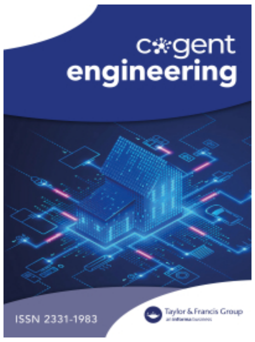

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Development of an integrative green building rating system for the Ethiopian public building projects using analytic hierarchy process

Rediet Gashaw[1], Solomon Belay[2*], Anmut Gizat[3], Solomon Hailu[3], Saeed Rokooei[4] and Jose Matos[5]

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*Corresponding author: Solomon Belay, Faculty of Civil and Water Resources Engineering, Bahir Dar University, Bahir Dar, Ethiopia
E-mail: solarmelaku@gmail.com

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Sanjay Kumar Shukla, School of Engineering, Edith Cowan University, AUSTRALIA

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Abstract: The design, construction, and maintenance of public infrastructures have a significant impact on the natural environment, and they are responsible for the degradation of scarce natural resources. In this respect, taking green building measures and initiatives has become a strategic concern for long-term development of nations around the world. Consequently, the study aims to develop a benchmarking green building rating system for public building projects in Ethiopia; investigate the current practice, and identify the key benefits and challenges of implementing green building schemes in the public infrastructure sector. To achieve these objectives, a questionnaire survey was employed, and mean score and the analytical hierarchy process (AHP) were used to analyse the collected data from various stakeholders including clients, consultants, and contractors. Data was analysed by using the Statistical Package for Social Sciences (SPSS) to conduct descriptive statistics and MS Excel for the AHP. The findings reveal that the top benefits of green building were identified as using renewable natural resources, enhancing and protecting ecosystem and biodiversity, and improving occupant's health and comfort. Similarly, the top challenges investigated were lack of adequate incentive for the promotion of green building, inadequate education/training about sustainable design and construction, and lack of awareness and readiness from the public. Moreover, the AHP analysis shows that the critical global weights were Site ecology (20.2%), Energy efficiency (23.33%), Water efficiency (24.7%), Indoor environmental quality (11.94%), and Transport (4.43%). The findings are believed to be helpful for various stakeholders and policy-makers in the Ethiopian construction industry.

Subjects: Environmental Health; Pollution; Engineering Project Management

Keywords: analytical hierarchy process; AHP; green building; sustainable construction

1. Introduction

Green construction can be defined as the use of environmentally responsible processes and resources throughout the life cycle of the building, from site selection to design, construction, operation, maintenance, renovation, and demolition phases (Ferreira et al., 2023; Vatalis et al., 2013). Green buildings consider better use of natural resources such as water and energy while producing minimal waste. Green buildings incorporate technologies and innovative systems such as efficient cooling, lighting, and energy operators that automatically adjust room temperature, control internal lighting, reuse water, and use less energy (Florez-Perez, 2020; Olawumi et al., 2020 & Darko & Chan, 2018).

Green buildings are rated based on their performance in energy efficiency, water saving, indoor air quality, and others (Jeganathan, 2016). One of the standard qualifying measures for a building to be "green" is based on some form of rating (Parida, 2020). Green Building Rating System is a voluntary, consensus-based measure for developing high-performance, sustainable structures in the world (Figueiredo et al., 2021; Tang et al., 2023). These rating systems include technical criteria for assessing the degree of sustainability and the extent of the environmental impact of buildings and construction projects (Huo et al., 2019; Šuman et al., 2020).

Recently, building construction has increased dramatically in Ethiopia, particularly in the capital Addis Ababa (Mohammed, 2018). The construction of buildings results in diverse environmental impacts (Akintayo et al., 2020). In most conventional buildings, open spaces and vertical greeneries are limited, and sustainable storm water management techniques are almost absent. The primary water source in most of the cities in Ethiopia is the municipal water line, which is overused with no intention of recycling or reusing. There is unnecessary energy consumption, and renewable energy sources are too limited. Concerning materials and resources, reusing and recycling wastes, using local and low-impact materials is a new concept in most buildings. Poor indoor environmental quality (IEQ) has caused health problems and decreased inefficiency in most buildings (Haileleul, 2015).

Developing countries adopt building codes and planning ideas from developed nations, which are often inconvenient for the local climate, economic, and social circumstances (Fischerbauer, 2016). According to (Negash, 2019), Ethiopia has no comprehensive regulation or standard for using a green building approach (Anshebo et al., 2022). The conference on promoting Green Building Rating Systems (GBRS) in Africa, recently organized by the United Nations Human Settlements Program (UN-HABITAT) in Nairobi, recommended the development of national and sub-regional GBRS and the establishment of national or sub-regional GBCs, which are non-profit, member-based coalitions that develop an objective, voluntary tool for rating the environmental performance of buildings (Alshboul et al., 2022; UN-HABITAT, 2010).

In many developing countries, such as Ethiopia, there is still a gap in assessing green building practices, identifying their benefits, establishing evaluation tools, and studying the challenges of implementing sustainable buildings (Shen et al., 2017). Above all, to promote the long-term development of the construction sector and improve sustainable construction practices, it is vital to develop a set of green building standards, systems, and protocols to improve the overall norm and quality of work. Hence, the objectives of this study are as follows: (1) to identify the benefits of green building in the Ethiopian public building projects, (2) to explore the challenges of implementing green building schemes in the Ethiopian public building projects, and (3) to develop a green building rating system for Ethiopian city public building projects.

The nobility of this study is the development of an integrative green building rating system for the Ethiopian construction industry. The proposed system is based on a multi-criteria-based assessment tool that can be helpful in improving the sustainable practice of the construction industry and assist the government and regulatory bodies in devising green building policies and regulations. The findings of the study enable the professionals, contractors, consultants, and design firms to understand the concepts and performance measurements of green building rating schemes across the public infrastructure sector. The results are also believed to be helpful to various stakeholders including the government, policy-makers, and the regulatory body to provide research-driven evidence for future construction and sustainability-related policy document developments.

2. Key benefits of green building practices

This section presents the concepts and key advantages of green building contextual implementation in infrastructure projects. These benefits can be classified as Environmental Benefits, Economic, and Social Benefits.

2.1. Environmental benefits

As noted by (Reddy, 2016), the main benefits of green building include the following: reducing energy consumption; decreasing the use of natural resources; protecting existing natural spaces; enhancing existing ecology; reducing water consumption; lowering greenhouse gas emissions and air pollution; improving indoor air quality; reducing volumes of solid waste; minimizing material use and using low-impact materials; reducing the use of high-energy materials in interiors, and acceptable outdoor and indoor noise levels (Alshboul et al., 2022).

Green building brings together a vast collection of practices, methods, and skills to decrease and ultimately eliminate the impacts of buildings on the environment and human health (Kamali et al., 2023; Nath et al., 2020). It often emphasizes taking advantage of renewable resources, e.g., using sunlight through passive solar, active solar, and photovoltaic techniques and using plants and trees through green roofs, green gardens, and reduction of rainwater runoff. Many other methods can be used, such as using wood as a building material or employing packed gravel or permeable concrete instead of conventional concrete or asphalt to enhance groundwater replenishment (Uparwat et al., 2012).

2.2. Economic benefits

Several authors have stated that the construction of green buildings has numerous economic benefits. The monetary usefulness of sustainable buildings is 10 times greater than the average initial investment required to design and construct a sustainable building in the long term. The benefits of life cycle cost savings on utility costs and maintenance costs make building green especially attractive to owners (Behnam, 2017).

From the life cycle point of view, the expense endeavours are similarly associated with the enhanced building efficiency of working for the most part. Appropriately, the operation cost is advanced. Green buildings are designed to save around 30% of essential energy compared to conventional structures (Ojo-Fafore et al., 2018). Building operating costs are drastically reduced as a result of the adoption of green buildings, resulting in increased productivity (Gbadegesin & Ogunba, 2010). Info and On (2019) posited that human capital, or employees' costs, are 70% and 80% of a company's expenses compared with rent at 5% and energy costs between 1% and 2%. It enhanced productivity. Ojo-Fafore et al. (2018) acknowledged about 14 green building advantages, including water and energy conservation, enhanced cost saving, improved quantity estimation, residential productivity growth, a 5% reduction in non-appearance, and additional benefits associated with comfort, hazard, attraction, and intensity.

2.3. Social benefits

Nowadays, the "feel-good" factor is a social motivator for building green buildings, especially in large cities. The social benefits of sustainable building design are about improving people's quality of life, health, and happiness. High-performance or sustainable buildings provide the best value to individuals and society. As a result, sustainable buildings have better indoor air quality, comfort, and economy and are more likely to persuade buyers that they directly affect their health and happiness.

The materials used to construct homes in non-green buildings contain hundreds of contaminants. These harmful chemicals have been connected to children's asthma, adult respiratory problems, and headaches. The contaminants, often called "sick building syndrome," directly affect the health of occupants in big cities. However, these concerns can be easily solved by utilizing green materials.

In addition to the above study results on the benefits of green building, the following benefits that have a significant contribution to sustainable construction were identified and will be discussed in detail as a result of an in-depth literature search. And meanwhile, these benefits will serve as a foundation for the study's questionnaire development. Table 1 summarizes the key benefits of green building considerations.

3. Challenges on the implementation of green building practices

Recent studies identified financial constraints, insufficient proactive plans, inadequate technology, the insufficient commitment of upper-level management, poor environmental competencies, lack of awareness among stakeholders, lack of sustainable waste management, lack of workers' training in sustainable operations, management's unwillingness, political impacts, and preferences of suppliers/institutional buyers as the barriers to the effective adoption of sustainable construction in the United States.

Similarly, Abdullah et al. (2018) explained that professionals in the built environment are still not fully trained in green construction principles, which causes a lack of the necessary education and experience to carry out such practices properly. Because it is a specialized field of study, it has not been studied or comprehensively covered at tertiary institutions. The main barriers to green building implementation include a lack of knowledge about green practices, a lack of knowledge about the effects of non-green practices on the environment, and a lack of training and education. The challenge in developing countries is combining locally sourced, sustainable materials with appropriate and sustainable new technologies to provide innovative solutions to meet the demand for more sustainable building projects rather than the sourcing or affordability of local materials.

Green construction projects have higher costs than conventional construction projects. Green projects typically have higher capital costs than traditional projects by 1–25%. The cost of a project rises as the complexity of the design rises, and modeling costs are required to incorporate green practices into projects. The cost of green technologies and materials is increasing as well. Green materials are typically 3–4% more expensive when compared to conventional construction materials (Ojo-Fafore et al., 2018).

In addition, Olawumi and Chan (2018) asserted that the implementation of sustainable (green) building involves green technologies. The creation and utilization of products, equipment, and systems conserves natural resources and the environment. These technologies have the potential to improve the environmental, human, and economic performance of buildings. Green projects require additional technology, and participants are more likely to be in an integrated work environment that brings construction management processes to another level (Assylbekov et al., 2021). One of the most common setbacks is a lack of corporate commitment and clear direction on green procurement adoption from top management. The lack of user support is due to a lack of awareness and understanding among them, as it is challenging to educate them after they have moved in (Bidin et al., 2020).

An external barrier resulting from inadequacy of regulation is due to a lack of adequate incentives for green building promotion, poor implementation of building and energy codes, poor commissioning standards, and other factors that negatively impact a stakeholder's interests (Abraham, 2018). In Nigeria (Faisal Koko & Bello, 2020), identified that the lack of available green products and materials in the building construction industry is also a hindrance to the implementation and use of green architecture. Several studies have found that green products are hard to obtain in most construction projects in developing countries. In summary, the various factors hindering the implementation of green building, as identified from various literatures, are categorized in Table 2.

Table 1. Key benefits of green building

No.	Key benefits	Reference
Environmental benefits		
1	Enhance and protect ecosystem and biodiversity	(Alohan & Oyetunji, 2021; Assylbekov et al., 2021; Oyebode, 2018; Reddy, 2016);
2	Reduce waste streams	(Alohan & Oyetunji, 2021; Assylbekov et al., 2021; Behnam, 2017; Durmus-Pedini & Ashuri, 2010; Oyebode, 2018; Reddy, 2016).
3	Conserve and restore natural resources	(Alohan & Oyetunji, 2021; Durmus-Pedini & Ashuri, 2010).
4	Reduce greenhouse gas & carbon dioxide emissions	(Behnam, 2017; Durmus-Pedini & Ashuri, 2010; Oyebode, 2018).
5	Reduce energy and water usage	(Durmus-Pedini & Ashuri, 2010).
6	Reduce construction and demolition waste	(Alohan & Oyetunji, 2021; Assylbekov et al., 2021; Oyebode, 2018; Reddy, 2016)
7	Leverage renewable energy technologies	(Assylbekov et al., 2021; Behnam, 2017; Durmus-Pedini & Ashuri, 2010; Oyebode, 2018; Reddy, 2016).
8	Using renewable natural resources	(Alohan & Oyetunji, 2021; Assylbekov et al., 2021; Behnam, 2017; Durmus-Pedini & Ashuri, 2010).
9	Maintain the integrity of the environment	(Alohan & Oyetunji, 2021; Reddy, 2016)
10	Reduce material use and use low impact material	(Alohan & Oyetunji, 2021; Assylbekov et al., 2021; Behnam, 2017; Oyebode, 2018; Reddy, 2016)
11	Improve air and water quality	(Alohan & Oyetunji, 2021; Assylbekov et al., 2021; Behnam, 2017; Durmus-Pedini & Ashuri, 2010).
Economic benefits		
12	Reduce operating costs	(Behnam, 2017; Durmus-Pedini & Ashuri, 2010; Hoxha & Shala, 2019; Oyebode, 2018)
13	Optimize life cycle economic performance	(Assylbekov et al., 2021; Behnam, 2017; Durmus-Pedini & Ashuri, 2010; Fapohunda et al., 2015; Hoxha & Shala, 2019; Oyebode, 2018)
14	Increased productivity	(Assylbekov et al., 2021; Fapohunda et al., 2015)
15	Lower health-related costs	(Assylbekov et al., 2021; Fapohunda et al., 2015; Hoxha & Shala, 2019; Oyebode, 2018)
16	Longer economic life of the facility	(Oyebode, 2018)
17	Reduce energy and water consumptions and costs	(Behnam, 2017; Durmus-Pedini & Ashuri, 2010; Oyebode, 2018);
18	Create market for green products and services	(Assylbekov et al., 2021; Fapohunda et al., 2015; Hoxha & Shala, 2019)
Social benefits		
19	Improve occupant health and comfort	(Assylbekov et al., 2021; Behnam, 2017; Fapohunda et al., 2015; Hoxha & Shala, 2019; Ojo-Fafore et al., 2018; Oyebode, 2018)
20	Minimize strain on local infrastructure	(Behnam, 2017; Hoxha & Shala, 2019; Ojo-Fafore et al., 2018b; Oyebode, 2018);
21	Improve overall quality of life	(Assylbekov et al., 2021; Hoxha & Shala, 2019; Oyebode, 2018)
22	Improve indoor air quality	(Assylbekov et al., 2021; Hoxha & Shala, 2019; Ojo-Fafore et al., 2018; Oyebode, 2018)
23	Minimizing cultural disruption	(Assylbekov et al., 2021; Behnam, 2017; Fapohunda et al., 2015; Ojo-Fafore et al., 2018)
24	Promoting harmony among human beings and between humanity and nature	(Behnam, 2017; Fapohunda et al., 2015; Ojo-Fafore et al., 2018; Oyebode, 2018);

Table 2. Summarized challenges of implementing green buildings

No.	Challenges	References
1	High upfront cost/initial investment	(Faisal Koko & Bello, 2020; Nikyema & Blouin, 2020; Olajumoke, 2019; Wu et al., 2019; Xiaolu, 2014)
2	High cost of sustainable materials and products	(Abraham, 2018; Faisal Koko & Bello, 2020; Nikyema & Blouin, 2020; Olajumoke, 2019; Wu et al., 2019; Xiaolu, 2014)
3	Long pay-back period	(Faisal Koko & Bello, 2020; Olajumoke, 2019; Wu et al., 2019)
4	Lack of demand from the public for green design and construction	(Abraham, 2018; Faisal Koko & Bello, 2020; Nikyema & Blouin, 2020; Xiaolu, 2014)
5	Lack of training and education in sustainable design and construction	(Abraham, 2018; Faisal Koko & Bello, 2020; Nikyema & Blouin, 2020; Xiaolu, 2014)
6	Poor knowledge of green building methods among professionals	(Abraham, 2018; Xiaolu, 2014)
7	Lack of awareness and readiness from the public	(Faisal Koko & Bello, 2020; Olajumoke, 2019; Wu et al., 2019)
8	Weak implementation and execution of building and energy codes	(Abraham, 2018; Faisal Koko & Bello, 2020; Nikyema & Blouin, 2020; Xiaolu, 2014)
9	Inadequacy of policies and regulations	(Abraham, 2018; Faisal Koko & Bello, 2020; Nikyema & Blouin, 2020; Olajumoke, 2019; Wu et al., 2019; Xiaolu, 2014)
10	Lack of inadequate incentives for the promotion of green building	(Xiaolu, 2014)
11	Difficulty/complexity of design and construction	(Abraham, 2018; Faisal Koko & Bello, 2020; Nikyema & Blouin, 2020; Olajumoke, 2019)
12	Lack of mature green technologies	(Faisal Koko & Bello, 2020; Olajumoke, 2019; Wu et al., 2019)

4. The need for developing a green building rating system

Ethiopia should accelerate the mainstreaming of environmental issues and strengthen its institutions to achieve sustainable development and a green economy (Belay et al., 2022). In 2011, Ethiopia published a climate-resilient green economy strategy to become a carbon-neutral middle-income country by 2025 (Birhnu, 2013). There are a variety of green building rating systems around the world (Giduthuri, 2019). A rating system developed for one region can only be applicable in that region. Even if it is applied to any other area, the building's ratings may not be accurate because the factors assumed for the rating differ from region to region (Reed et al., 2011).

Several studies have found that building assessment tools do not give due consideration to local conditions. The majority of currently existing rating systems were developed in developed countries with cold climates, stable economies, and diverse social values. Implementing the latest sustainable technologies is not feasible in developing countries with different climatic conditions (Khan et al., 2021). According to (Banani et al., 2013), some environmental factors could make it impossible to use currently functional tools in a country other than one's own. Some of these are as follows: climate context, geographic features, resource consumption, understanding of building stocks, government policy and regulation, understanding the importance of historical attributes, and understanding cultural value and public awareness. Table 3 summarizes the criteria and sub-criteria developed for this study.

5. Research design

The research was started by formulating a problem based on experience, observations, and gaps from previous studies through unstructured literature reviews, which formed the basis for the research problem formulation. The research design was prepared subsequently. A descriptive type of research was employed in this study. Based on this, the primary and secondary sources of data were determined, and also the literature review was conducted to identify variables that enabled

Table 3. Criteria and sub-criteria of the proposed green building rating system

No.	Criteria and sub-criteria	Designation	Reference
1	Site ecology	S	(Ali & Al, 2009; Darko & Chan, 2016; Olawumi & Chan, 2018)
1.1	Habitat protection and restoration	HPR	(Abdullah et al., 2018; Ali & Al, 2009)
1.2	Heat island effect reduction	HIER	(Olawumi & Chan, 2018)
1.3	Rain/storm water management	RWM	(Li et al., 2014)– (Doan et al., 2017)
1.4	Outdoor light pollution reduction	OLPR	(Mao et al., 2009)
1.5	Reduced load on local infrastructure	RLI	(Bernardi et al., 2017; Olawumi & Chan, 2018; Seyis & Ergen, 2017)
2	Energy efficiency	EE	(Alyami & Rezgui, 2012; Mao et al., 2009; Marchi et al., 2021)
2.1	Improved natural energy utilization	INEU	(Motawa & Carter, 2013; Seyis & Ergen, 2017; Shi et al., 2016)
2.2	Use renewable energy	URE	(Marchi et al., 2021; Seyis & Ergen, 2017)
2.3	Energy monitoring and metering	EMM	(Mao et al., 2009; Marchi et al., 2021; Ye et al., 2015)
2.4	Use of energy efficient equipment	UEEE	(Darko & Chan, 2016; Seyis & Ergen, 2017)
2.5	Efficient building service systems	EBSS	(Ali & Al, 2009; Li et al., 2017; Seyis & Ergen, 2017; Shi et al., 2016)
3	Water efficiency	WE	(Marchi et al., 2021)
3.1	Water consumption reduction	WCR	(Alyami & Rezgui, 2012; Mao et al., 2009)– (Motawa & Carter, 2013)
3.2	Water efficient equipment	WEE	(Li et al., 2014; Ye et al., 2015)
3.3	Water monitoring and metering	WMM	(Ali & Al, 2009; Ye et al., 2015)
3.4	Rain water and grey water	RWGW	(Alyami & Rezgui, 2012)
3.5	Water leak detection and prevention	WLDP	(Ali & Al, 2009; Ojo-Fafore et al., 2018; Olawumi & Chan, 2018)
4	Indoor environment quality	IEQ	(Mao et al., 2009; Marchi et al., 2021)
4.1	Indoor air quality	IAQ	(Mao et al., 2009; Motawa & Carter, 2013; Olawumi & Chan, 2018)
4.2	Thermal comfort	TC	(Mao et al., 2009; Rossi et al., 2009)
4.3	Visual comfort	VC	(Yu et al., 2018)
4.3	Lighting comfort	LC	(Doan et al., 2017; Olawumi & Chan, 2018; Ye et al., 2015)
4.5	Acoustic comfort	AC	(Ojo-Fafore et al., 2018)
5	Materials and resources	MR	(Ali & Al, 2009; Olawumi & Chan, 2018)– (Li et al., 2014)
5.1	Local/regional material sourcing	LMS	(Shi et al., 2016; Yu et al., 2018)
5.2	Renewable materials	RM	(Ali & Al, 2009; Ojo-Fafore et al., 2018)
5.3	Sound and thermal insulation materials	STIM	(Darko & Chan, 2016)
5.4	Materials with low health risks	MLHR	(Ali & Al, 2009; Doan et al., 2017; Li et al., 2014)
5.5	Sustainably manufactured products	SMP	(Shi et al., 2016)
6	Transport	T	(Doan et al., 2017; Li et al., 2017)

(*Continued*)

Table 3. (*Continued*)

No.	Criteria and sub-criteria	Designation	Reference
6.1	Transport accessibility	TA	(Olawumi & Chan, 2018)
6.2	Proximity of amenities (hotels, banks)	PA	(Darko & Chan, 2016; Ojo-Fafore et al., 2018; Ye et al., 2015)
6.3	Alternative mode of transport (pedestrian, bicycle-oriented spaces)	AMT	(Ali & Al, 2009; Cao et al., 2019; Shi et al., 2016)
6.4	Optimal car parking capacity	OCPC	(Li et al., 2017; Olawumi & Chan, 2018)

to meet the research objectives. Then, the questionnaire was designed and distributed to the respondents to obtain their opinions. The document reviews and observations were performed simultaneously. Based on the study findings, extensive discussions and conclusions were conducted to draw conclusions and suggest recommendations.

5.1. Sampling technique and sample size determination

Both convenience and purposive sampling techniques were used in this research. Purposive sampling, also known as judgment sampling, is the deliberate selection of a participant based on the participant's characteristics. It is a non-random technique that does not require any underlying theories or a predetermined number of participants (Etikan, 2016). Purposive sampling technique was used to select respondents from under construction public building projects. The total number of ongoing public building projects was 63. The numbers of consultants and contractors participating in the construction of those projects were 55 and 60, respectively. For practical reasons, it is only possible to include some of its members in the investigation. In this study, the target population was contractors and consultants, who are currently working on ongoing public building projects in Ethiopia.

To determine the sample size of experts (includes contractors, consultants, academics and regulatory bodies); the extant literature on AHP applications in construction management indicates that there is no strict requirement on the minimum sample size for AHP analysis. Some studies used sample sizes ranging from 4 to 9; only a few studies used sample sizes greater than 30 (Belay et al., 2022; Medineckiene et al., 2015). Taking this into account, the number of participant experts in this research was 10. The criteria to select the respondents were their work experience knowledge about green construction, educational level, interest in having a green building rating system, and whether they use or want to use green building rating systems in their work. Figure 1 summarizes the overall research flowchart of the study.

5.2. Data collection

The research used both primary and secondary sources of data. The sources of the primary data were an interview, a questionnaire, and a document review designed to gather adequate data from respondents. The questionnaire was structured based on the objectives of the research. The independent variables for the benefits of green building, the challenges of implementing green buildings, and categories of green building rating system for the Ethiopian public building construction sector.

Two types of questionnaires were distributed to the respondents. The questionnaires were developed based on the Likert and Saaty scales. Responses were given to each statement using a 5-point Likert scale of 1 "strongly disagree" to 5 "strongly agree". In contrast, for the AHP analysis; and a 9-point Saaty scale (1 "equal importance" to 9 "extreme importance") were used.

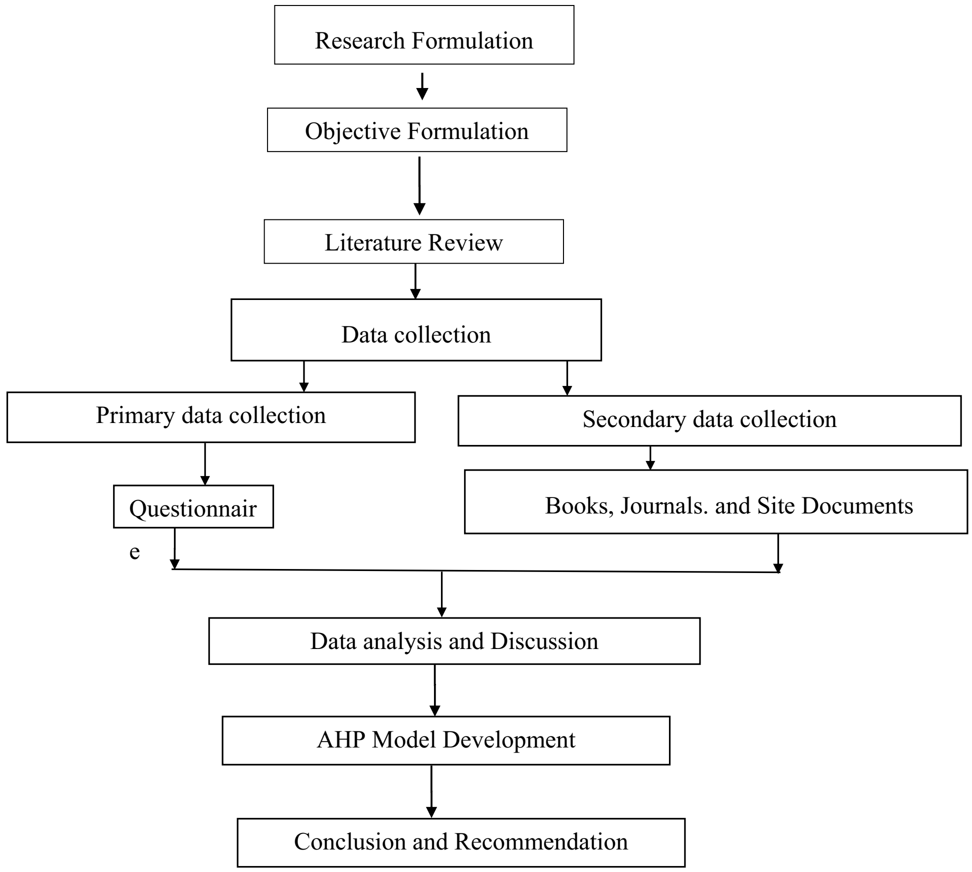


Figure 1. Research design flow chart.

5.3. Demographic profile

From the total of 83 distributed questionnaires 74 were completely filled and returned. Table 4 presents the demographic profile of respondents involved in the study. It is observed that a majority of respondents were consultants (44.6%) and 55.4% of respondents were contractors. A more or less equal distribution of employees will facilitate the complete and unbiased views of professionals in the Ethiopian public construction projects during data collection.

Table 4. Demographic summary of respondents

	Frequency	Percentage	Cumulative percentage
Stakeholders			
Contractor	41	55.4	55.4
Consultant	33	44.6	100
Year of Experience			
0–5 years	20	27.1	27.1
5–10 years	28	37.8	64.9
10–15 years	18	24.3	89.2
15–20 years	6	8.1	97.3
Above 20years	2	2.7	100
Experience			
BSc	55	74.3	74.3
MSc	19	25.7	100

5.4. Methods of data analysis

Data analysis is a process where one tries to gather and present the data in a way that has a good structure and becomes easy to understand (Keyvanfar et al., 2021; Patra et al., 2018). In addition, data analysis is a process of bringing order, arrangement, and meaning to the mass of collected data. The goal of the analysis is to come up with valid conclusions based on the empirical data. The data collected to achieve the first objective will be discussed qualitatively through a case study, the second and third objectives will be analyzed using the mean score method, and the fourth objective will be analyzed using the analytical hierarchy process (AHP).

5.4.1. Mean score method

The mean score analysis method will be used to analyze the benefits of green building and the challenges of implementing green building in the Ethiopian public building projects. The mean score ranking method was used along with SPSS. The mean score (MS) for is computed using the following expressions:

$$MS = \frac{\sum \mathrm{fx}\mu}{\mathrm{N}} \tag{1}$$

Where:

MS = Mean score

f = frequency of response for each score

μ= score given to each factor from 1 to 5

N= total number of responses for benefits and challenges.

5.4.2. Analytical hierarchy process

The Analytic Hierarchy Process (AHP) was developed in the 1970s by T. L. Saaty (Harker, 1987). It has been applied in studies with small sample sizes to survey and determine the hierarchical analysis, commonly based on experts' opinions (Kil et al., 2016). AHP is a tool that combines quantitative and qualitative data analysis. It breaks down the problem into small sub-problems. This is conducted by establishing various criteria and sub-criteria that can be employed to compare the different solutions to a problem.

These criteria and sub-criteria are organized in a hierarchical scheme that is easier to understand and compare at a lower level. The comparisons can be carried out with the help of significant numbers having ratio properties. The ratios can be utilized to generate weights or priorities that reflect the relative importance of the decision criteria (Gokhale, 2007).

According to Podvezko (2014), the method is based on the pairwise comparison matrix $C = \| c_{ij} \|$ (i, j = 1, 2, … , m). Experts compare all the evaluation criteria c_i and c_j (i, j = 1, 2 … m), where m is the number of the criteria compared. In an ideal case, the elements of the matrix present the relationships between the unknown criteria weights.

$$C = \begin{bmatrix} \mathrm{C11} & \mathrm{C12} & \ldots & \mathrm{C1m} \\ \mathrm{C21} & \mathrm{C22} & \ldots & \mathrm{C2m} \\ \ldots & \ldots & \ldots & \ldots \\ \mathrm{Cm1} & \mathrm{Cm2} & \ldots & \mathrm{Cmm} \end{bmatrix} \tag{2}$$

Normalize the comparison matrices by dividing each element with the sum of elements in the corresponding column in the Excel sheet. Then, the local criteria weights (W) were developed by taking row averages in the normalized matrices. The matrix CW is created by multiplying the comparison matrix A with a weight (priority) of matrix W, expressed as:

$$CW = \begin{bmatrix} c11 & c12 & \dots & c1m \\ c21 & c22 & \dots & c2m \\ \dots & \dots & \dots & \dots \\ cm1 & cm2 & \dots & cmm \end{bmatrix} \begin{bmatrix} w1 \\ w2 \\ \dots \\ wm \end{bmatrix} \tag{3}$$

Priorities from individual experts are aggregated into a single priority through a geometric mean in order to get an overall estimate of the weights for each criterion in every level of hierarchy. The geometric means for aggregating individual priorities using Microsoft Excel and the formula by Bhatt et al. (2010) is expressed as:

$$G(a1, a2, a3 \dots\dots an) = (a1, a2, a3 \dots\dots an)1/n \tag{4}$$

Where:
G = Geometric mean of individual priorities
a = Priority weight given by expert
n = Number of experts

The global priority weight of each parameter is calculated as per Equation (Belay et al., 2022).

$$GWP, i = WC, i * WP, i \tag{5}$$

Where: i = hierarchy level,
Wp = sub-criteria local priority weightage and
W_C = criteria local priority weightage.

5.4.2.1. Consistency. The AHP verifies consistency ratios (CR) to measure the consistency of experts' judgments that were arranged in pairwise comparisons from the survey result. A CR value greater than 0.10 indicates that the respondent is believed to give reasonable answers. In addition to the CR, the consistency index (CI) and random index (RI) will be measured. The CI evaluates the consistency of the matrix order n to determine how much inconsistency is in a matrix. RI is the average CI depending on the order n of the matrix. The formulas for CR and CI are shown below:

$$CR = \frac{CI}{RI} \tag{6}$$

$$CI = \frac{(\lambda \max - n)}{(n - 1)} \tag{7}$$

Where:
λ max is the maximum eigenvalue of the matrix
Wp = sub-criteria local priority weightage and
RI is the average CI for a number of randomly generated matrices.

Note:

- λ max is obtained by using average values of vector λ (i.e. λ is obtained by dividing the elements of CW by the corresponding elements of W or λ=w/CW).
- If the Consistency Ratio (CR) <0.10, the expert's pair-wise comparisons are relatively consistent.
- If the Consistency Ratio (CR) >0.10, the experts should seriously consider re-evaluating his/her pair-wise comparisons, the sources of inconsistency must be identified and resolved and the analysis revised.

5.4.3. Reliability test

One of the most popular methods for assessing the reliability of scales is Cronbach's alpha method. Cronbach's alpha determines the average correlation or internal consistency among variables in a survey questionnaire to assess the questionnaire's reliability. The Cronbach's alpha coefficient (α)

Table 5. Reliability test of variables using Cronbach's alpha

Variables	Cronbach's alpha coefficient	No. of items	Internal consistency
Environmental benefits	0.818	11	Good
Economic benefits	0.786	7	Acceptable
Social benefits	0.766	6	Acceptable
Cost related	0.767	4	Acceptable
Knowledge related	0.739	3	Acceptable
Government related	0.716	3	Acceptable
Technology and technique related	0.723	2	Acceptable

value ranges from 0 to 1 and can be used in describing the reliability of variables extracted from multipoint and/or dichotomous formatted scales or questionnaire. The higher the value, the more reliable is the adopted scale of measurement. However, the general rule is that to conclude that the scale is reliable, the value must not be less than 0.70. In this study, this coefficient was used to measure the reliability of the questionnaire. As shown in Table 5, the alpha coefficient was greater than 0.7 that confirmed the questionnaire reliability by all respondents.

Therefore, the internal consistency of 24 benefits of green building and 12 challenges of implementing green construction, which constitute a total of 32 variables of Likert Scale questions, were verified by calculating "Cronbach's alpha" from the valid responses.

5.4.4. Validity

The scientific soundness of a research finding is determined by the validity of the instruments used. All possible efforts were exerted to make the data collection instruments easily understandable by the respondents so that the intended information can be collected, thereby increasing the trustworthiness of the ultimate findings. As a pilot study, a content validity test was carried out.

The researcher conducted a pilot study with five participants from each type of organization to increase the clarity of the questionnaires and their flow and two for experts' opinions on the AHP questionnaire concerning the research objectives before the questionnaires were distributed to the respondents. As per the feedback gained from the participants (i.e., contractors, consultants, and experts), the researcher adjusted some of the questions and rephrased them accordingly. Then, validation of the instrument was given by an academic advisor prior to the data collection.

6. Findings

This section presents the results and analysis of data collected through a questionnaire survey.

6.1. Mean score ranking

6.1.1. Benefits of Green Building

The benefits of green buildings according to the respondents' perspectives have been studied. Respondents who participated in this study were asked to rank their level of agreement regarding the benefits of implementing green buildings. The rank of the three categories and each 24 benefits of green building were analyzed using descriptive statistics and ranked using Mean Score value. According to the obtained results, the first three groups are ranked as shown in Table 6.

As shown in Table 7, all of the categories have a mean value which is greater than 4.0 that indicate each of the selected benefits were agreed by the respondents. Each of these three categories is discussed in detail according to their rank.

Table 6. Benefits of green building adoption				
Benefits	**N**	**Mean**	**Standard deviation**	**Rank**
Environmental benefits	74	4.4312	0.387	1
Social benefits	74	4.3896	0.396	2
Economic benefits	74	4.1969	0.506	3

Table 7. Environmental benefits of green building adoption			
Environmental benefits	**Mean**	**Standard deviation**	**Rank**
Using renewable natural resources	4.70	0.591	1
Enhance and protect ecosystem and biodiversity	4.62	0.488	2
Improve air and water quality	4.62	0.542	3
Reduce construction and demolition waste	4.57	0.599	4
Conserve and restore natural resources	4.57	0.551	5
Leverage renewable energy technologies	4.46	0.686	6
Reduce energy and water usage	4.46	0.578	7
Reduce material use and use low impact material	4.42	0.811	8
Maintain the integrity of the environment	4.28	0.712	9
Reduce waste streams	4.09	0.863	10
Reduce greenhouse gas and carbon dioxide emissions	3.95	0.792	11

6.1.1.1. Environmental benefits. From environmental aspect, the responses of the respondents were aggregated to ascertain the perceived environmental benefits of the green building, and it was revealed that using renewable natural resources (MS = 4.70) ranked first. Enhancing and protecting ecosystem and biodiversity and improving air and water quality (MS = 4.62)" ranked second and third respectively, while reducing construction and demolition waste as well as conserving and restoring natural resources (MS = 4.57) ranked fourth and fifth respectively. The results are in line with the findings of (Scrucca et al., 2023; Zuo & Zhao, 2014). Other important benefits were: leveraging renewable energy technologies (MS = 4.46) ranked sixth; reducing energy and water usage (MS = 4.46) coming in seventh place; reducing material use and use low impact materials (MS = 4.42) ranked eighth; maintaining the integrity of the environment (MS = 4.28) ranked ninth; reducing waste streams (MS = 4.09) ranked tenth while reducing greenhouse gas and carbon dioxide emissions (MS = 3.95) ranked eleventh (Table 7).

6.1.1.2. Social benefits. Table 8 shows the respondent's insight towards social benefits of green buildings. Respondents ranked improving occupant health and comfort as the first significant benefit with a mean score value of 4.62. Based on the responses, improving indoor air quality was ranked as the second benefit with mean value of 4.61. The third ranked benefit according to the responses collected was Promoting harmony among human beings and between human and nature with a mean value of 4.55. The least social benefit was minimizing cultural disruption with mean value 4.12.

6.1.1.3. Economic benefits. Economic benefits were analyzed using mean score and results were given in Table 9. Respondents identified that creating market for green products and services (MS = 4.45) is the most beneficial economical component in constructing green building in Ethiopia. Lowering health-related costs, reducing water and energy consumptions and costs, and reducing operating costs were identified as the next top three economic benefits out of the seven. Based on the respondent's perception, longer economic life of the facility (MS = 4.02) is the least beneficial economical component of green building.

Table 8. Social benefits of green building adoption

Social benefits	Mean	Standard deviation	Rank
Improve occupant health and comfort	4.62	0.541	1
Improve indoor air quality	4.61	0.544	2
Promoting harmony among human beings and between human and nature	4.55	0.705	3
Minimize strain on local infrastructure	4.23	0.673	4
Improve overall quality of life	4.20	0.860	5
Minimizing cultural disruption	4.12	0.721	6

Table 9. Economic benefits of green building adoption

Economic benefits	Mean	Standard deviation	Rank
Create market for green products and services	4.47	0.624	1
Lower health-related costs	4.39	0.718	2
Reduce water and energy consumptions and costs	4.24	0.755	3
Reduce operating costs	4.23	0.786	4
Increased productivity	4.09	0.779	5
Optimize lifecycle economic performance	3.99	0.802	6
Longer economic life of the facility	3.96	0.898	7

6.1.2. Challenges of implementing green buildings

Knowledge of the challenges of implementing green building projects will aid in identifying ways to promote sustainability in the built environment. It is important to understand the hindrances that exist to provide pragmatic solutions and recommendations to mitigate such challenges and expedite the growth of the sustainable construction industry. The challenges listed in the questionnaire were devised from the literature review. The challenges of green buildings implementation according to the respondents have been studied and summarized in Table 10. Respondents who participated in this study were asked to rank their level of agreement regarding the challenges of implementing green building. Table 11 indicates that all challenges significantly hinder the implementation of sustainable buildings with an average MS of 4.0.

6.1.2.1. Knowledge related. Table 11 illustrates the results of the respondents towards the knowledge-related challenges and ranked according to the mean value. The challenges identified by the respondents were inadequate education or training about sustainable design and construction (MS = 4.64), lack of awareness and readiness from the public (MS = 4.49), and poor knowledge of green building methods among professionals (MS = 3.99), respectively.

6.1.2.2. Government related. Governments are key stakeholders in green building development because they are under pressure to reduce the carbon footprint of the built environment. As

Table 10. Challenges of implementing green building adoption

Challenges	Mean	Standard deviation	Rank
Knowledge Related	4.369	0.470	1
Government Related	4.284	0.520	2
Cost-Related Challenges	3.686	0.782	3
Technology Related	3.676	0.881	4

Table 11. Knowledge-related challenges			
Knowledge-related challenges	**Mean**	**Standard deviation**	**Rank**
Inadequate education/training about sustainable design and construction	4.64	0.487	1
Lack of awareness and readiness from the public	4.49	0.617	2
Poor knowledge of green building methods among professionals	3.99	0.829	3

a result of the urgency imposed by internal requirements and external market conditions, governments around the world are promoting mandatory policies. Governments have recognized the importance of productivity and well-being benefits in establishing the acceptance of green design by the general public (Parida, 2020). From the point of government-related challenges, lack of adequate incentives for the promotion of green building (MS = 4.69) was ranked first, inadequacy of policies and regulations (MS = 4.30) was ranked second, and weak implementation and execution of building and energy codes (MS = 3.86) was ranked third (Table 12).

6.1.2.3. Cost related. Table 13 illustrates the results of the respondents towards the cost-related challenges and ranked according to the mean value. The results demonstrate that challenges as considered by the respondents were lack of demand from the public for green design and construction (MS = 4.41), long payback period (MS = 3.64), high upfront cost or initial investment (MS = 3.50), and high cost of sustainable materials and products (MS = 3.20) and ranked from first to fourth, respectively.

6.1.2.4. Technology related. Comparing the two technology- and technique-related challenges, the lack of mature green technology (MS = 3.77) was ranked as a prior challenge and the difficulty or complexity of design and construction (MS = 3.55) was ranked next (Table 14).

7. Discussion and practical implication

This section describes the overall green building rating model development along with the comparison of the model with the LEED rating system as part of the validation process.

Table 12. Government-related challenges			
Government-related challenges	**Mean**	**Standard deviation**	**Rank**
Lack of adequate incentives for the promotion of green building	4.69	0.521	1
Inadequacy of policies and regulations	4.30	0.754	2
Weak implementation and execution of building and energy codes	3.86	1.011	3

Table 13. Cost-related challenges			
Cost-related challenges	**Mean**	**Standard deviation**	**Rank**
Lack of demand from the public for green design and construction	4.41	0.810	1
Long payback period	3.64	0.987	2
High upfront cost or initial investment	3.50	1.037	3
High cost of sustainable materials and products	3.20	1.158	4

Table 14. Technology-related challenges

Technology- and technique-related challenges	Mean	Standard deviation	Rank
Lack of mature green technology	3.77	0.987	1
Difficulty or complexity of design and construction	3.55	1.022	2

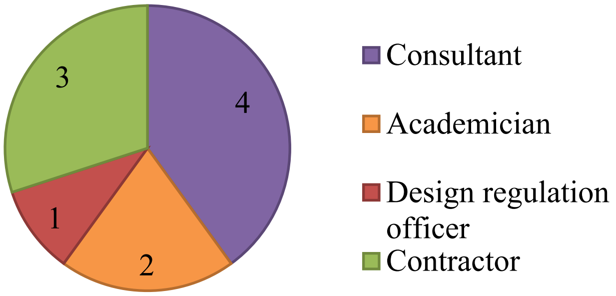


Figure 2. Experts' professional engagement for the AHP analysis.

Table 15. Summarized weights of criteria and sub-criteria

Criteria	Weights of criteria	Sub-criteria	Local weights of sub-criteria	Global weights
Site ecology	0.2020	HPR	0.364	0.0735
		HIER	0.292	0.0591
		SWM	0.142	0.0287
		OLPR	0.116	0.0234
		RLLI	0.086	0.0173
Energy efficiency	0.2133	INEU	0.325	0.0692
		URE	0.356	0.0760
		EMM	0.097	0.0208
		UEEE	0.091	0.0193
		EBSS	0.131	0.0280
Water efficiency	0.2470	WCR	0.374	0.0925
		WEE	0.222	0.0549
		WMM	0.152	0.0376
		RW	0.070	0.0172
		WLDP	0.182	0.0448
Indoor environment quality	0.1194	IAQ	0.303	0.0362
		TC	0.320	0.0382
		VC	0.167	0.0199
		LC	0.139	0.0166
		AC	0.070	0.0084
Materials and resources	0.1741	LMS	0.108	0.0189
		RM	0.335	0.0584
		STIM	0.095	0.0166
		LHRM	0.255	0.0444
		SMP	0.206	0.0358
Transport	0.0443	TA	0.304	0.0135
		PA	0.379	0.0168
		AMT	0.244	0.0108
		OCPC	0.072	0.0032

7.1. AHP analysis

Initially, the performance criteria for the proposed rating system were developed and discussed with three of the participant experts and made some improvements before developing a questionnaire to determine the weights of each criteria. The questionnaire was filled by 10 experts from different types of organizations covering a large range of the market. As shown in Figure 2, four consultants, two academicians, one design regulation officer, and three contractors participated in the AHP analysis.

The study refined six main criteria of green buildings rating system. The obtained criteria scores are as follows: Site ecology (20.2%); Energy efficiency (21.33%); Water efficiency (24.7%); Indoor environment quality (11.94%); Materials and resources (17.41%); and Transport (4.43%). It can be observed that the transport category of the sustainability was given the least weightage (4.43%) compared to all other categories, and water category was considered to be important greater with a weightage of 24.7%. The results indicate that water efficiency accounts for the largest distribution of priority weighting for the Ethiopian public building projects. Meanwhile, energy and site ecology were also indicated as a second and third significant issue (see Table 15).

Figure 3. The proposed green building rating system model.

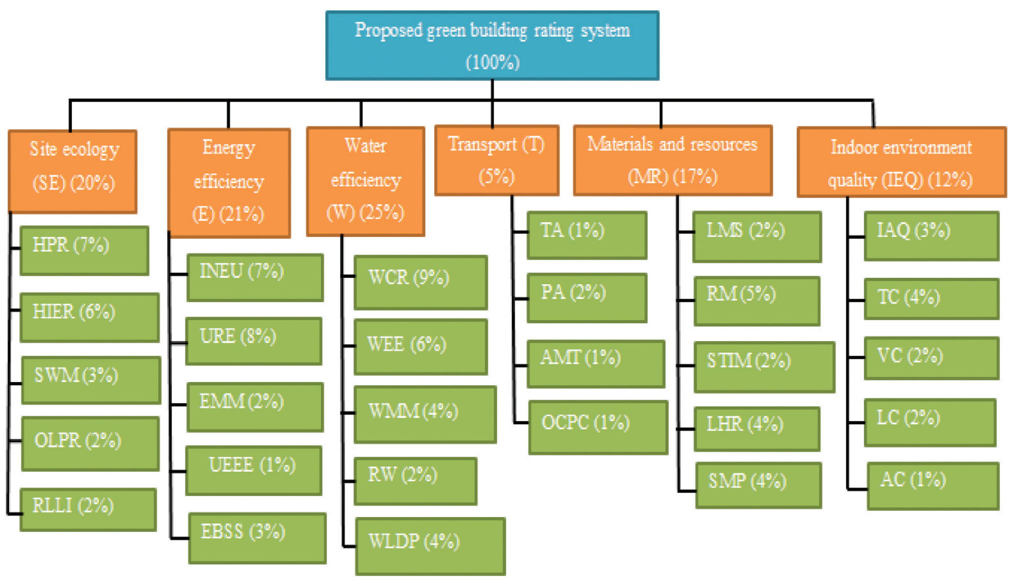


Figure 4. Comparison between the proposed and LEED rating systems.

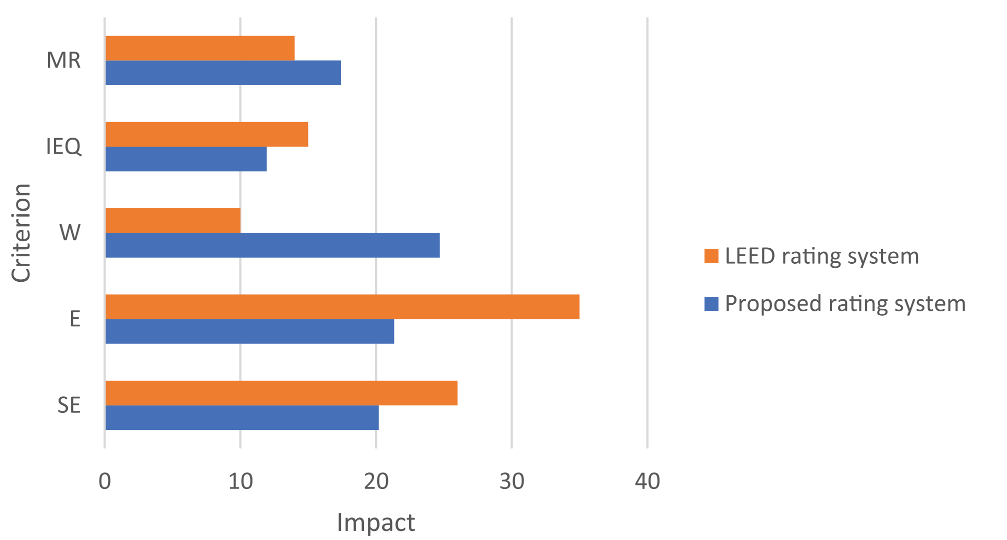
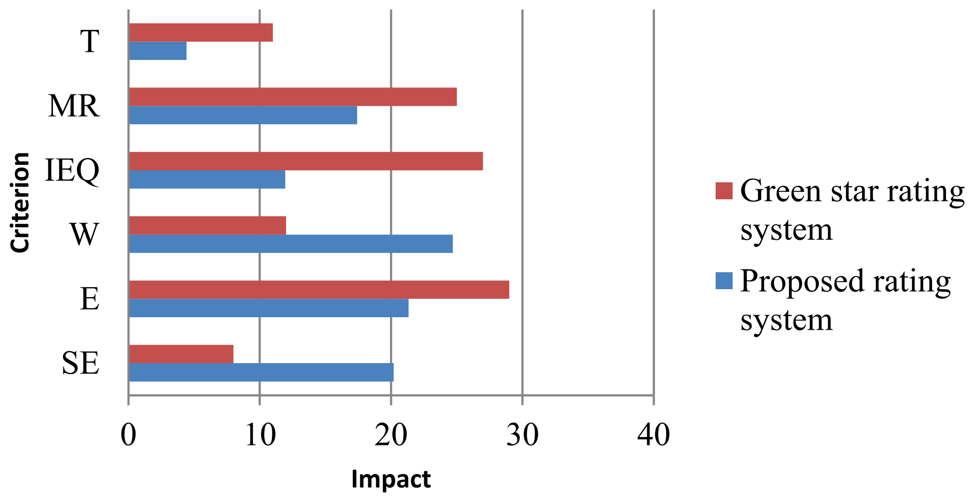


Figure 5. Comparison between the proposed and green star rating systems.



The total maximum point given for this system was 100%. Each criterion consists of a number of sub-criteria and the scores for each criterion were divided and allocated to sub-criteria based on the expert's opinion and ranking. The rating system certification criteria were based on summation of scores of sub-criteria for a maximum score of 100 points.

Figure 3 outlines the final rating model consisting of 6 major criterions and 29 sub-criterions covering various aspects of sustainability principles.

7.2. Comparison and model validation

The environmental impact of the construction industry has been well documented. Many rating tools have been developed since the 1990s to suggest efficient solutions to assess the construction impacts on the environment. Unlike LEED, many available green building rating tools lack inclusiveness and focus on various aspects of sustainable performance of buildings across the project life cycle. This section outlines the comparison of the proposed green building rating system against the LEED rating system.

The LEED rating tool provides emphasis on energy efficiency, while the newly developed rating system focuses on water efficiency. The municipal waterline is usually the primary source of water supply during the building's operational period. The study reveals that energy efficiency and site ecology are the second and third necessary criteria in which buildings are going to be measured for their greenness (see Figure 4).

Similarly, the Green Star mainly gives special attention to water efficiency criteria, as shown in Figure 5.

8. Conclusion

The goal of this study was to develop a benchmarking green building rating system for the Ethiopian public building construction projects.

- Initially, this study focused on identifying the benefits of green buildings in the local context of Ethiopia. These benefits range from using renewable natural resources, enhancing and protecting ecosystem and biodiversity, and improving occupant health and safety, respectively.
- Similarly, the current study examined the critical challenges of implementing green buildings in the Ethiopian context. The findings revealed that knowledge-related challenges were the main barriers that impede the implementation of sustainable construction.

- Moreover, the study identified 6 criteria and 29 sub-criteria as the most appropriate rating criteria for rating of the performance of green buildings in Ethiopia. The criteria include site ecology, energy, water, indoor environment quality, materials and resources, and transport.
- As per the proposed model, water has the highest weightage, and energy has a second higher weightage of the overall system. Site ecology weighs about 20.2% of the total, and is placed third relevant criteria. This shows that during the construction of buildings, water efficiency, energy efficiency, and site ecology should be strongly considered to achieve sustainability in the Ethiopian public infrastructure projects.
- The limitation of the study is threefold. First, the data only focus on active public building construction projects that are more than 50% completed for the ease of evaluating the most relevant criteria.
- In addition, main players including contractors and consultants participated in the study. However, it is also important to include the perspective of other stakeholders including academia in the data collection.
- Finally, this study does not cover gender influences on sustainable construction practices in Ethiopia.
- Future studies could focus on identifying the key drivers to overcome the challenges facing the implementation of green buildings, and the development of performance criteria to evaluate public and private building projects.

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Author details
Rediet Gashaw[1]
Solomon Belay[2]
E-mail: solarmelaku@gmail.com
ORCID ID: http://orcid.org/0000-0002-5931-9089
Anmut Gizat[3]
Solomon Hailu[3]
Saeed Rokooei[4]
Jose Matos[5]
[1] Department of Construction Technology and Management, Debre Markos University, Debre Markos, Ethiopia.
[2] Faculty of Civil and Water Resources Engineering, Bahir Dar University, Bahir Dar, Ethiopia.
[3] Department of Construction Technology and Management, University of Gondar, Gondar, Ethiopia.
[4] College of Architecture, Art and Design, Mississippi State University, Starkville, USA.
[5] Department of Civil Engineering, Campus De Azurem, University of Minho, Guimaraes, Portugal.

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