SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V11I12P102

Volume 11 Issue 12, 12-29, December 2024

Original Article

Influences of Technological Innovations on the Construction Methodology for Sustainable Low-Rise Buildings in the Philippines

M. B. Javier[1], C. E. F. Monjardin[2]

[1,2] *School of Civil, Environmental, and Geological Engineering Mapua University, Muralla St, Manila, Intramuros, Philippines.*

[1]*Corresponding Author : mbjavier@mymail.mapua.edu.ph*

Received: 04 October 2024 Revised: 09 November 2024 Accepted: 24 November 2024 Published: 26 December 2024

Abstract - *The construction of ecologically friendly structures has increased dramatically during the last forty years. The advantages of green buildings are becoming more widely understood. Rising energy and construction material costs and legislative incentives are also driving the expansion of the sustainable building sector. One barrier to sustainable building is the capability to accomplish a sustainable project within realistic cost limitations and timetables while considering health-safety impact and environmental risk. Traditional building construction must adapt for project managers to provide sustainable construction that meets their client's expectations in terms of cost, schedule, health and safety requirements, and environmental acceptance. This can be accomplished by implementing Smart and Innovative construction techniques to provide a more comfortable built environment while minimizing a site's carbon impact. Sustainable buildings with technology and lifestyle practices can increase water and energy efficiency. This study focused on Technological Innovations in the Construction Methodology for the Sustainability of Low-Rise Buildings in the Philippines. Furthermore, the goal was to provide an idea to the owners and professionals regarding the impact of technological innovations that they can follow to make decisions in the construction of green buildings, as well as to provide a value-focused tool to improve system performance that can be applied to other projects.*

Keywords - *Green building, Sustainability of Low-rise Buildings, Construction of environmentally friendly buildings, Smart and Innovative construction, Low carbon footprint.*

1. Introduction

Sustainability has developed from its initial popularity in the late 1970s. Initially, it was viewed solely economically, with little consideration for the environment. This concept was linked to environmental concerns in the late 1980s, culminating in the recognized concept of sustainable building evolution. Furthermore, the current realities of construction in the industrialized world have highlighted the importance of sustainable new building construction and upkeep. Building quality and efficiency impact people's environmental, economic, and social issues. Sustainable building ensures that by improving human activity on all fronts—economic, social, and environmental—future generations' livelihoods are not compromised. In contrast, the current generation's quality of life is preserved or improved (M.P. Amado et al., 2007) [1].

Several studies have looked into the relationship between technology innovation and sustainable construction. Akbari et al. (2020) [2] provide one example of a bibliometric assessment of sustainable innovations, which offers a bibliometric review of sustainable technology studies in the sustainability field. A thousand of hundred twenty-two publications published between 1970 and 2019 were included in the Web of Science (WoS) database.

Sustainable construction is gaining popularity as people become more aware of its environmental benefits. As a result, more local governments are establishing green building legislation and regulations, as well as providing permits and financial incentives to promote sustainability. Furthermore, with the growing need for sustainable construction, many contractors utilize technical advancements to help structures become self-sustaining. Green development has obstacles and barriers owing to technology breakthroughs, including cost premiums, project timelines, and environmental impact.

This study seeks to determine and categorize various technological innovations by usage based on their impact on construction aspects such as environmental and health safety impacts, cost, and resources—the timeframe for constructing sustainable low-rise buildings—to assist clients and contractors in overcoming the construction issues associated with creating sustainable low-rise structures.

2. Literature Review

2.1. Overview of Sustainable Building

The Sustainable Development Goals (SDGs) initiatives, which serve as the framework for the global agenda, are moving the world forward faster. These goals indicate a sustainable growth path, which gave rise to the concept of green buildings and established it as a new trend in the cutting-edge technological domain of the built environment. Many industrialized and developing countries have set goals and programs to prioritize the planning and executing of sustainable-building projects (Kibert, 2004) [3].

A sustainable structure is one that, by means of design, construction, or execution, reduces or eliminates adverse effects on our climate and natural surroundings without retaining a chance to produce positive ones. Green buildings protect natural resources while improving residents' quality of life.

According to Aquino et al. (2013) [4], sustainable construction can protect natural resources by lowering negative environmental impacts and expenses associated with transport and water consumption. Sustainable buildings offer social, economic, and environmental advantages. Furthermore, sustainable buildings increase overall quality of life by maintaining a healthier indoor environment and air quality, improving tenant health and comfort, and reducing the burden on public infrastructure. In addition, they promote community growth and innovation. Sustainable structures have also proven to be economically beneficial. They boost revenue, save operational expenses, and improve tenant productivity. Because sustainable buildings are now sustainable, they have the potential to influence people's lives and the course of the future.

In addition, L. Zheng (2021) [5] claims that green buildings involve three factors: energy saving, which is generalized to include the four parts (energy, land, water, and material saving), primarily focusing on reducing resource waste; environmental considerations, which emphasize reducing environmental pollution and carbon dioxide emissions; and meeting user needs, which involves providing people with appropriate amenities.

Green buildings substantially impact the entire use cycle and are related to resident health, operational costs, and user function. "health" and "high efficiency" refer to the sensible use of resources and energy while lowering carbon dioxide emissions and environmental pollution. "Applicable" refers to conserving resources rather than lavish waste. Making the design "green" is a prerequisite for creating green buildings.

2.2. Overview of Technological Innovation

The Construction Industry Institute describes technological innovations in construction as the collection of novel equipment, machines, materials, modifications, and software used during the building phase of a project to enable advancements in field construction procedures. Koskela and Vrijhoef (2001) [6] and Slaughter (1998) [7] define innovation as the real implementation of a sophisticated modification and growth in a process, outcome, or method that is unique to the institution's modification. Toole (1998) [8] provides the most detailed review of building innovation. He describes it as the implementation of a new technology within a company. It enhances the design and construction of living spaces by lowering installed costs, improving installed efficiency, and optimizing the business procedure by shortening lead times or increasing flexibility. According to Aurellado (2015) [9], people perceive the effect of green technology on time and cost differently. Increasing environmental awareness and high energy costs have also propelled architects, designers, and builders to create energy-efficient, climate-adaptive buildings. The five critical components of green architecture call for creativity. Its components include a cooling system, lighting system, water management system, sustainability in walls (low carbon footprint), and alternative energy sources.

2.3. Technological Innovations in Sustainable Building

Several studies and research on technological advancements for sustainable buildings have been conducted, such as the research of G. Elshafei et al. (2022) [10], who studied artificial intelligence-based green building technologies. As per the writers, the Analytical Hierarchy Process (AHP) integrated techniques are practical, efficient, and successful in sustainable green building under various environmental and research difficulties.

In addition to the process of green building technologies, other studies involve technological advancements in sustainable building construction, such as Mousa et al. (2014) [11], who proposed a 3-D Panel System as a sustainable solution that provides structural and architectural advantage embraces green building demands and ensures modern practices in the Egyptian construction market. Modern HVAC technologies like evaporative, desiccant, and demand control ventilation are examples of sustainable building construction innovation. According to Hui (2001) [12], these advancements have been successfully applied in a few specialized applications. Performance enhancements will continue to lower system costs and speed up the introduction of new technology into current HVAC equipment. In addition, more building owners would seek to incorporate environmentally friendly innovations if it resulted in happier tenants and better occupancy rates giving them a competitive advantage. The new technology will contribute to the green revolution, which will be made possible by HVAC and building designers.

Table 1. Five Aspects of Technological Innovations in Sustainable Building with their Example

Five Aspects of Technological Innovations in Sustainable Building	
Example of a Cooling System • Demand Control Ventilation • Desiccant Cooling • Night-Time Radiative Cooling	**Example of Lighting System** • Occupancy Sensor • Dimmer Switches • Preset Lighting Controls
Example of Water Management • Greywater and Rainwater Collection for Toilets • Low-Flow Toilets • Composting Toilets	**Example of Sustainable Wall – Minimized Carbon Footprint** • Modular Panel • Blocks with Foam • Insulation 3D Printing
Example of Alternative Energy • Solar Energy or Photovoltaic (PV.) Systems • Wind Turbines • Hydroelectric Systems	

For water management, demographic expansion in a setting marked by urbanization and economic growth puts additional strain on the world's traditional water supply (Filali et al., 2022) [13]. In dry and semi-arid areas, where the lack of variety in rainfall and substantial absorption damages the water and salinity balance in the soil, increased focus is now necessary on other water resources. Sheth (2017) [14] discussed different water technologies for sustainable construction, such as Low-Flow Plumbing Fixtures, Water-Efficient Toilets, appliances, water audits, and Wastewater Treatment. According to the author's study, water technologies can help reduce water consumption by 30% compared with standard fixtures. Furthermore, Zhang et al. (2021) [15] investigated Sustainable Building Design using Solar Energy. According to the authors' results, with the increasing challenges of global warming, environmental degradation, and resource scarcity, lowering building energy consumption and attaining sustainable building development have become critical themes in construction research. Solar project collaboration, rooftop photovoltaic panels, supplementary sunlight booths, solar heating systems, and other ways to use solar energy are some examples. Lastly, technological innovations in sustainable structures include lighting systems. Norsyafizan and Muhamad (2010) claimed that a building's lighting uses electricity the most. Lighting is often attributed to 20%–50% of all electricity use. Consequently, managing the lights in a low-rise building will result in effective cost and energy savings. Utilizing lighting wisely and economically can save considerable amounts of energy and money. These are just a few examples of the technological innovations used to construct sustainable buildings. These technologies are some of the example studies conducted by other researchers for Sustainable Building Construction that will influence the project's outcome in terms of cost, timeframe, and environmental impact.

2.4. Cost, Timeframe, Environment, and Health-Safety on Technological Innovations in Sustainable Building

Although the literature reviewed in the previous section does not explicitly address the factors that determine the success of an innovative building product or what relative advantage means for the construction of new sustainable buildings, it suggests that innovation is significant and relevant in determining the success of green building projects.

Discussed below are the criteria that determine the success of green building technology:

2.4.1. Cost

The most crucial specification for a new building product is its price (CERF, 1994; Toole, 1998; PATH, 2000). The total installed cost, the most significant cost aspect, is the total material, labor, equipment, and other indirect costs incurred by the contractor in connection with a particular project area until the point of owner acceptance. These expenses could be connected to a single activity carried out by the contractor's employees or a group of operations carried out by the subcontractors. A contractor will be able to retain its price and boost profit margins by adopting new technologies or will be able to cut their prices and expand their market share. Additionally, the consistency of costs is significant, in addition to the average cost reduction. From a risk management perspective, a development that lessens the unpredictability of work but does not necessarily lower the average task cost is preferable. (T.M Toole, 2001) [16].

2.4.2. Timeframe

According to Toole (2001) [16], time is analogous to cost in that the total amount matters most, and the less it is, the better (NAHBRC, 1993; CERF, 1994). Both direct and indirect benefits can be attained within a short cycle duration. Two examples of direct benefits are reduced expenditures for general conditions (superintendents, trailers, etc.) and building financing. The capacity to command better prices, which some clients will pay more, could likewise be considered a direct gain. Reducing two project risks: cost risk (the possibility that the project may cost more than estimated) and market risk is one of the indirect benefits (the risk that the market will not support the estimated sales rate or prices). Because expenses can be fixed for the duration of a subdivision, reducing the cycle time lowers the possibility of cost overruns.

2.4.3. Environment and Health and Safety Impact

Sustainable technology innovation is part of the broader concept of technological and managerial innovation aimed at environmental protection. While some innovations can considerably enhance production, they fail to address the environmental effects. For example, technical innovation is centered entirely on increasing output in energy-intensive businesses. As a result, many sections of society embrace the "green" mindset and prioritize economic growth and environmental concerns (Gorelick & Walmsley, 2020 [17]; Sukharev, 2020) [18].

There are two (2) ways to analyze the influence of sustainable technology on health and safety in sustainable building: during and after construction.

In construction, health and safety can be described as the degree to which workers and those directly or indirectly affected by site operations are unaffected by accidents, illnesses, injuries, and other health conditions caused by specific construction activities. (Nnedinma, 2016) [19].

In contrast, the project's end-user health and safety following construction will determine the effectiveness of green building construction.

3. Methodology

3.1. Statement of the Problem

According to the 2022 Global Status Report for Buildings and Construction [20], the building area's operating energy-related Carbon Dioxide emissions totalled 10 gigatonnes of CO2 equivalent, a 5% increase over 2020. Heating, cooling, lighting, and building equipment operational energy demand increased by 4% in 2021 compared to 2020 and 3% in 2019. Buildings are at fault for this predicament; thus, there is an urgent need to address sustainability in all new developments. As a result, the planet's ecology will be stable, and the ecosystem will be healthy. Conversely, Technological developments have created difficulties and constraints to sustainable growth, such as cost expenses, project deadlines, and adverse ecological effects.

Although many theorists and practitioners have experimented with and theorized about innovative building systems in the construction of green buildings, little research has been published that will help stakeholders identify what technological advancement needs to be prioritized for projects to become more likely to succeed.

3.2. Research Objectives

The specific objectives of this research are outlined as follows:

1. Determine the Technological Innovations in Sustainable Building Based on Literature Review.
2. Identify and rank the different technological innovations per usage according to their effect on construction aspects such as environmental and health safety impacts, cost, and resources—the timeframe for constructing sustainable low-rise buildings. This can be achieved by carrying out pairwise comparisons. The weighted average of the pairwise comparisons was computed using the Analytical Hierarchy Process (AHP).
3. Create an Output of Research Development Model.

The author anticipates that achieving the research objective by utilizing the AHP report's evaluation of technological innovations that will be highlighted in the study will significantly assist stakeholders in achieving a headache-free building by avoiding the typical problem of budget overruns and time constraints by prioritizing the technological innovations that will be more beneficial to the project, in addition to having a more environmentally friendly building.

3.3. Significance of the Study

The significance of this study is that it provides owners and professionals with informative data that they can use to make decisions about the construction of green buildings and a value-focused tool to improve system performance that can be applied to other projects.

3.4. Scope and Limitations

The scope of this study is to assess the impact of technological innovations on the construction methodology of sustainable low-rise buildings.

The limitations of the research study include the following:

1. According to the Philippine Statistics Authority (PSA), residential construction accounted for 71.2 percent of total new construction in Q1 2022 (26,546 units) [21]. This type of building experienced a 4.0% increase. Single-family dwellings accounted for 85.9% of all housing construction. As a result, this study focuses on the most common type of building: low-rise buildings, which include residential, warehouse, and commercial structures. Therefore, the study excluded high and medium-rise buildings. High- and medium-rise buildings can be included in a separate study to ensure consistent results across all types of buildings.
2. The research study solely considers the environmental impact, cost, timeline, and risk to human health and safety in the construction of green buildings by employing various technological advancements. Since it was anticipated that all technological innovations would have the same level of quality, they were not included in the study.
3. The study will not address project-related contracts, testing, or structural calculations.
4. The impact of technological innovations on the construction of low-rise green buildings in the

Philippines was investigated. Therefore, this study did not consider the construction per phase of the project.

5. The research study will not address Green Building Standards and Criteria such as LEED, BREEAM, and BERDE.

3.5. Conceptual Framework

A conceptual framework is a visual tool that helps the reader analyze and gain a full understanding. It is commonly used for visually organizing and describing systems, relationships, concepts, and ideas. This analytical tool has numerous uses and contacts, making it helpful in various professional contexts.

The project's success depends on stakeholders' decision-making, including the consultant, contractor, and designers. Moreover, stakeholders' involvement should carefully select and prioritize the technological innovations they will use in their green building projects.

Therefore, this study explores the effects of technological innovations in sustainable building construction on choosing and ranking different technological advancements related to technology that will impact the project's cost, schedule, environmental impact, and health safety risk to help stakeholders in decision-making and project planning.

The relationship between green buildings and technological innovations can be determined by exploring different research papers, websites, and articles related to sustainability and technological advancements. Moreover, by reviewing the literature of different research papers, the author can determine five aspects of technological innovations in green building construction: sustainable walls, cooling systems, lighting systems, water management, and alternative energy.

Subsequently, a poll will be conducted with a group of people to compare various technology requirements for green building development. After completing the study, this will serve as the foundation for the researcher's Pairwise Comparison presentation.

A pairwise comparison can help determine the comparison of cost, timeframe, environmental impact, and health/safety risk between different aspects of green building technology.

3.6. Research Design

The current study's research approach includes a research design with inductive and deductive reasoning methodologies and qualitative and quantitative procedures. This includes data gathering methods, which describe primary and secondary data collection and the motivation for doing so. This section will also specify the data collection method, such as a survey, questionnaire, or research.

After evaluating the relevant literature on technological advancements in sustainable buildings, the following step is to select a sample because the data from the respondents must be acquired for further analysis. As a result, the sample must be chosen using various criteria, including the nature of the study, aims, convenience, a lack of resources, and time and money. After the data has been collected, it is evaluated with various tools and procedures. Data analysis can be carried out using either software or manual tools. Ideally, the data analysis process comprises procedures for testing the data to get the desired findings. In this case, data were examined utilizing the AHP Online System for Pairwise Comparison.

3.7. Area of Study

Many technological advancements are taking place today, some of which only apply to certain nations. Thus, the author limits developments in the Philippines to addressing the problems associated with a broad field of study.

3.8. Data Collection Method

Surveys, a popular form of data collection for this study, will be used in the field research. These are especially useful for descriptive, non-experimental methods depicting reality. As a result, a survey method was utilized to determine the prevalence and incidence of various concerns. (Nathan Mathers et al., 2009) [22]. The author employed closed-ended questions and a comparison poll, with respondents given choice answers. The survey's goal was to offer a precise, clearly recognized, and readily classified answer, allowing the interviewer to obtain the same information from a diverse variety of respondents in the same manner.

3.9. The Population of the Study and Sampling Techniques

Some research may involve a limited population, insufficient to warrant covering everyone. However, this study may include a large population that cannot be investigated. The sample represents a fraction of the population under investigation (Nworgu, 1991, p. 69) [23]. In this study, the sample was a smaller group chosen from a larger population using a predetermined technique. The components of this sample were used in the research. In the first part of the second stage of the study, five experienced sustainability specialists were tasked with identifying the most common technological breakthroughs across various aspects of the sustainable construction project, specifically for low-rise buildings. All participants had extensive experience in sustainable construction, with the majority having over 16 years in the industry. Their ages varied: some were over 50, while others were under 45.

The quantitative investigation is the second part of the second stage phase of the research; a survey with a sample size of at least fifty (50) participants was planned. They were instructed to compare two technological breakthroughs in sustainable building construction, with three examples from each area.

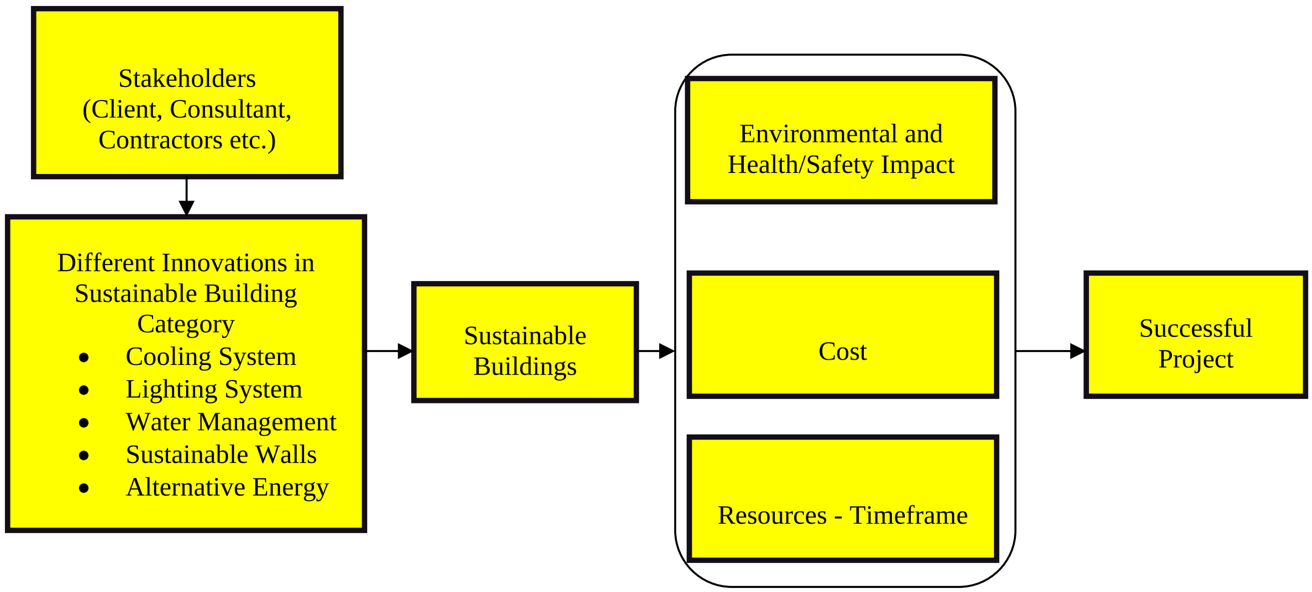

Fig. 1 Conceptual framework

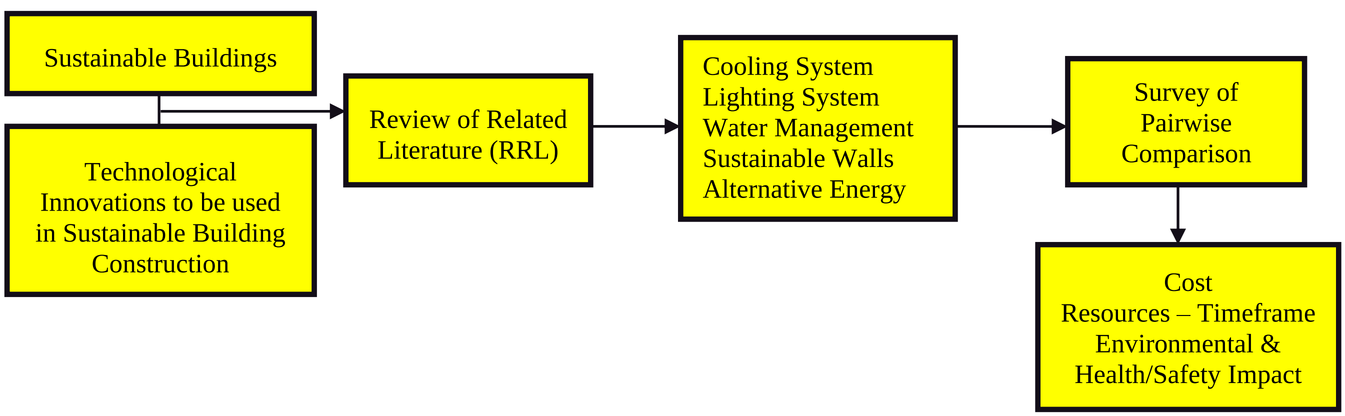

Fig. 2 Schematic diagram of the research flow

Purposive sampling was employed to choose participants who completed the questionnaire for the study under discussion. This method, which falls under non-probability sampling techniques, selects sample members based on their knowledge about, connection to, and experience with research.

The sample members chosen for the current study had considerable relevant job experience in the sustainable construction industry, a research background, and knowledge of sustainable buildings.

Sample sizes greater than 30 but fewer than 500 are adequate for most studies. However, non-probability sampling methods do not permit a margin of error or confidence interval computation. As a result, it is difficult to identify the proper sample size for non-probability sampling. Consequently, the author determined that the study would contain a minimum of 50 participants.

3.10. Data Analysis using the Analytical Hierarchy Process (AHP)

Thurstone's work laid the groundwork for the design and guiding principle of scale creation utilizing the pairwise comparison approach (1927, 1959) [24]. Thurstone developed a method and model for scaling a collection of stimuli by directly comparing two stimuli simultaneously. He described the law of reasonable decisions as the formalization of the procedure.

The study used a fieldwork methodology for the research paper to obtain the required results, including survey questionnaires. The author requested at least 50 participants to answer the survey by comparing two technological innovations in green building construction. Furthermore, the survey will also indicate the current profession of contributors to validate their awareness of the technological development of green building structures.

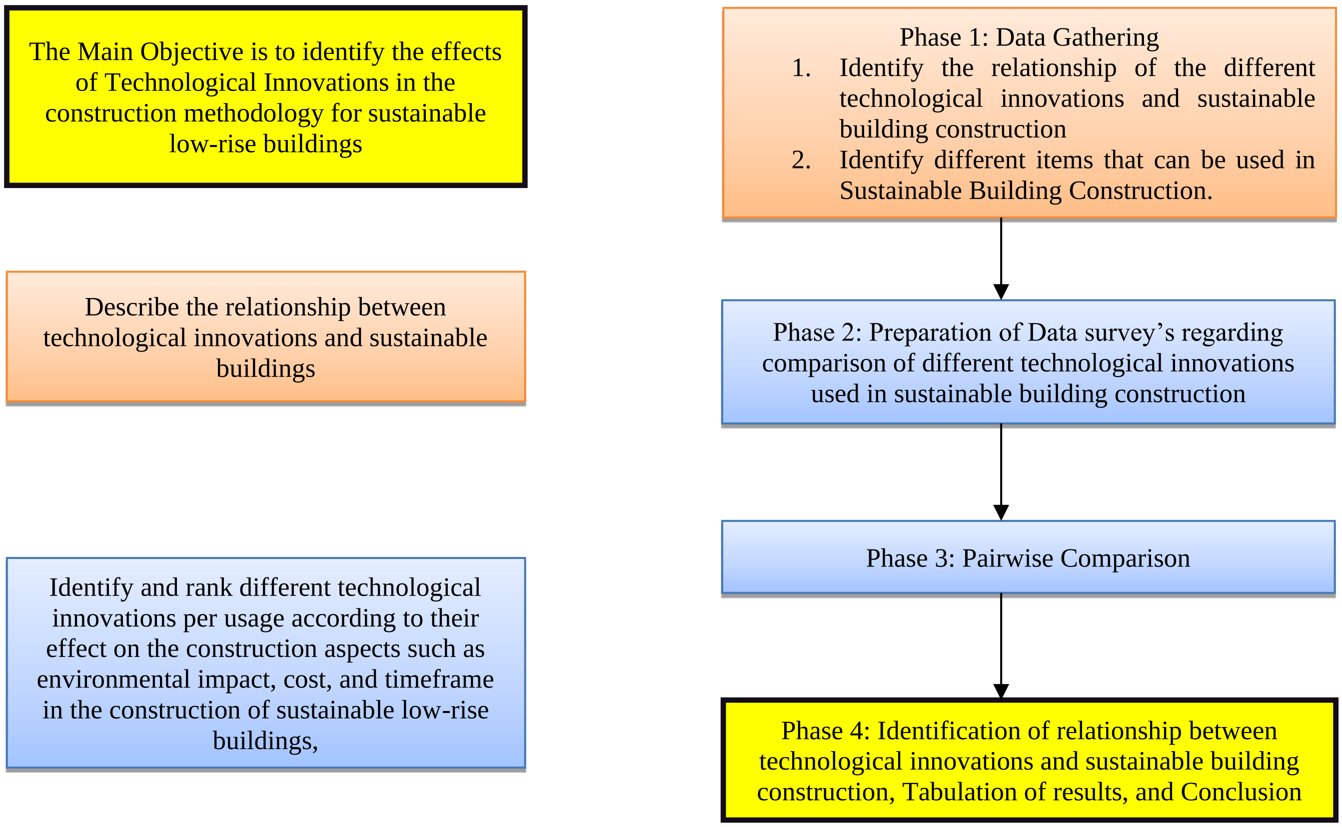

Fig. 3 Objectives and Step-by-Step Flow of the Research

The matrix-like questionnaire used to determine the criteria hierarchy included those listed in both directions (i.e., columns and rows). Respondents' use of pairwise comparisons was the intended outcome. This method aims to analyze which is more important and gives stakeholders an idea of what to prioritize in green building – technological innovations, considering the construction project's cost, time, environmental impact, and health safety risk.

The Analytical Hierarchy Process (AHP) was utilized to calculate the weighting scale for pairwise comparison. AHP is among the numerous quantitative and qualitative tools used to assess data. Thomas Saaty developed it in 1970 for decisions that require criteria and a range of options. Options typically differ in preference for each criterion, and the criteria typically have varying degrees of relevance. A measurement mechanism is required to make these trade-offs and decisions. A thorough understanding of the measurement techniques and ranges is necessary. (T. Saaty, 2004) [25].

Refer to Table 2 and Figure 4 for scale interpretation of pairwise comparison according to Saaty (1980) [25].

Interpretation:

- Desiccant Cooling is essential compared to Demand Ventilation.
- Demand Ventilation is absolutely important compared to Radiative Cooling.
- Desiccant Cooling is of equal importance to Radiative Cooling.

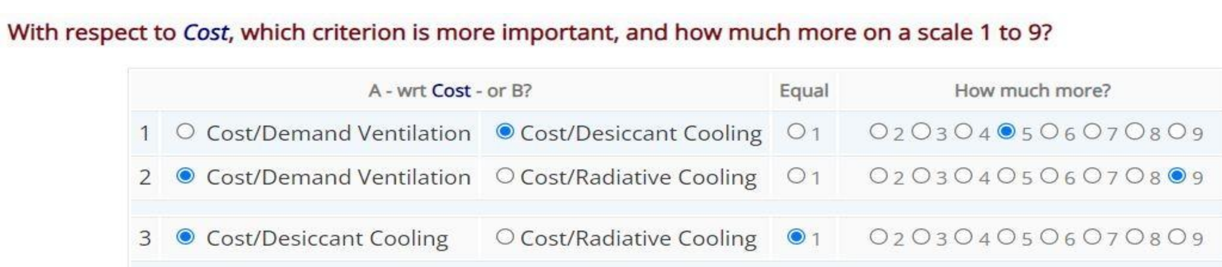

Fig. 4 Sample Survey Accomplish Form for Pairwise Comparison to be Used for Analytical Hierarchy Process (AHP) Study. Image Credit: Goepel K.D (2018) [26]

Table 2. Scale Interpretation for Pairwise Comparison according to Saaty (1980) [25]

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate Importance	Slightly in favor of one option over another based on experience and judgment
5	Essential or Strong Importance	Firmly in favor of one option based on experience and judgment
7	Very Strong Importance	Very Strongly in favor of one option over another based on experience and judgment
9	Extreme Importance	The evidence favoring one option over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed

Analytical Hierarchy Process (AHP) is a decision-aided approach that creates a hierarchy from a complex multifactor problem. Construction researchers have extensively utilized this technology extensively (Kim & Nguyen, 2018) [27];

$$W = \lim_{k\to\infty} \frac{A^{e}.e}{e^{T}.A^{k}.e}$$

Prascevic & Prascevis, 2017 [28]; Raviv et al., 2017 [29]). The overall goal of AHP is to create a top tier, the following criteria, sub-criteria, and decision alternatives on each descending level of the model.

Because decision-making processes are more superficial, AHP is a practical approach to structuring judgment in solving quantitative problems, particularly management. However, any proposed AHP model must be tested in the field. AHP will be used following the collection of participant responses to the pairwise comparison survey; the principal.

When dealing with an inconsistent matrix, the calculation should be repeated several times to ensure integration in the responses to successive repetitions of this operation. The raw data were then transformed into intelligible absolute values and normalized weights using the formula w = (w1, w2, w3,..., wn).

$$Aw = \lambda_{max}\, w, \quad \lambda_{max} \geq n$$

right eigenvector of the analysis is computed as' w.'

The Eigenvector approach is used if ik. kj = ij is not verified for all k, j, and i (Jalaliyoon et al., 2012) [30]. Furthermore, the pair comparison matrix cannot be utilized as

$$\lambda_{max} = \sum \frac{ajwj-n}{w1}$$

a normalizing column to obtain Wi if the matrix is incompatible or if there is insufficient consistency.

$$A = (aij\} \text{ with } aij = \frac{1}{aij}$$

A: pair-wise comparison
W: normalized weight factor
λ_{max} : maximum eigen value matrix A
a_{ij} : numerical comparison between the values i and j

However, the eigenvector approach can be applied to a positive and reversed matrix, resulting in the following equation:

$$e^{T} = (1, 1, \ldots\ldots, 1)$$

The consistency ratio (CR) was then determined using the formula CR = CI/RI, and the consistency index (CI) was measured using the formula below to validate the AHP outcomes.

$$CI = \frac{\lambda max - n}{n-1}$$

The value of RI is taken from Table 3 and is related to the dimension of the matrix. It should be emphasized that a consistency ratio of less than 0.10 confirms the validity of the comparison's findings.

The Value of Random Consistency Index, Source: Golden and Wang (1990) [31]

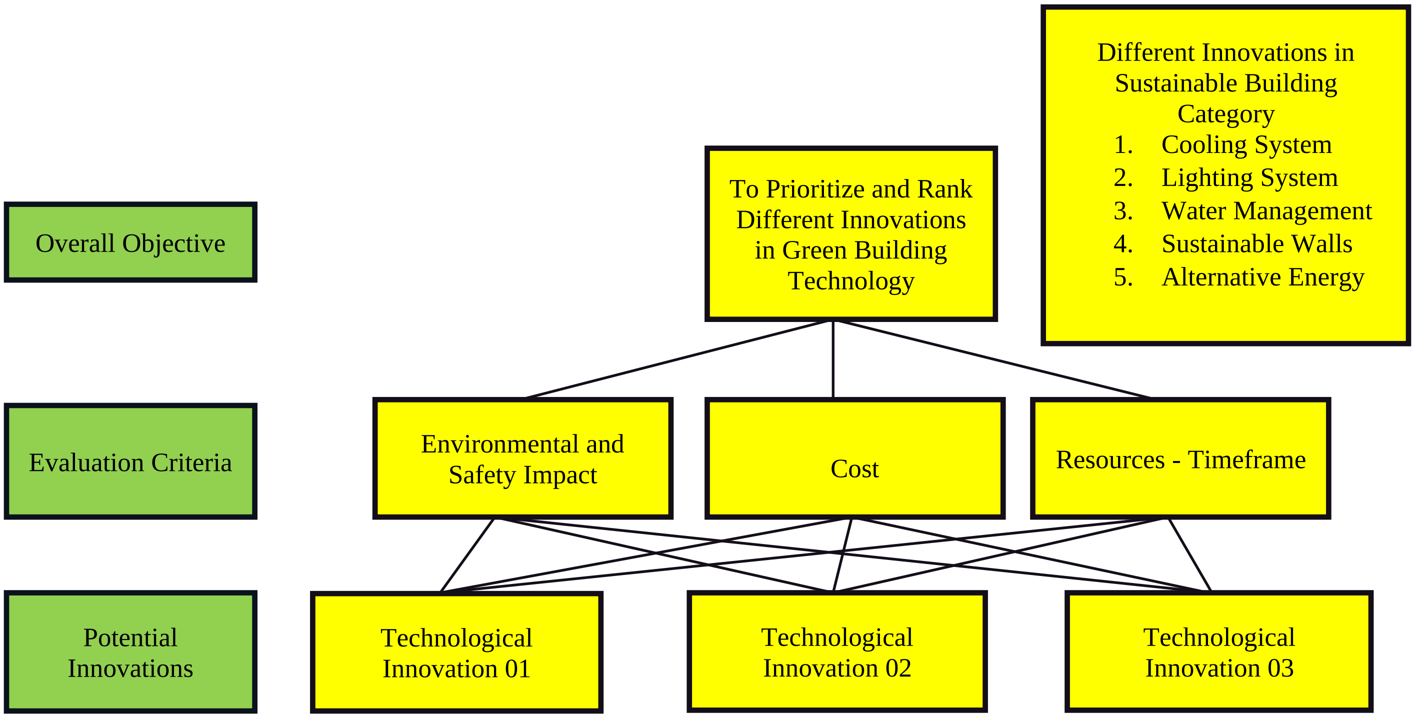

Fig. 5 Schematic Representation of Analytical Hierarchy Process (AHP)

This study considers all the examples of technological advancements that impact the creation of green buildings. The author obtained each category's average factor weighting scale to determine the overall priority.

Global priority WSPn for each technological aspect = (WSec1 × WSpi1) + (WSec2 × WSpi1) + (WSec3 × WSpi1) + (WSec4 × WSpi1)

Note: WSPn = Weighing Scale (Pairwise Comparison – Analytical Hierarchy Process)

WSec1, WSec2. .... WSec4 = Weighing Scale Value for Technological Aspects in Innovation (cost, timeframe, environmental risk, and health safety impact)

WSpi1, WSpi2............. WSpin = Weighing Scale Value for Each innovation

The author gathered data from respondents and carried out the necessary calculations using Goepel KD's (2018) AHP online application [26]. In addition, a Google Form was utilized to collect personal information from respondents to ensure their understanding of the subject.

3.11. Tabulation of Results and Conclusion

After conducting a Pairwise Comparison, the author tabulates the results, provides a conclusion for the research topics, and answers all the objectives. In the conclusion stage, the researcher evaluates the influence of technological advancements on sustainable low-rise building construction. Additionally, the researcher must respond to the following specific research objectives:

Determine the Technological Innovations in Sustainable Building Based on Literature Review, (2) identify and rank the different technological innovations according to their effect on the construction, such as environmental risk, cost, timeframe, and health/safety impact in the Green Building Construction, and (3) Create an Output of Research Development Model.

4. Data Analysis and Results

4.1. Background Information of Respondents and their Organizations

Managers, engineers, architects, and other positions, such as planners, estimators, and CAD/BIM, accounted for 7.84 percent, 64.71 percent, 19.61 percent, and 7.84 percent, respectively, of the study sample.

In addition, 56.9% were associated with large companies, 39.2% with mid-level companies, and only 3.9% with smaller companies. The respondent's organization type comprised 5.9% of subcontractors, 33.3% of consultants, and 60.8% of contractors of the respondents, 86.3% reported having more than 16 years of job experience, whereas 13.7% reported having between 11 and 15 years of work experience.

Table 3. The Value of Random Consistency Index, Source: Golden and Wang (1990) [31]

Dimension	RI
1	0
2	0
3	0.5799
4	0.8921
5	1.1159
6	1.2358
7	1.3322
8	1.3952
9	1.4537
10	1.4882

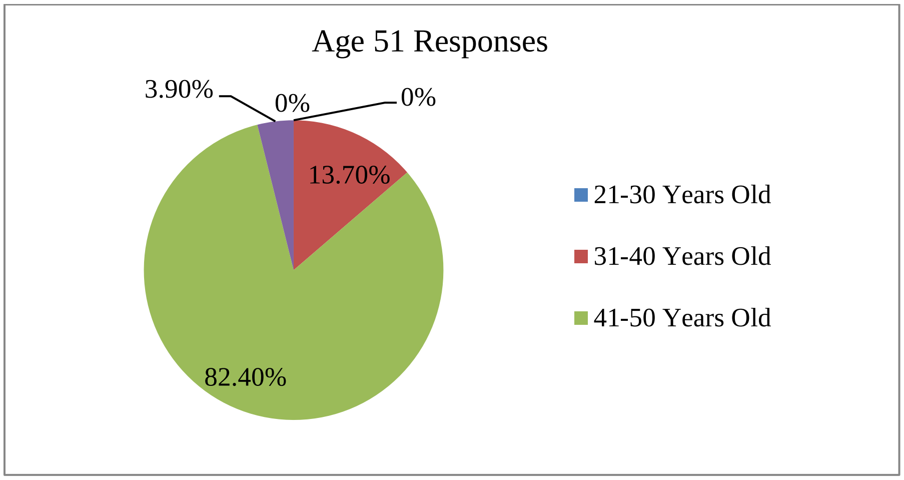

Fig. 6 Chart showing the age of respondents

4.2. Results of Pairwise Comparison

4.2.1. Cooling System

One effective way to regulate the amount of moisture in the supply air has been suggested for desiccant cooling systems. Unlike vapor compression systems, desiccant cooling does not utilize coolants that deplete the ozone layer and require less electricity. Energy from conditioned air, often exhausted from buildings, is recovered by desiccant cooling systems. Furthermore, compared to conventional cooling systems, the potential annual energy savings are projected to be between 20 and 30 percent.

Demand-control ventilation, on the other hand, refers to a ventilation system with a regulated air flow rate determined by the interior air quality. When Demand-Control Ventilation is set to zero, the airflow rates are reduced, and compared to a constant-air-volume ventilation system, fan operation requires less energy. Demand-control ventilation resulted in an average energy savings of 17.8%.

Energy efficiency is the main advantage of radiant cooling systems. Unlike traditional heating methods, which release heat all at once, these systems release heat gradually over an extended period at a low temperature. This implies that they require less energy, which lowers their operating cost. Hot water is circulated through a hydronic system of pipes or tubes under the floor. A boiler or water heater is attached to the tubes or pipelines. Heat radiated into the space from the moving fluid. Radiative cooling can reduce cooling power usage by up to 11%, according to a study by Hanif et al. [32]. The AHP online system software computation results indicate that the Consistency Ratio (CR) is 0.010804, below the permitted value of 0.1, as indicated by Thomas Saaty. As a result, the author concluded that the respondents' selections were reliable and could be used as a reference for the study. Based on the results, participants reported that environmental impact is the most important aspect of the cooling system of green building technologies. Cost and resources took second and third place, accounting for 51, 35.50 and 13.50 percent of the total, respectively.

In addition, desiccant cooling is the most significant technological advancement for green building cooling systems, according to the Decision Hierarchy Global Priorities, because of its environmental impact (22.2%), followed by demand ventilation (21.8%), and desiccant cooling because of its cost impact (16.4%), which ranks third in terms of technological advancement for green building cooling systems.

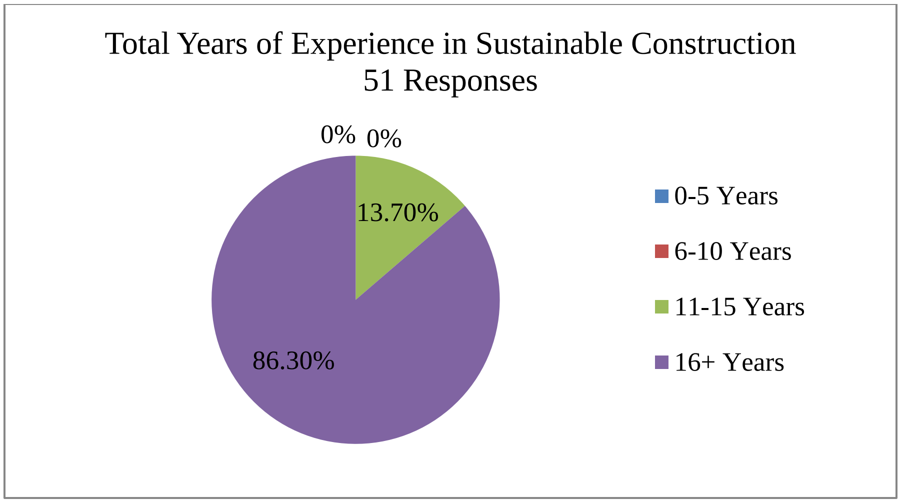

Fig. 7 Chart showing the total years of working experience in sustainable construction of the respondents

Written below is the Summary of Global Priority for AHP of Cooling System: - Refer to Table 4.

- Rank 1 to 3: Desiccant Cooling - Environmental Impact (1), Demand Ventilation – Environmental Impact (2), Desiccant Cooling – Cost (3)
- Rank 4 to 6: Radiative Cooling – Cost (4), Radiative Cooling – Environmental Impact (5), Radiative Cooling – Resources (6)
- Rank 7 to 9: Demand Ventilation – Cost (7), Demand Ventilation – Resources (8), Desiccant Cooling – Resources (9).

4.2.2. Lighting System

The Consistency Ratio (CR) is 0.010446, according to the computation results of the AHP online system software. The CR fell below the allowed 0.1, as specified by Thomas Saaty. Consequently, the respondents' choices were trustworthy and may serve as a basis for research.

Based on the findings of the lighting system AHP study, participants stated that the environmental impact of green building technologies is the most significant feature.

The following two and third positions are occupied by cost and resources, contributing 50.50, 35.90, and 13.50 percent of the total, respectively.

In addition, Decision Hierarchy Global Priorities indicates that the occupancy sensor is the most important technological advancement for green building lighting systems owing to its environmental impact (24.4%), followed by the preset lighting system (19.3%) owing to its environmental impact and dimmer switches (17.4%) because of its cost impact, which is the third most important technological advancement for lighting systems in green buildings.

Technical advancements in lighting systems have several benefits and drawbacks. One such feature is the occupancy sensors, frequently used to lower electricity costs. Occupancy sensors are made to recognize when humans are in a room and to modify the lighting in response. When they detect someone entering a room, they turn on the lights; when they detect that nobody is there, they turn them off. In addition, occupancy sensors lower electricity bills and energy use. They conserve energy and stop unnecessary lights. In addition to being more convenient, occupancy sensors also increase security. Lights that must be turned on and off manually are not concerning. Occupancy sensors automatically detect light that is vacant or in dark areas.

However, occupancy sensors also have certain drawbacks. For example, they waste energy when activated by moving objects, including insects and animals. This may also result in lights turning on and off abruptly, which could be upsetting or distracting.

Preset lighting is a category of lighting controls that allows one to program the precise moments when lights are turned on and off. They can be integrated with switches, fixtures, analog, or digital devices. In addition, they can be set up to follow a weekly, monthly, or seasonal schedule. Timer devices can help conserve energy and money by automatically turning the lights on and off at preset intervals.

Over time, this can result in significant cost savings, particularly in expensive lighting environments. Timers provide convenience and security by automatically illuminating specific locations and occasions. On the other hand, timers can make the schedule more complex or challenging to set up and modify. It can be inconvenient for them to manually override the timer if their schedule changes or if they want to change the illumination for a particular occasion.

Table 4. AHP for cooling system

Decision Hierarchy					
Level 0	**Level 1**		**Level 2**		**Global Priority**
Cooling System	Cost	0.355	Demand Ventilation	0.152	5.40%
			Desiccant Cooling	0.461	16.40%
			Radiative Cooling	0.387	13.8%
	Resources	0.135	Demand Ventilation	0.373	5.0%
			Desiccant Cooling	0.146	2.0%
			Radiative Cooling	0.481	6.50%
	Environmental Impact	0.510	Demand Ventilation	0.427	21.80%
			Desiccant Cooling	0.436	22.20%
			Radiative Cooling	0.137	7.0%
TOTAL					100%

Dimmers are well-liked and adaptable lighting controls that allow them to change the amount of light in a room. Using these, the brightness of the light can be adjusted because they control the electricity sent to the light fixture. Dimmers offer several advantages. First, they can save money and energy by prolonging the life of fixtures and lowering the power use.

A 25% light dimming can double the building's life while saving approximately 20% energy. Their versatility is another advantage. The light level can be adjusted to suit taste and activity. However, flickering and incompatibility are disadvantages. These can be inconvenient or even dangerous, especially when visual performance is crucial, such as in the workplace or sporting events broadcast on television.

According to Melissa (n.d.) [33], Each Lighting System has a varied cost; Motion Sensor Lights cost between $85 and $144, including labor and material costs, whereas Dimmer Switches cost between $78.50 and $130.80. On the other hand, the pre-set lighting system costs around $78.50 to $195. (Conversion: 1 £= 1.30 USD).

The author stated that respondents assessed the advantages and disadvantages of three (3) technological innovations: dimmer switches, occupancy sensors, and preset lighting systems. Occupancy sensors were selected as the most innovative solution to help green buildings achieve optimal lighting systems owing to their environmental impact. However, many businesses also choose to integrate many systems to achieve the best results, even though each lighting control has its own advantages and disadvantages.

Written below is the Summary of Global Priority for AHP of Lighting System: - Refer to Table 5

- Rank 1 to 3: Occupancy Sensor - Environmental Impact (1), Preset Lighting – Environmental Impact (2), Dimmer Switches – Cost (3)
- Rank 4 to 6: Occupancy Sensor – Cost (4), Dimmer Switches – Environmental Impact (5-6), Occupancy Sensor – Resources (5-6)
- Rank 7 to 9: Preset Lighting – Cost (7), Preset Lighting – Resources (8), Dimmer Switches – Resources (9)

Table 5. AHP for lighting system

Decision Hierarchy					
Level 0	**Level 1**		**Level 2**		**Global Priority**
Lighting System	Cost	0.359	Occupancy Sensor	0.381	13.70%
			Dimmer Switches	0.484	17.40%
			Preset Lighting System	0.135	4.90%
	Resources	0.135	Occupancy Sensor	0.513	6.90%
			Dimmer Switches	0.130	1.80%
			Preset Lighting System	0.357	4.80%
	Environmental Impact	0.505	Occupancy Sensor	0.482	24.40%
			Dimmer Switches	0.136	6.90%
			Preset Lighting System	0.382	19.30%
TOTAL					100%

4.2.3. Water Management

One method for reducing wastewater discharge is engineering techniques that focus on installing cutting-edge water management technologies, such as greywater systems, composting toilets, and low-flow toilets. According to a study by West Virginia University (ACTAT) [34], toilet use accounts for over 40% of indoor residential water use at approximately 3.5% gallons per flush [gpf]. An average family may flush 230 gallons of garbage annually, using 9,000 gallons of water. Toilets that are ultra-low-flow (efficiency) require 1.6 gallons or less of water to flush, whereas ordinary toilets require 3.5 to 5 gallons or more. These toilets improve the overall efficiency of the wastewater system because they utilize less water, which lowers the amount of wastewater produced. On the other hand, Domestic wastewater, or greywater, comprises the washable water from clothes washers, laundry tubs, and kitchen sinks and tubs. Reusing greywater helps utilize nutrients that would otherwise be squandered if the greywater and blackwater were not separated, conserved drinkable water, cut down on water bills, and clean up natural rivers.

Apart from the two (2) technological advancements in water management previously covered, composting toilets are waterless and made to break down waste disposed of inside the container. The main process involves microbes that break down the human waste. Adding a bulking agent such as sawdust is necessary to absorb liquids and aid odor control. Periodically, the compost produced during the treatment must be removed. The two main benefits of composting toilets are minimal maintenance and water conservation. However, the requirement for more room to position the unit and a larger initial expenditure are drawbacks.

Each low-flow toilet model incurs a different cost. Low-flow gravity toilets cost between $80 and $300, whereas pressure-assisted toilets cost between $200 to $800 per toilet. Water savings must also be considered. A household of four can save roughly 16 to 20 gallons per day or 7,500 gallons annually by switching from 3.5 gpf to 1.6 gpf, which equates to 2 gallons saved per flush. The local water rates determine monetarily valued savings.

Conversely, composting toilets, which may cost up to $2,000 and comes with enormous compost containers, heating, and ventilation, which can also be costly. Although minor electric expenditures exist, turning and emptying the compost pile by hand are the main maintenance expenses.

Likewise, the average cost of a greywater system, including installation, falls between $1,000 and $4,000. A modest system that connects the laundry room to the yard can cost as little as $700, while a more sophisticated, whole-house system can cost $20,000 or more.

As evidenced by the findings of the AHP study on water management systems, the participants believed that the environmental impact of green building technologies is their single most significant feature. With contributions of 50.20 percent, 36.50 percent, and 13.30 percent of the total, costs and resources are second and third, respectively.

Furthermore, Decision Hierarchy Global Priorities, the low-flow toilet, which accounts for 22.6 percent of the total, is the most significant technological advancement for green buildings' water management systems due to its environmental impact. This is followed by the Composting Toilet, which accounts for 21.2 percent of the total, due to its environmental impact, and the cost impact of the composting toilet, which accounts for 17.9% of the total and ranks as the third most significant technological advancement for the water management system. The allowable range set by Thomas Saaty was not exceeded by a global priority Consistency Ratio of 0.010686. Therefore, the outcomes are logical.

The author believes that the participants' selection of a Low-Flow Toilet and its environmental effect as the best technological innovation for low-rise buildings are based on the fact that a Low-Flow Toilet will help reduce consumers' water consumption costs and contribute to preserving the environment by protecting groundwater depletion and possible contamination.

Table 6. AHP for water management

Decision Hierarchy					
Level 0	**Level 1**		**Level 2**		**Global Priority**
Water Management	Cost	0.365	Low Flow Toilet	0.368	13.40%
			Composting Toilet	0.491	17.90%
			Grey Water System	0.141	5.10%
	Resources	0.133	Low Flow Toilet	0.509	6.80%
			Composting Toilet	0.128	1.70%
			Grey Water System	0.363	4.80%
	Environmental Impact	0.502	Low Flow Toilet	0.451	22.60%
			Composting Toilet	0.423	21.20%
			Grey Water System	0.126	6.30%
TOTAL					100%

Written below is the Summary of Global Priority for AHP of Water Management: - Refer to Table 6.

- Rank 1 to 3: Low Flow Toilet - Environmental Impact (1), Composting – Environmental Impact (2), Composting Toilet – Cost (3)
- Rank 4 to 6: Low Flow Toilet – Cost (4), Low Flow Toilet – Resources (5), Grey Water System – Environmental Impact (6)
- Rank 7 to 9: Grey Water System – Cost (7), Grey Water System – Resources (8), Composting Toilet – Resources (9)

4.2.4. Sustainable Walls

According to the AHP online system software calculation results, the Consistency Ratio (CR) is 0.009901. Thomas Saaty noted that the CR was below the allowable limit of 0.1. The author concluded that the decisions made by the respondents were dependable.

Participants stressed that, as shown by AHP's sustainable walls study, the most important aspect of green building technologies is their effect on the environment. Cost and resources came in second and third place, with contributions of 50.40 percent, 36.10 percent, and 13.40 percent of the total, respectively.

Moreover, because of its impact on the environment, the Modular Panel, which makes up 25.5% of the total, is the most significant technological innovation for green buildings' sustainable walls, according to the Decision Hierarchy Global Priorities. Next comes the environmental impact of 3D printing, which makes up 17.8% of the total, the second most important technological innovation for sustainable walls, and the financial impact of blocks with insulation, which makes up 16.0% of the total, comes in third place.

Among all the limitations associated with construction and restoration projects, time is one that, whether appropriate or not, significantly affects the selection of building materials and techniques. In contrast to conventional building techniques (insulation-filled blocks), composite panels are constructed off-site and are ready to be installed. However, basic fitting knowledge is required. Additionally, the Panel Manager may arrange the panels to fit together as they come, eliminating the need to overstock or hunt for the missing puzzle piece. Doors, windows, and hatches can now be ordered using pre-cuts. On the other hand, compared to conventional methods, walls may be printed much more quickly, saving weeks of construction time. The effectiveness of the remaining processes, such as interior finishing and utility installation, determines the total completion time.

Similarly, reduced labor and material waste may lead to lower initial costs of 3D printing. Nevertheless, the overall cost can change based on the experience level of the construction crew and the accessibility of 3D printing technology. However, economies of scale, labor savings, and material procurement in large quantities are the advantages of modular dwellings. Modular homes are frequently more cost-effective because of these efficiencies, even though moving and building modules on-site can increase costs.

A lower carbon footprint is achieved by the airtight construction of many panels, which are also offered in partially recycled materials. While traditional building methods (Blocks with Insulation) frequently require external specialized boards, panels can also reduce sound. A panel can have additional benefits, such as a slower rate of deterioration. 3D printing and modular buildings have a lower environmental effect than conventional building methods (blocks with insulation) because 3D printing reduces material waste, and modular homes benefit from improved production efficiency.

However, modular panels can also reduce waste using more efficient manufacturing processes and sustainable materials. In contrast to 3D printing, greater resource management and reduced waste are possible in industrial settings. Thus, it is reasonable that modular panels rank among the three choices as the respondents' top choices for the greatest technological advancement in a sustainable wall.

Table 7. AHP for Sustainable Walls

Decision Hierarchy					
Level 0	**Level 1**		**Level 2**		**Global Priority**
Sustainable Walls	Cost	0.361	Modular Panel	0.164	5.90%
			Blocks with Insulation	0.442	16.0%
			3D Printing	0.394	14.20%
	Resources	0.134	Modular Panel	0.391	5.30%
			Blocks with Insulation	0.469	6.30%
			3D Printing	0.140	1.90%
	Environmental Impact	0.504	Modular Panel	0.505	25.50%
			Blocks with Insulation	0.142	7.20%
			3D Printing	0.353	17.80%
TOTAL					100%

Written below is the Summary of Global Priority for AHP of Sustainable Walls: - Refer to Table 7.

- Rank 1 to 3: Modular Panel - Environmental Impact (1), 3D Printing – Environmental Impact (2), Blocks with Insulation – Cost (3)
- Rank 4 to 6: 3D Printing – Cost (4), Blocks with Insulation – Environmental Impact (5), Blocks with Insulation – Resources (6)
- Rank 7 to 9: Modular Panel – Cost (7), Modular Panel – Resources (8), 3D Printing – Resources (9)

4.2.5. Alternative Energy

Based on the results, the participants emphasized that the environmental impact of green construction technology was the most significant factor. With contributions of 49.50 percent, 37.80 percent, and 12.70 percent, respectively, cost and resources are in second and third place, respectively. Furthermore, Decision Hierarchy Global Priorities states that the most important technological breakthrough for green buildings' alternative energy is solar energy, which accounts for 26.2% of the total and substantially impacts the environment. The environmental impact of wind turbines, which accounted for 16.3% of the total, was the third-best technological innovation selected by the respondents, and the cost impact of solar energy, which accounted for 20.7% of the total, was the second most important technological innovation for sustainable walls. The Consistency Ratio of the Global Priorities was 0.009991, within the allowable set by Thomas Saaty. Therefore, the results were acceptable. According to Cathy (2023) [35], despite their sustainability, all three energy sources, hydropower, wind turbines, and solar panels, have downsides. Solar panels emit more CO2 than wind turbines but make less noise. Wind energy, however, outperforms solar energy. A wind turbine can create the same amount of electricity as 48,704 solar panels. Turbines are unattractive and can endanger animals.

In addition, hydropower is the most expensive of the three low-carbon solutions, according to a cost study released by the Brookings Working Papers (Cathy, 2023) [35]. Solar energy costs $50,938, wind energy costs $74,412, and hydropower is estimated to cost $141,991 in net energy per megawatt. Solar energy has the lowest cost after deducting all expenses. Solar power is becoming a viable option due to decreased costs and more access to sunlight. Therefore, the most common option is no longer hydropower because climate change has made droughts more prevalent in some areas. In addition, the wind is not constantly present. Solar panel technology, the respondents' top choice, is the best option for technological advancement in alternative energy.

Written below is the Summary of Global Priority for AHP of Alternative Energy: - Refer to Table 8.

- Rank 1 to 3: Solar Energy - Environmental Impact (1), Solar Energy – Cost (2), Wind Turbine – Environmental Impact (3)
- Rank 4 to 6: Wind Turbine – Cost (4), Hydroelectric System – Environmental Impact (5), Wind Turbine – Resources (6)
- Rank 7 to 9: Hydroelectric System – Cost (7), Solar Energy – Resources (8), Hydroelectric System – Resources (9)

Table 8. AHP for alternative energy

Decision Hierarchy					
Level 0	**Level 1**		**Level 2**		**Global Priority**
Alternative Energy	Cost	0.378	Solar Energy	0.548	20.70%
			Wind Turbine	0.302	11.40%
			Hydroelectric System	0.150	5.70%
	Resources	0.127	Solar Energy	0.349	4.40%
			Wind Turbine	0.509	6.50%
			Hydroelectric System	0.142	1.80%
	Environmental Impact	0.495	Solar Energy	0.529	26.20%
			Wind Turbine	0.330	16.30%
			Hydroelectric System	0.141	7.0%
TOTAL					100%

5. Conclusion and Future Directions

The Analytic Hierarchy Process (AHP) findings for lighting systems, cooling systems, water management, sustainable walls, and alternative energy building aspects show that environmental impact is the most important factor in stakeholder selection. According to the respondents, desiccant cooling is the best option for cooling systems because of its remarkable energy savings and decreased ozone depletion potential. Owing to their affordability and energy efficiency, occupancy sensors are the best options for lighting systems. Low-flow toilets are another important invention in water management that has reinforced water efficiency.

Furthermore, using modular panels in sustainable walls suggests that this type of wall reduces the negative effects on the environment and advances the building sector. Finally, because of its rising accessibility and cost advantages, respondents chose solar energy as their preferred alternative energy source. The respondents' preferred technological innovations highlight how urgently sustainable technology must be integrated into the built environment. Stakeholders must prioritize these innovative ideas to make future changes and guarantee that the project is more environmentally friendly and cost-effective.

Adopting these technologies is critical to our shared progress in creating a more resilient and sustainable future as the project moves forward. Furthermore, widespread usage of the AHP report's evaluation of technological improvements highlighted in the study will considerably assist the Philippines Sustainable Building in attaining a headache-free building by avoiding the typical problem of budget overrun and time constraints by prioritizing the technological innovations that will be more helpful to the stakeholders, aside from having a more environmentally friendly building.

Furthermore, the author emphasizes how the respondents' technological achievements might be integrated with other technological developments to get the best results. The chosen innovations served as a roadmap for stakeholders to decide which technological advancements should first be targeted in sustainable low-rise building developments. The author proposes additional research to incorporate diverse perspectives and obtain more exact results. The author feels the proposed issue will assist future stakeholders in developing more worry-free and environmentally friendly building projects.

There are various recommended areas for future research. First, scholars can analyze a real-world scenario by considering numerous technological innovations, such as budgetary limits, legal problems, and labor shortages. Further research may include case studies demonstrating the effective integration of technological improvements in sustainable low- and high-rise structures. These studies would show the feasibility of the research and place it in perspective. Additional recommendations for future research include Stakeholder Engagement, which focuses on decision-making frameworks, stakeholder participation, and how the public, commercial, and community sectors may encourage the use of sustainable building practices. Comparative analysis can also be used to identify gaps and best practices by comparing the Philippines' approach to similar efforts in other nations with comparable economic or climatic conditions.

Alternatively, researchers can create a quantitative model for ranking innovations according to regional differences. Researchers can also add sensitivity analysis or return-on-investment calculations for the suggested technology to the cost analysis. Making decisions would be aided by this information. Finally, a thorough analysis of the costs, timelines, and environmental metrics can be conducted and compared for each technological innovation. The case for their adaptation can be strengthened by conducting such research.

Conflict of Interest

The author recognizes that all affiliations needed to be revealed under Conflict of Interest have previously been declared and that, except as mentioned, none of the implications present a conflict of interest. The author declares that the publication of this paper does not include any conflicts of interest.

Funding Statement

This study acquired no explicit financing from any public, business reasons, or charitable organization entities.

Acknowledgement

The author would like to acknowledge his wife, Theresa Azalea A. Javier, and his entire family for their constant support and tolerance while he undertook this research.

Furthermore, the author wants to convey his appreciation to God for leading him through these hardships. Each day, he feels steered. Thanks to the Lord, he was able to complete this research.

References

[1] Miguel P. Amado et al., "The Sustainable Building Process," *RMIT University, Australia*, vol. 65, 2007. [Google Scholar]

[2] Morteza Akbari et al., "A Bibliometric Study of Sustainable Technology Research," *Cogent Business & Management*, vol. 7, no. 1, pp. 1-25, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[3] Charles J. Kibert, "Green Buildings: An Overview of Progress," *Journal of Land Use & Environmental Law*, vol. 19, no. 2, pp. 491-501, 2004. [Google Scholar] [Publisher Link]

[4] Diocel Harold M. Aquino et al., "Study on the Relative Importance of Green Building Attributes in Philippine Urban Setting Using Analytical Hierarchy Process," pp. 1-10. [Google Scholar] [Publisher Link]

[5] Leilei Zheng, "Research on the Application of Green Building in Building Design," *IOP Conference Series: Earth and Environmental Science, 2nd International Conference on Geology, Mapping and Remote Sensing*, Zhangjiajie, China, vol. 783, pp. 1-6, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[6] Lauri Koskela, and Ruben Vrijhoef, "Is the Current Theory of Construction a Hindrance to Innovation?," *Building Research & Information*, vol. 29, no. 3, pp. 197-207, 2001. [CrossRef] [Google Scholar] [Publisher Link]

[7] E. Sarah Slaughter, "Models of Construction Innovation," *Journal of Construction Engineering and Management*, vol. 124, no. 3, pp. 226-257, 1998. [CrossRef] [Google Scholar] [Publisher Link]

[8] T. Michael Toole, "Uncertainty and Home Builders' Adoption of Technological Innovations," *Journal of Construction Engineering Management*, vol. 124, no. 4, pp. 323-332, 1998. [CrossRef] [Google Scholar] [Publisher Link]

[9] Eliseo A. Aurellado, "The Greening of the Project Management Cycle in the Construction Industry," *Graduate School of Business Faculty Publications*, 2015. [Google Scholar] [Publisher Link]

[10] Ghada Elshafei et al., "Opportunities for Using Analytical Hierarchy Process in Green Building Optimization," *Energies*, vol. 15, no. 12, pp. 1-24, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[11] Ahmad Mousa, and Ahmed Zidan, "3-D Panel System: A Sustainable Building Solution for Egypt," *International Conference on Industry Academia Collaboration-IAC 2014*, pp. 2-5, 2014. [Google Scholar]

[12] Sam C.M. Hui, "HVAC Design and Operation for Green Buildings," *Proceeding of the Shaanxi-Hong Kong Refrigeration and HVAC Seminar 2001*, pp. 44-51, 2001. [Google Scholar]

[13] Hanen Filali, "Greywater as an Alternative Solution for a Sustainable Management of Water Resources—A Review," *Sustainability*, vol. 14, no. 2, pp. 1-13, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[14] K.N. Sheth, "Water Efficient Technologies for Green Buildings," *International Journal of Engineering Innovation and Scientific Research*, vol. 1, no. 3, pp. 5-10, 2017. [Google Scholar]

[15] Yongwang Zhang et al., "Green Building Design Based on Solar Energy Utilization: Take a Kindergarten Competition Design as an Example," *Energy Reports*, vol. 7, no. S7, pp. 1297-1307, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[16] T. Michael Toole, "Technological Trajectories of Construction Innovation," *Journal of Architectural Engineering*, vol. 7, no. 4, pp. 107-114, 2001. [CrossRef] [Google Scholar] [Publisher Link]

[17] Jeremy Gorelick, and Neil Walmsley, "The Greening of Municipal Infrastructure Investments: Technical Assistance, Instruments, and City Champions," *Green Finance*, vol. 2, no. 2, pp. 114-134, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[18] Oleg S. Sukharev, "Structural Analysis of Income and Risk Dynamics in Models of Economic Growth," *Quantitative Finance and Economics*, vol. 4, no. 1, pp. 1-18, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[19] Umeokafor Nnedinma, "Approaches, Drivers and Motivators of Health and Safety Self-Regulation in the Nigerian Construction Industry: A Scoping Study," *Architectural Engineering and Design Management*, vol. 12, no. 6, pp. 460-475, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[20] Sharm El Sheikh, CO2 Emissions from Buildings and Construction Hit New High, Leaving Sector off Track to Decarbonize by 2050: UN, UN Environment Programme, 2022. [Online]. Available: https://www.unep.org/news-and-stories/press-release/co2-emissions-buildings-and-construction-hit-new-high-leaving-sector

[21] Construction Statistics from Approved Building Permits, First Quarter 2022, Philippine Statistics Authority, 2022. [Online]. Available: https://psa.gov.ph/content/construction-statistics-approved-building-permits-first-quarter-2022

[22] Nigel Joseph Mathers, Nicholas Jeremy Fox, and Amanda Hunn, *Surveys and Questionnaires*, NHS Executive, Trent, vol. 1998, pp. 1-57, 1998. [Google Scholar]

[23] B.G. Nworgu, "Educational Research: Basic Issues and Methodology. Ibadan," *Wisdom Publishers Ltd, NGO Clients Total Number Distributed*, vol. 3, no. 6, pp. 3-10, 1991. [Google Scholar]

[24] Louis L. Thurstone, "A Law of Comparative Judgment," *Psychological Review*, vol. 101, no. 2, pp. 266-270, 1994. [Google Scholar] [Publisher Link]

[25] Thomas L. Saaty, *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*, Business & Economics, McGraw-Hill International Book Company, pp. 1-287, 1980. [Google Scholar] [Publisher Link]

[26] Klaus D. Goepel, "Implementation of an Online Software Tool for the Analytic Hierarchy Process (AHP-OS)," *International Journal of the Analytic Hierarchy Process*, vol. 10, no. 3, pp. 469-487, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[27] Soo-Yong Kim, and Viet Thanh Nguyen, "An AHP Framework for Evaluating Construction Supply Chain Relationships," *KSCE Journal of Civil Engineering*, vol. 22, pp. 1544-1556, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[28] Natasa Prascevic, and Zivojin Prascevic, "Application of Fuzzy AHP for Ranking and Selection of Alternatives in Construction Project Management," *Journal of Civil Engineering and Management*, vol. 23, no. 8, pp. 1123-1135, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[29] Gabriel Raviv, Aviad Shapira, and Barak Fishbain, "AHP-Based Analysis of the Risk Potential of Safety Incidents: Case Study of Cranes in the Construction Industry," *Safety Science*, vol. 91, pp. 298-309, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[30] Neda Jalaliyoon, Nooh Abu Bakar, and Hamed Taherdoost, "Accomplishment of Critical Success Factor in Organization; Using Analytic Hierarchy Process," *International Journal of Academic Research in Management*, vol. 1, no. 1, pp. 1-9, 2012. [Google Scholar] [Publisher Link]

[31] Bruce L. Golden, and Qiwen Wang, *An Alternative Measure of Consistency*, The Analytic Hierarchy Process, pp. 68-81, 1989. [CrossRef] [Google Scholar] [Publisher Link]

[32] M. Hanif et al., "Potential Energy Savings by Radiative Cooling System for a Building in Tropical Climate," *Renewable and Sustainable Energy Reviews*, vol. 32, pp. 642-650, 2014. [CrossRef] [Google Scholar] [Publisher Link]
[33] Melissa, Smart Lighting Cost, 2023. [Online]. Available: https://www.myjobquote.co.uk/costs/smart-lighting
[34] Alternative Technologies, West Virginia University Institute of Sustainability and Energy Research. [Online]. Available: https://actat.wvu.edu/wastewater/onsite-wastewater-systems/alternative-technologies
[35] Cathy, Solar Vs Wind Vs Hydro: Which is the Best Renewable Energy Source?, 2023. [Online]. Available: https://www.canhydro.com/discover/solar-vs-wind-vs-hydro/