes depicted that for the eight categories (Table 8) and the criteria for Energy Efficiency Category (Table 9) as well as Resources and Materials Category (10) is acceptable that is ≤ 0.1, which confirms the selected building evaluation categories are valid.

Table 12 shows the given points/scores for the classified and prioritized sustainable building evaluation criteria based on the experts' judgment by extracting criteria with a mean/average greater than 2.5 from a list of 67 criteria separated into eight (8) categories. The writer used the findings of researchers [34] who classified the mean/average of the experts' judgment for allocating the scores/points for each selected criteria, such as 1 point/score for criteria with a mean/average of 2.0–2.9; 2 points/scores for criteria with a mean/average of 3.0–3.9; and 3 points/scores for criteria with a mean/average of 4.0–5.0. The study has utilized this classification of points/scores for each category’s criterion and summed these points/scores to arrive at the category’s points/scores.

The results in Table 13 below depict the % value, criteria’s number, plus the points/scores of each selected category that were employed to create assessment technique to the Ethiopian context.

The results in Table 13 show that out of the eight available categories, resources and materials received the highest priority score of 18.66 percent, making it the most acceptable sustainable building assessment category. This assessment of resources and materials as sustainable building materials is based on the fact that it has performed best in the majority of the study's sustainability categories. Working appropriateness, environmental, and social advantages sustainability have all been outperformed by the resources and materials category. The categories ecology and sustainable sites, with a relative priority vector value of 16.92 percent, and interior ecological quality, with a relative priority vector value of 16.78 percent, outperform the categories resources and materials in the sustainability category, and are thus ranked second and third better alternatives, respectively. Furthermore, the assessment categories of energy efficiency, economic aspects, and water efficiency have relative priority vector values of 12.60 percent, 10.41 percent, and 10.30 percent, respectively, and their rankings in the sustainability are 4th, 5th, and 6th, respectively, indicating that they performed less than the aforementioned three assessment categories. Management and location and transportation are the least used assessment categories, with relative priority vector values of 8.06 percent and 6.27 percent, respectively, and rank 7th and 8th. As a result, these categories receive the least attention in the development of Ethio-SBAT.

Depending upon the (%) results of every category depicted in Table 13 below, checklists are prepared for evaluating and certifying current buildings. The proposed allocated points and awards for the assessed buildings were <40 points: Certificate with Not Green rank; 40–59 points: Certificate with Green rank; 60–79 points: certificate with...
Table 13. The % value, criteria’s number, plus points/scores of the Ethiopian building evaluation technique.

| Category                        | Relative Priority (%) | Criteria’s number | Points/scores | Description                                                                                                                                 |
|---------------------------------|-----------------------|-------------------|---------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| Resources and Materials         | 18.66                 | 7                 | 18            | Use of locally available materials is highly recommended-Use of materials of low environmental impact-Reuse of structural frame materials-Materials with recycled content should be used-Use of finishing materials- Material efficiency as well as Use of non-renewable-virgin materials |
| Ecology and Sustainable Sites   | 16.92                 | 8                 | 20            | Site selection and protection-Reuse of Land-Ecological/Land Value- Reclaimed Contaminated Land-Enhance site Ecology- Use of local/indigenous plants/Bora Protect or Restore Open Space and Existence of open space, green area, playground area, plus civic place. |
| Interior Ecological Quality     | 16.78                 | 14                | 32            | Noise level- Sound insulation-Sound absorption-Thermal comfort concerning Cooling control and comfort-Thermal comfort concerning Heating control and comfort-Thermal comfort concerning Humidity control and comfort-Lighting & illumination concerning Lighting Controllability-Lighting & Illumination concerning View out-Lighting & Illumination concerning Glare measure and control-Indoor Air Quality-Visual Comfort-Existence of natural ventilation-Availability of Ventilation system-Air purification-supply of fresh air. |
| Energy - Efficiency             | 12.60                 | 8                 | 19            | Utilizing monitoring/management system-Energy for internal lighting-Energy for external lighting-Use of energy-efficient equipment-Utilize Renewable Energy-Use of Hot Water/Steam-HVAC Systems and Energy savings |
| Economic Aspects                | 10.41                 | 10                | 24            | Building’s affordability concerning the distance of facilities of Transportation- Building’s affordability concerning the distance of workplace- Building’s affordability concerning the distance of getting Health services- Building’s affordability concerning the distance of getting Education Services- Building’s affordability concerning the distance of getting Shops/market places- Building’s affordability concerning rental for residential-Operation and maintenance cost-Life cycle cost (LCC)-Investment risk and Construction cost. |
| Management                      | 10.30                 | 6                 | 17            | Facility Management-Commissioning-Consultation-Construction process of overall administration and Waste Management during construction and operation-Security. |
| Water Efficiency                | 8.06                  | 7                 | 15            | Water consumption-Regular water leak detection and monitoring-Use of rain Water Harvesting-Utilizing water fixtures plus equipment-Regular water Usage Monitoring-Recycling of wastewater and Recharge of groundwater. |
| Location and Transportation     | 6.27                  | 7                 | 17            | Availability of alternative modes of transportations (Buses, Taxi, Bicycle, Pedestrian/Foot, Light Rail Transport (LRT))-Provision of parking area-Community/Local Connectivity-Density Development location-Sensitive land protection-Surrounding density and diverse uses and Accessibility to public transportation. |
| Total                           | 100                   | 67                | 162           | Very Green rank; ≥80 points: a certificate with Extreme Green rank. The newly developed evaluation technique for Ethiopia is the Ethiopian Sustainable Building Assessment Tool (Ethio-SBAT). Because it is based on the most relevant and applicable assessment tools used internationally, the climatic and socio-cultural conditions, and the consensus-based conclusions of famous professionals in Ethiopia’s building sectors, the proposed technique is considered effective and feasible. |

5. Conclusions and recommendations

Sustainable construction is seen as a means for the construction industry to strive toward environmental protection. The goal of promoting sustainable building methods is to strike a balance between economic, social, and environmental performance when constructing projects. Due to growing worries about climate change and sustainability around the world, sustainable building in Ethiopia is a major issue for the construction industry. Unfortunately, research in the field of sustainable building in Ethiopia and other developing countries is lacking.

The study’s main assumption is that developing a sustainable building assessment tool requires reviewing and examining the most widely and commonly used practices of industrialized nations using the AHP technique, which is appropriate for the Ethiopian context by taking into account agreement among Ethiopian experienced experts on relevant sustainability categories and criteria.

In addition; the current AHP analysis results revealed that materials and resources, as well as ecology and sustainable sites are the main categories, with high priority given to these categories over others, followed by energy efficiency and interior ecological quality. The use of locally available materials and material efficiency over its life cycle are the most significant factors when developing sustainable building assessment tools for Ethiopia within the category of material and resources.

Furthermore, this research will serve as a blueprint for future studies to advance the field of green building research in developing countries, such as Ethiopia, and to carry out more related projects, and also a step forward in examining current structures and transforming them into green and sustainable structures.

Therefore; Ethio-SBAT is an anticipated evaluation technique designed for the Ethiopian context, consisting of eight (8) categories and sixty-seven (67) criteria depending upon scientific examination, knowledge, plus professionals’ experiences in collaborative manner and fitted to the home-grown settings of Ethiopia; its culture, concerns, resources, priorities, and practices.

The recommended suggestions for establishing the Ethio-SBAT are:

- Developing such an evaluation technique should be depending upon scientific examination plus the capabilities of experts.
- Experts (Architects, Designers, Planners, Engineers, and Construction Managers) ought to partake in establishing an evaluation technique because it calls for a participatory and cooperative process.
- The consideration of international codes and guidelines plus triple bottom lines of sustainability must be incorporated.

Declarations

Author contribution statement

Melkonnen Abebe: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.
Wubishet Jekale: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.
Daniel Lirebo: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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