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Framework for a Simulation Learning Tool to Optimize Green Star Buildings in South Africa

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Abstract: The Green Building Council of South Africa specifies nine parameters for energy efficiency in buildings. These parameters are in dynamic systemic interaction with each other and with other building design elements. Therefore, the issue of optimization in terms of the Green Star rating system is a complex problem that defies complete resolution and sustainability. Partial resolution, using algorithmic optimization convergence and simulation techniques, holds potential. The specific problem that this paper confronts is the need for engineers, and others, to be able to assess energy-efficient early design decisions within tight time frames. A proposition is made regarding further developing a "green" simulation learning tool for practitioners. This paper explores the potential of MATLAB and EnergyPlus to create a simulated learning space for green energy optimization. While recognized as being an abstraction from the total set of nine Green Building Council of South Africa parameters, the purpose is to introduce principles that can be extended into a multi-variable, more complex context of multiple sustainability criteria. This paper concludes with a framework for a simulation model that optimizes one of the Green Star criteria of the Green Building Council of South Africa supported by case study data for four, five, and six star rated buildings.

Keywords: green criteria; energy efficient; green building; sustainability; learning tools

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1. Introduction

The contribution of the built environment to greenhouse emissions is well documented and is known generally to be very significant. According to a recent report of the World Green Building Council (WGBC), buildings are collectively responsible for approximately eighty percent of global energy related greenhouse emissions throughout their life cycle [1,2]. Reduction goals, seen against a projected global population of ten billion by 2050, are ambitious. Considering new and renovated buildings, a forty percent reduction by 2030 and net zero by 2050 [1,3,4] are the defined global targets. In specific terms, these targets comprise the following actions [3]:

1. Net zero-energy buildings (nZEBs).
2. More rigorous codes of building practice.
3. Retrofit of existing buildings.
4. Disclosure of the energy performance of buildings.
5. Use of renewable elements and materials.

1.1. Motivation

Most buildings are the existing stock rather than new, or additions to stock. These older buildings present specific challenges in meeting the above targets due to the design and building orientation decisions made in the past. The energy consumption of green buildings (sustainable or high-performance buildings) is the key to reducing the impact on the environment, economy, and society and achieving the goals of sustainable development (SDGs). Whilst recognizing that the United Nations defines eighteen Sustainable

Development Indicators [2], in the South African context, only nine are emphasized for local applications.

Buildings, inevitably, are also remarkably diverse in their intended use, at least at the point of initial design. This is the time in the life cycle of the building that typically requires quick decisions regarding all aspects of design. Much compromise is also required amongst a diverse range of consultants, all of whom have focused areas of expertise. In [5], the collective intent is, of course, to produce a product that satisfies both client-defined and legal parameters. The increasing emphasis on "green credentials" also affords developers general marketing credibility, in addition to an improved environment for the occupiers of buildings and society at large. Efforts to improve green building credentials in South Africa include both new and retrofit in older buildings, and embrace the nine Green Star parameters identified by the Green Building Council of South Africa (GBCSA) as follows:

1. Management;
2. Indoor Environment Quality;
3. Energy;
4. Transport;
5. Water;
6. Materials;
7. Land Use and Ecology;
8. Emissions;
9. Innovation.

1.2. Significance of the Research

Aside from the diversity inherent in the buildings themselves, the GBCSA's nine Green Star parameters are in dynamic systemic interaction with each other and, indeed, with other building design elements. "Sustainable building" and "green building" can be used as interchangeable terms based on the scope, objective, and context of the design, construction, and operation of the building The issue of optimization of all nine parameters included in the Green Star rating system is a complex problem that defies complete resolution. Partial resolution, involving best practical solutions which use algorithmic and other optimization techniques should assist engineers, and others, to assess the effect of decisions regarding design at an early stage of the design process. Investigations of optimization techniques in building design are not new but continue to be developed and improved. Building information modelling (BIM), for example, represents an integrated approach to real time design decisions across a range of disciplines. However, the conversation has other dimensions that add complexity to building design decisions. Geographic location affects building orientation [6]. Building size, shape, and use are also significant considerations. These considerations have led to the development of various modelling approaches [7,8], e.g., MATLAB, EnergyPlus, ESP, TRAN-203 SYS, Revit, SketchUp, and Rhino 7 in attempts to unravel the complexity inherent in green building design [9,10]. This paper does not intend to critically evaluate the various software packages available, all of which have merit. The main purpose is to demonstrate the application of the most suitable software packages for entry-level practitioners. MATLAB and EnergyPlus are the chosen software packages for simulation due to their accessibility, compatibility, and user friendliness for entry-level practitioners.

It is self-evident that buildings exist to serve human purposes [11]. As such, they serve as factors of production and habitation in which people spend eighty to ninety percent of their time [11]. It is therefore not surprising that considerable emphasis would come to rest on the quality of the internal environment of buildings and how people feel about, and perceive, the environments in which they work and live. The historic focus on the technical aspects of green buildings has partially lost the essential focus of buildings as a means for the service of human activity [12]. This, in turn, translates into visual, acoustic, and physical comfort through ventilation and spatial arrangements, all of which facilitate the enhanced experience for the building user [13]. In placing emphasis on user, as opposed to owner, perceptions [14] has emphasized the centrality of four factors in green building perceptions: belief in sustainability, materials and methods, personal experience in the building, and schema congruity, where the last item listed refers to the social, cultural, and aesthetic elements of the building. The relationships are complex and dynamic. This paper only considers the GBCSA Green Star certification method and the potential for optimization, using simulation, of the factors that influence the personal experience of the building. University curricula are unlikely to create extensive learning space in the medium term for green energy considerations, other than through the potential for simulation to enable learning, hence the inclusion in this paper of learning taxonomies as the illustrative means for learning growth through machine learning and simulation.

A socio-economic factor has been recently added to the nine GBCSA parameters [1]. Three out of the original nine factors are outlined in Table 1 below.

Table 1. GBCSA existing building performance score sheet criteria.

Credit	Credit Name	Points Available
	Management Category	
EB-Man-1	Accredited Professional	1
EB-Man-2	Certified Buildings	1
EB-Man-3	Building Management	5
EB-Man-4	Green Cleaning Performance	3.5
EB-Man-5	Green Leasing	6
EB-Man-6	Ongoing Monitoring and Metering	2
EB-Man-7	Learning Resources	2
	Management credits	**20.5**
	Indoor Environmental Quality Category	
EB-IEQ-1	Indoor Air Quality	5
EB-IEQ-2	Lighting Comfort	2
EB-IEQ-3	Thermal Comfort	2
EB-IEQ-4	Occupant Survey	2
EB-IEQ-5	Acoustic Comfort	3
EB-IEQ-6	Daylight and Views	2
	Indoor Environmental Quality credits	**16**
	Energy Category	
EB-Ene-1	Energy Consumption	25
EB-Ene-2	Peak Electricity Demand	2
	Energy credits	**27**

Central to the nine GBCSA parameters is energy, which impacts not only aspects of human comfort but also task performance. For this reason, energy and learning about energy are focal for this paper. This is illustrated in Figure 1 [11] that conveniently shows the linkage between internal environment quality, United Nations Sustainable Development Goals (SDGs), and energy. At the base of the pyramid are five (5) energy-dependent factors, which are both physical and non-physical, and impact internal environment quality. Located on the outer side of the pyramid are SDG-driven factors that contribute to green building. The intention is to define mechanisms and improve targets for various aspects of the physical and mental health of citizens. This is substantially consistent with the allocation of points as shown in Table 1 and indeed with other rating systems, such as Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREAM).

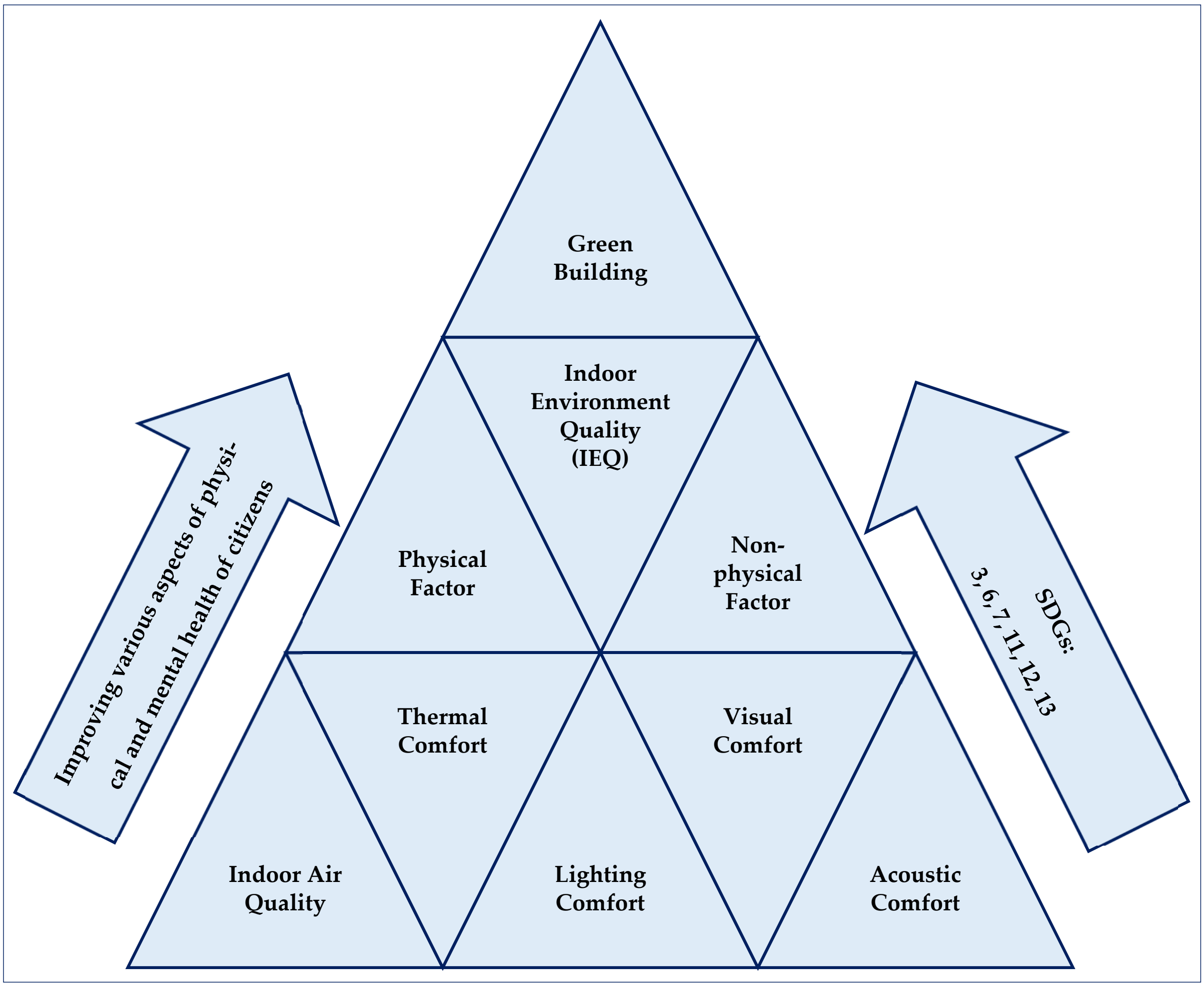

Figure 1. Energy-driven factors contributing to green Buildings [11].

1.3. Aim and Contribution

The primary aim of this study is to offer guidance to designers and professionals involved in the field of green building design. Specifically, this study aims to optimize the sustainable design process within green buildings. This implies a focus on improving the efficiency, effectiveness, and overall quality of sustainable design practices, with an emphasis on their application in the context of green building projects [15]. With a specific focus on green design, the authors aimed to enhance the learning process of green design through a systematic approach. The authors also incorporated essential aspects of green design, such as recognizing objectives and needs, identifying problems, creating one or more physical configurations, analyzing the performance of each configuration, and selecting the most suitable alternative. Additionally, this paper illustrates a methodology for teaching and accelerated learning, which includes a straightforward yet effective model for assessing methods and evaluating design feedback:

1. Guidance for Designers: This study offers practical guidance to designers, architects, and other stakeholders involved in green building projects. It provides insights, best practices, and recommendations to enhance the sustainable design process, making it more accessible and effective for practitioners.
2. Optimized Sustainability Practices: By emphasizing the optimization of sustainable design, this study promotes a more systematic, streamlined, and integrated approach to sustainability within green buildings. This contributes to the creation of buildings that are not only eco-friendly but also more functional and comfortable for occupants.

3. Enhanced Decision-Making: This study's guidance can improve the decision-making process during the design phase. Designers are equipped with the knowledge and tools needed to make informed choices about materials, technologies, and strategies that align with green building standards and goals.
4. Efficiency Gains: Through optimization, this study encourages the identification of opportunities for efficiency gains in sustainable design. This includes minimizing resource usage, reducing waste, and enhancing the overall performance of green building systems.
5. Environmental Impact Reduction: This study's contributions extend to the reduction of environmental impacts associated with green building construction and operation. By optimizing sustainability practices, this study aids in mitigating the environmental footprint of these structures.
6. Integration of Sustainable Design: This study promotes the seamless integration of sustainable design principles into the broader green building process. This integration ensures that sustainability is not an afterthought but an integral component of the entire design and construction process.
7. Resource Efficiency: By optimizing the sustainable design process, this study contributes to resource efficiency. This is essential in achieving the goals of sustainability and reducing resource consumption.

This research paper is structured in the following manner: Section 2 depicts the literature review, while Section 3 illustrates the research methodology. Section 4 provides the intended outcomes of the learning tool, indicating the flow process and case studies, while Section 5 presents the future model of the assessment method and evaluation criteria. Section 6 presents the successes, effects, and future targets, and then Section 7 concludes the work presented in this paper.

2. Literature Review

Knowledge and practice gaps between university and practice are unlikely to close. Knowledge gaps within industry and between practitioners are also likely to persist as technology advances and new systems emerge [16,17]. The application of knowledge to real situations, and to evolving situations, has been, and remains, a challenge. It is further illustrated in [18] through the application of system dynamics and stock and flow analysis that there are potential institutional limits to the capacity of teachers to impart complete knowledge. For the most part, although there are other factors to consider, the literature suggests that the most significant gaps in the university/practice divide include graduates with poor communication and interpersonal skills, lacking independent problem-solving capacity and the ability to work with other individuals, in a team and in inter-team contexts [18].

It is, of course, untrue to say that students are not exposed to practical work as part of their curricula. Projects are, however, often removed from reality, have been long-established and therefore dated within curricula, and have predictable outcomes that deprive students of the full value of a more realistic learning experience [19,20]. Further elaboration is offered in [20] regarding the need for more stimulating opportunity for practical discovery and innovation on the part of student practitioners. In addition, the growth in student numbers, constrained laboratory space, old equipment, tight budgets, and staffing considerations indicate the need for developing learning opportunities that mitigate and improve learning experiences through simulation. In the context of this paper, and previously indicated and justified in the explanation of Figure 1, the focal concern is the optimization of energy use in "Green Buildings" as part of a learning tool.

This paper also recognizes the absence of a simulation learning tool not only for students but also for graduate engineers, whose continuing professional learning needs are like those of senior students, i.e., a learning tool that enables exploration through simulation, hence facilitating learning and design decisions in a complex context. This paper does not, however, presume to do more than present a framework for a simulation model that seeks to optimize one of the Green Star criteria of the GBCSA. While recognized as being an abstraction from the total set of defined criteria, the purpose is to introduce principles that can be extended into a multi-variable, more complex context of multiple criteria. Considering only one, in this case energy, it is evident that it cannot be considered or optimized in isolation from other factors on the GBCSA score card.

Passive and low-energy design techniques have been presented for green-rated buildings. An analysis was carried out between two buildings in determining the eligibility of achieving a green star rating. This is the basis for initiating a learning tool model towards targeting green criteria and optimization in buildings [21].

Adapting the work of [22], that relates to the construction sector, and considering the relationships between some "green" variables shown in static form in Figure 1, feedback loops and contradictory relationships between factors can be exposed using system dynamics. For instance, energy efficiency, taken in isolation, impacts life cycle costs. This is good for Green Star rating in the energy arena. However, optimal energy efficiency may mean less than optimal internal environment quality, with the potential to negatively affect building users and hence the Green Star rating for that factor. A balance needs to be achieved. In the example given, the exclusive consideration of energy, that is not cognizant of the impact on internal environment quality, means gain for GBCSA energy points that are diminished through the lack of balance with internal environment quality. This is illustrated in Figure 2. Other relationships in the GBCSA schema could be similarly discussed.

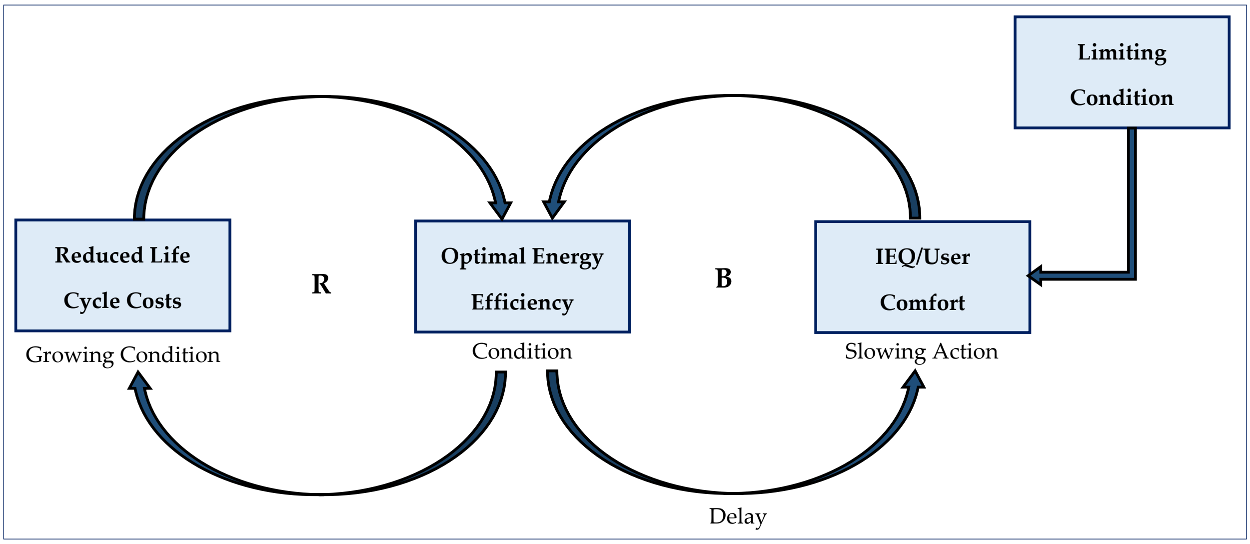

Figure 2. Dynamic relationship between the reinforcing and balancing conditions.

The concept illustrated in Figure 2 highlights the importance of recognizing that an exclusive focus on optimal energy efficiency, while it may reduce life cycle costs, can have consequences. The reinforcing (R) loop suggests that an initial drive for optimal energy efficiency might lead to a positive feedback loop, resulting in further emphasis on energy efficiency. However, the balancing (B) loop introduces a delay and suggests that, over time, there could be an impact on user comfort. This means that the quest for energy efficiency, if pushed too far without considering user comfort, may eventually result in negative consequences. The limiting condition, in this case, becomes user comfort, influencing decisions on how energy efficiency is optimized.

This dynamic interplay between reinforcing and balancing loops emphasizes the need for a comprehensive and balanced approach in green building design [23]. It suggests that optimizing one aspect, such as energy efficiency, should be performed while considering its broader implications, including its impact on user comfort and other factors.

Achieving balance in green building practices is an intricate challenge, as it involves a web of interconnected factors that are challenging to optimize in isolation. This complexity is thoroughly discussed in [24], where system dynamics is investigated as a learning tool for engineering practitioners dealing with sustainability applications, potentially including buildings, using either specialized or standard packages. As mentioned earlier, the complete optimization of each of the nine GBCSA factors is not entirely feasible, and a holistic understanding is necessary.

3. Research Methodology

Aspects of learning and knowledge development were touched on earlier. To elaborate, the concept of the learning, knowledge-based, creative organization has its genesis in the foundations laid in 1956 in what is commonly known as Bloom's cognitive taxonomy. Bloom's original work has formed the basis for curriculum design and application and is still in current use. This does not mean that it has not been further researched and refined, with new meaning added, and parallel work being completed.

There is a growing demand for specialized skills in the building design professions, particularly in the field of energy, where simulation studies are crucial. The authors note the challenges of studying dynamic systems with algorithmic optimization for buildings, highlighting the complexity of this task. Various simulation software tools are mentioned, such as MATLAB, EnergyPlus, ESP, TRANSYS, Revit, SketchUP, Rhino, and Green Building Studio (GBS 3.4). However, the authors point out that most of these tools are not used in real time, and many are coupled with external simulation engines to complete specific tasks. Moreover, the authors suggest that these software packages are designed to enhance learning capacity, accelerate knowledge growth, and facilitate data acquisition for practitioners through machine learning that supports learning and professional development.

According to [25], organizational and personal development is predicated upon the ability for creative or generative learning to occur. This suggests learning that has incremental growth potential for both individuals and teams. It also presupposes an environment that is conducive to a move towards strategies that are embedded in an ongoing organizational dialogue, rather than imposed from "above" or a product of periodic strategic planning workshops. This thinking is consistent with the thinking that has led to revision of Bloom's taxonomy in 2001. These revisions are summarized in [26]. The most significant ones are the renaming of elements of the original taxonomy and the insertion of "create" at the center, as illustrated in Figure 3. This strongly suggests the significance of innovation as an ultimate learning goal. It is also consistent with the element of innovation embodied in the GBCSA schema. This revised taxonomy reflects the progression from lower order thinking skills (remembering, understanding, and applying) to higher order thinking skills (analyzing, evaluating, and creating). It provides educators with a framework to design and assess learning objectives at different levels of cognitive complexity.

Further amendments to the original Bloom's taxonomy have been more fundamental. In [27], more focus is placed upon the practitioner as central to defining, executing, and reacting to the learning process. This includes emotion and a sense of personal significance of the learning experience for the practitioner. Fink [27] illustrated in Figure 4 the idea of a taxonomy of learning that indicates the circular nature of knowledge growth. This is not fundamentally different to Bloom's taxonomy, except for the integration of human feelings, values, and self-reflection into the learning process in a manner akin to that of participatory action research (PAR), where actions are followed by reflection and revised action. This is facilitated by simulation.

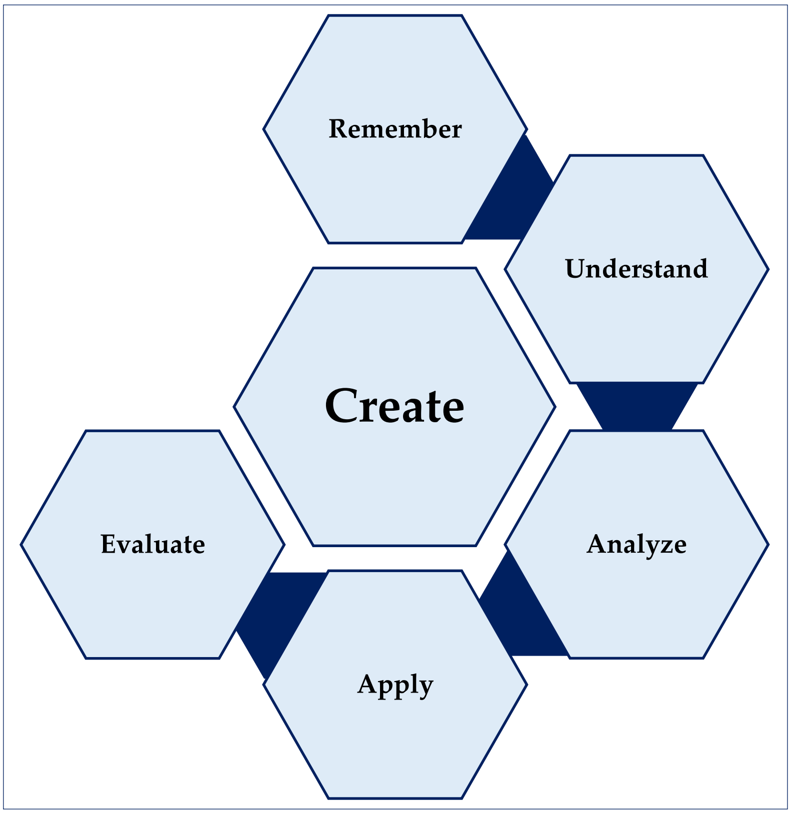

Figure 3. Revised Bloom's taxonomy.

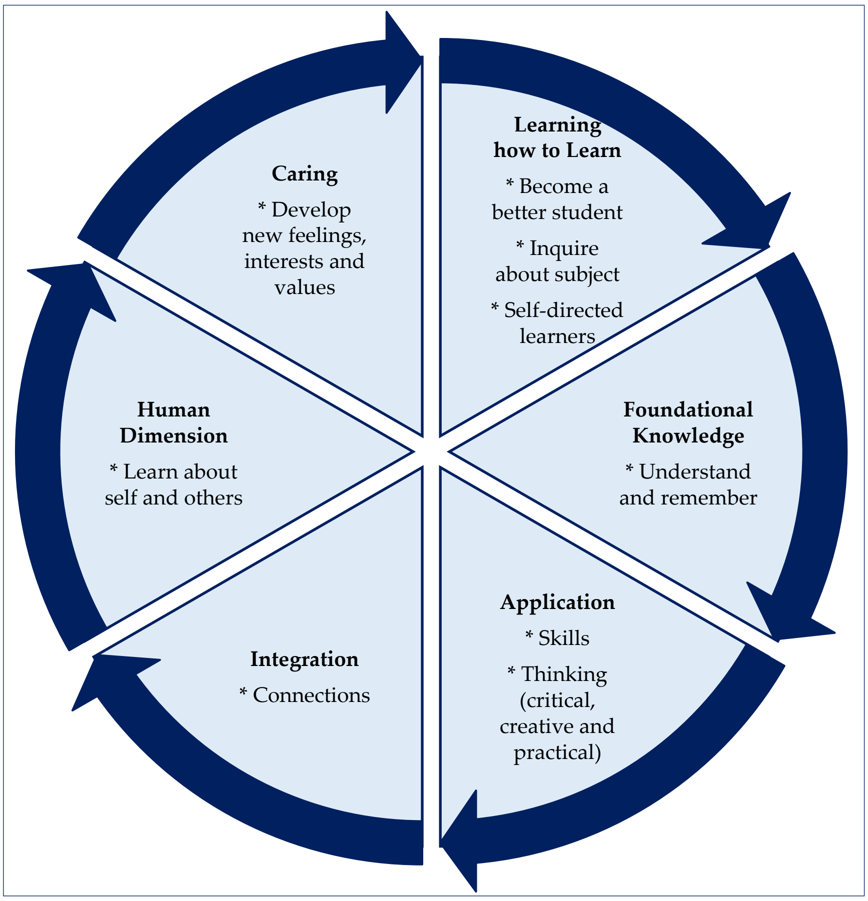

Figure 4. Fink's taxonomy of learning.

Others [27,28] have added further dimensions to the factors affecting the acquisition of knowledge. In the case of [26], the insight provided is related to perspectives, or how problems are perceived to affect learning as a result. In essence, people differ in how they understand problems and how they respond to them. This is particularly acute in the case of complex problems where team effort, as noted by [25], is likely to produce improved outcomes. A further insight is personal, professional, and societal influences that collectively impact an individual's learning. In the case of [28], learning is considered as a path towards wisdom that begins with data, that are assembled to form information, leading to a growing body of knowledge, and ultimately wisdom [29]. In this system, wisdom is the ability to detect patterns and make informed judgements [30,31]. In a context where rapid and accurate decisions are required, as is typical of the early design stages of buildings, simulation and modelling can accelerate the testing of design decisions and their potential revision [32,33].

The research process used in this paper is one where machine learning accelerates the movement towards pattern detection and the emergence of wisdom to enable informed judgments in the matter of early-stage green building design. By elaborating on these aspects and providing specific details, this research paper communicates the novelty and significance of the work in the context of green building design at early stages:

1. Methodology for Green Building Design: In this context, the methodology involves employing MATLAB and EnergyPlus to analyze data related to building design, energy consumption, and environmental impact. The simulated model is designed to make informed decisions about architectural features, materials, and systems.
2. Data Sources: Data sources include architectural plans, climate data, historical energy consumption for the buildings, and information about sustainable building materials. These data sources provide valuable insights into the design process.
3. Case Studies: The input data are the architectural plans, local climate data, and other parameters into the system. The model optimizes the design by suggesting changes, such as improved insulation or renewable energy integration. The changes aim to reduce energy consumption and carbon emissions.
4. Applications in Green Building Design: The simulated model's applications in green building design are diverse. It analyzes the library's design, identifies inefficiencies, and suggests improvements. For instance, it determines the optimal angle and placement of solar panels, which HVAC systems are most efficient, or which local materials have the lowest environmental impact. It provides data-driven recommendations.
5. Interdisciplinary Impact: The project involves collaboration between architects, sustainability experts, and data scientists. They use machine learning as a common platform to analyze data from various disciplines. The architects can make design changes informed by environmental impact assessments, while sustainability experts can ensure that the design aligns with green building standards and the electrical engineers cover the energy aspect.

4. Model of Learning Tool

It is acknowledged that the early-stage design process of buildings requires rapid decision-making [21]. Learning and knowledge about hypothesized design decisions need to occur simultaneously with multiple decisions being made by diverse consultants. Communication amongst consultants who have diverse interests serves to add complexity to an already complex design landscape.

Learning, and learning processes, such as have been outlined by the various taxonomies, need to be anchored in a focal concern. In the context of this paper, energy consumption and learning about energy consumption in the building life cycle and its associated impacts on internal environmental quality are focal. This does not negate other green building factors, but it simplifies them for the purpose of discussion. The true complexity of the optimization of all factors is readily acknowledged.

The purposes of simulation are self-evident. One purpose is to enable the testing of interactions between variables as one, or more, are changed. A further purpose is to be able to learn from the changes to develop more advanced understanding, and thus to improve applications, consider outcomes, and rapidly reach an optimal position with the aid of machine learning and artificial intelligence. This is illustrated in Figures 5 and 6. Using the example of the energy element in green building design, the exploration to find an optimal solution considers other design concerns, including architectural layouts (window and wall ratio, and space usage), climate factors, energy consumption in a building, and internal factors (lighting, heating, and cooling). From this total data pool, those data which are most relevant are extracted to become the foundation for a first attempt at building a simulated optimized model. Several iterations with data manipulation and experiment would lead to a simulated convergence towards an optimized outcome, with a considered modification of the data pool as learning occurs. Each iteration is part of a learning cycle that accumulates knowledge and develops the human capacity to grow and become more innovative over time.

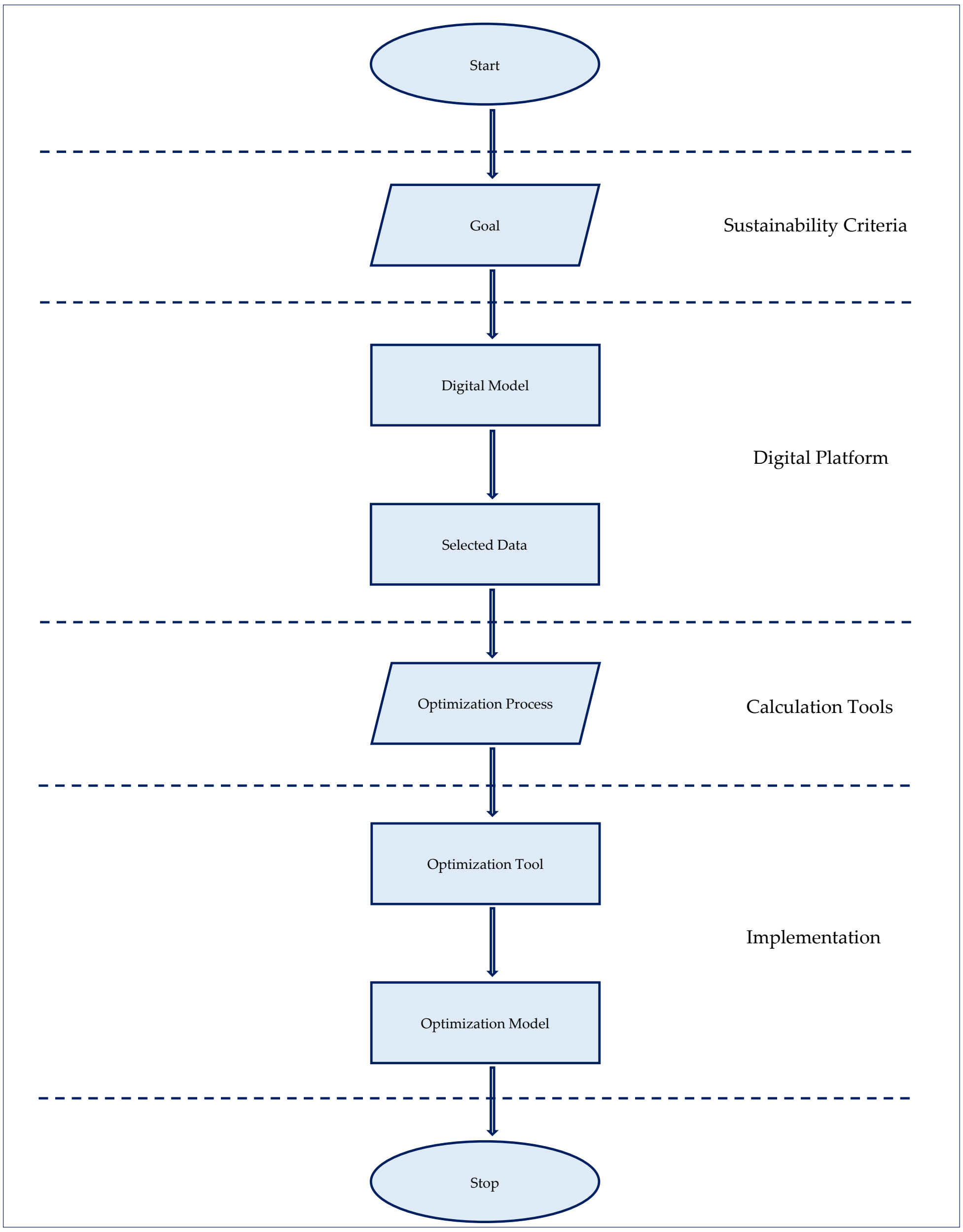

Figure 5. Process of learning tool [15].

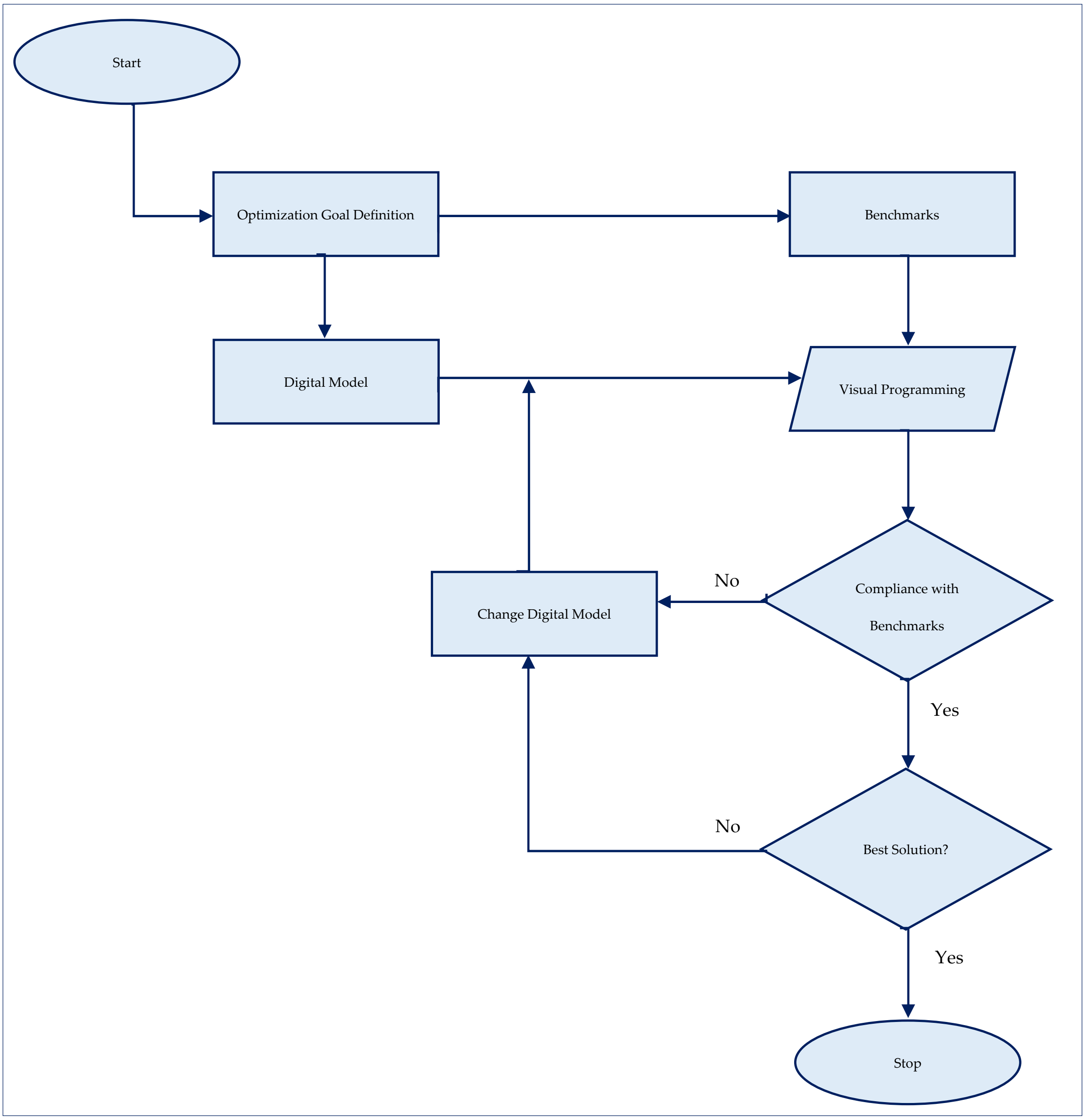

Figure 6. The workflow of the optimization process [15].

4.1. Flow of the Process of Learning Tool

In the development of the learning tool model for green buildings, significant emphasis is placed on intervention strategies designed to achieve the objectives of green criteria in a building. This focus is illustrated in Figure 5. The aim is to create a comprehensive tool that can guide and inform stakeholders involved in the design and construction of green buildings. Here is a breakdown of the key elements:

- Goal: The diverse objectives of an architectural project can be encapsulated within the three fundamental pillars of sustainable development: environmental, social, and economic. These encompass goals related to energy efficiency, economic viability, occupant comfort, environmental impact, social considerations, urban planning, and more. Under these overarching categories, specific and nuanced objectives can be delineated.
- Digital Model and Selected Data: The subsequent stages involve the creation of the digital model and the identification of pertinent data essential for the optimization pro-

cedure. In the implementations outlined below, the BIM model serves as the kingpin of the methodology. Leveraging its previously outlined capabilities, particularly its ability to encompass comprehensive design information, the BIM model obviates the need to gather and integrate missing data throughout the process. Once the objectives and constraints are established, the subsequent phase involves exploring the digital representation of the building and extracting the requisite input data.

- Optimization Process: The next phase in the methodology involves the formulation of the optimization process. This stage encompasses several elements that are common to all optimization problems (algorithms). Numerous techniques are available for complex optimization problems, yet not all of them are suitable or applicable to the construction field, especially considering the type of available information.
- Optimization Tool: Having identified the objectives, developed the digital model, and selected the data and methods in the earlier phases, the next step involves utilizing specific software (MATLAB) to implement the optimization process and resolve the problem.
- Result: Following numerous iterations and the removal of unsuitable solutions, the outcome of the optimization process is either an optimal solution or a collection of optimized design alternatives, aligning with the established objective functions. This provides the designer with insights into design solutions, enabling more informed decision-making, especially in dealing with intricate challenges like assessing the sustainable aspects of construction from the outset.

This research paper is focused on creating a tool that integrates these elements. It is intended to provide a structured and systematic approach for stakeholders involved in green building projects to understand, implement, and achieve green criteria effectively. The intervention strategies are a critical part of this tool, as they offer practical steps and actions that can be taken to meet green building objectives. Overall, this learning tool model aims to contribute to the field of green building design by providing a resource that supports informed decision-making, promotes sustainable practices, and helps stakeholders navigate the complexities of green criteria and certification standards. It can be a valuable resource for architects, engineers, builders, and others involved in the green building industry to enhance their knowledge and skills in creating environmentally friendly and sustainable structures.

4.2. Optimization Process of the Learning Tool

The optimization process of the learning tool is shown in Figure 6. Building upon the model process illustrated in Figure 5, this figure outlines how the case studies were used in the research and how they contributed to the optimization process. Here is an explanation of the key elements in this context:

- Optimization Process (Figure 6): This is the structured process for refining and improving the learning tool. It outlines the specific steps taken to enhance the tool's effectiveness in guiding green building design and achieving sustainable objectives.
- Case Studies: These are real-world examples of green building projects. The case studies serve as practical sources of data and insights. Each case study is examined in detail to extract valuable information related to the targeted categories for scoring, which are typically related to green building criteria.
- Model Process: This refers to the earlier model introduced in Figure 5, emphasizing the importance of intervention strategies to achieve green criteria in buildings.
- Targeted Categories for Scoring: In the context of green building and sustainability, these are the specific aspects or criteria within a building's design that are evaluated and scored. Examples include energy efficiency, water usage, material selection, and indoor air quality.
- Data Comparison: The data collected from each case study are systematically compared. This comparison involves evaluating how well each case study performs in terms of the targeted categories for scoring. The goal is to identify which projects excel in specific criteria.

- Flow Chart Process: The flow chart represents a systematic decision-making or evaluation process. It is used to guide the analysis of data from case studies. By following this flow chart, practitioners can determine the best solution and the maximum points achieved for each sub-category of scoring within the case studies.
- Benchmarking and Compliance: Benchmarking involves comparing the performance of a building or project against recognized standards or benchmarks. Compliance refers to meeting specific requirements or standards, often related to green building certifications. These aspects are vital for assessing how well a project aligns with industry standards and best practices.

The optimization process aims to extract valuable insights from the case studies, identify best practices, and develop or refine intervention strategies within the learning tool. It is about learning from real-world examples and using that knowledge to enhance the tool's ability to guide and inform stakeholders in the green building industry. This approach contributes to the advancement of sustainable building practices by providing a data-driven and evidence-based tool for decision-making and design optimization.

A list of 57 case studies in South Africa were examined, focusing on the Green Star rating system and its functionality criteria. The case studies were divided into three sections based on their Green Star ratings: four stars, five stars, and six stars. The primary focus of each case study was on modelling, with an emphasis on energy-related aspects. The aim was to analyze the points achieved in specific areas related to energy modelling and other sub-categories. These case studies likely aimed to evaluate the energy efficiency and sustainability performance of green buildings in South Africa.

This study involved a detailed examination of each case study to understand how different green building projects in South Africa performed in terms of energy efficiency and their compliance with Green Star criteria. As explained, this relates to green buildings in the South African context. Furthermore, the case studies were used to provide insights into the performance of green buildings in South Africa concerning energy efficiency and sustainability, as assessed by the Green Star rating system. The findings would help stakeholders, including architects, developers, and policymakers, understand how different buildings have approached energy modelling and achieved Green Star ratings. This information can be valuable for promoting sustainable building practices and improving energy efficiency in the South African construction industry.

4.3. Case Studies Targeting Four-Star Rating

The case studies concentrated on specific categories for optimization and scoring, namely, management, indoor environment quality, and energy. This indicates a targeted approach to achieving green building certification in these areas, reflecting priorities in sustainability and occupant well-being. The GBCSA scoresheet indicates that the criteria and scoring align with the Green Building Council of South Africa's standards. This suggests a commitment to adhering to recognized and standardized green building practices. The case studies are presented in the table in a ranked order, from maximum to minimum points. This ranking provides a clear understanding of which projects excelled in incorporating green design alternatives, offering insights into best practices and potential benchmarks for future projects.

A detailed examination of the case studies is tabulated in Table 2, emphasizing their achievements in specific categories, and providing a structured view of their optimization efforts for green building certification. The presentation of projects based on their optimization efforts offers a visual representation of the commitment to green design. This is valuable for stakeholders, policymakers, and industry professionals seeking to understand the landscape of green building initiatives. The three specified categories, i.e., management, indoor environment quality, and energy, shed light on the specific aspects that were prioritized in the pursuit of green building certification. This specificity aids in understanding the targeted sustainability goals of each project.

Table 2. Case studies of four-star-rated buildings [34].

Four-Star Projects	Categories									
	Management	Indoor Environment Quality	Energy	Transport	Water	Materials	Land Use and Ecology	Emissions	Innovation	Total Points
Wierda Gables Sandton, Gauteng	✓	✓	✓	✓	✓	✓	✓	✓		**57**
Silverstream Business Park, Building 1, South Bryanston	✓	✓	✓	✓	✓	✓	✓	✓		55
The Towers Alice Lane, Sandton	✓	✓	✓	✓	✓	✓	✓	✓		54
Centennial Place Milnerton, Cape Town	✓	✓	✓	✓	✓	✓	✓	✓		53
The Oval, Bryanston, Johannesburg	✓	✓	✓	✓		✓	✓	✓		52
Stoneridge Office Park, Building D, Modderfontein, Lethabong	✓	✓	✓	✓	✓	✓	✓	✓		51
Sandown Erf 169 Sandown Ext. 9, Sandton	✓	✓	✓	✓	✓	✓	✓	✓		49
Podium at Menlyn Menlyn, Pretoria	✓	✓	✓	✓	✓	✓	✓	✓	✓	49
West Quay Offices, V&A Waterfront, Cape Town	✓	✓	✓	✓	✓	✓	✓	✓	✓	49
28 Fricker Road Illovo, Johannesburg	✓	✓	✓	✓	✓	✓	✓	✓		48
2929 on Nicol Bryanston, Johannesburg	✓	✓	✓	✓	✓	✓	✓	✓		48
Nicol Main Office Park Bryanston, Johannesburg	✓	✓	✓	✓	✓	✓	✓	✓		48
Rosebank Office Park Rosebank, Johannesburg	✓	✓	✓	✓	✓	✓	✓	✓		48
Nautica, Granger Bay	✓	✓	✓	✓	✓	✓	✓			47
Buckhurst Building, Essex Gardens, Westville, KZN	✓	✓	✓		✓	✓	✓	✓		47
Mariendahl House Newlands, Cape Town	✓	✓	✓	✓	✓	✓	✓			47
1 & 1A Protea Place Sandton, Johannesburg	✓	✓	✓	✓	✓	✓	✓	✓	✓	47
Equity House Dunkeld West, Johannesburg	✓	✓	✓	✓	✓	✓	✓	✓		46
Kirstenhof Office Park Sandton, Johannesburg	✓	✓	✓		✓	✓	✓	✓		46

Table 2. *Cont.*

Four-Star Projects	Categories									Total Points
	Management	Indoor Environment Quality	Energy	Transport	Water	Materials	Land Use and Ecology	Emissions	Innovation	
138 West Street Sandown, Sandton	✓	✓	✓	✓	✓	✓	✓	✓		46
Lincoln on the Lake Umhlanga, Kwazulu Natal	✓	✓	✓	✓	✓	✓	✓	✓		46
Pharos House Westville, Durban	✓	✓	✓	✓	✓	✓	✓	✓		46
Waterfall Park: Phase 1 Vorna Valley, Midrand	✓	✓	✓	✓		✓	✓	✓		45
19 Impala Road Chiselhurston, Sandton	✓	✓	✓	✓	✓	✓	✓	✓		45
Upminster, Essex Gardens Westville, KZN	✓	✓	✓	✓	✓	✓	✓	✓		45

Note: The ticks represent the scoring for each of the categories, i.e., for each of the projects.

The Wierda Gables project achieved the highest score amongst the 25 case studies reviewed in the four-star category. This indicates an exemplary commitment to green building principles, surpassing its peers in terms of adherence to sustainability standards. The project earned a total of 57 out of 100 points. This numerical representation provides a clear measure of the project's success in meeting the criteria for green building certification. The use of a percentage (57%) offers an additional perspective on the completeness of achievement. The project's success is attributed to its focus on three major scoring categories: management, indoor environment quality, and energy. This indicates a strategic approach, homing in on key aspects that contribute significantly to green building objectives.

Figure 7 is a visual representation of how the project targeted management, indoor environment quality, and energy as major scoring categories. Overall, the information emphasizes the exceptional performance of the Wierda Gables project, both quantitatively (in terms of points) and qualitatively (in its focus on specific categories). It positions the project as a benchmark for others in the four-star category, providing insights into effective strategies for achieving green building certification.

The Upminster project in KZN, SA, achieved the fewest points, i.e., 45 out of 100 points. This suggests a comparatively low performance in meeting the criteria for green building certification. The project's weakest aspect appears to be in the energy category. This indicates that the strategies or implementations related to energy efficiency, renewable energy, or other energy-related criteria were less pronounced and effective in this project. While the energy category was weak, the management and indoor environment quality categories were described as "average". This implies that, in comparison to other projects, Upminster performed reasonably well in these aspects but still had room for improvement.

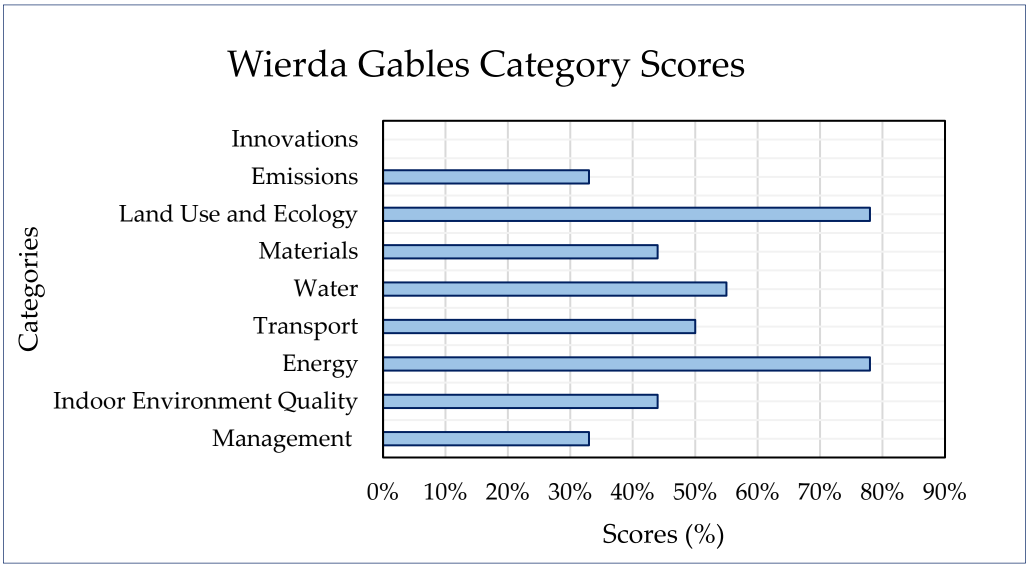

Figure 7. Wierda Gables four-star maximum scoring per category.

Figure 8 is a visual representation of how the Upminster project targeted management, indoor environment quality, and energy. The mention of a weaker performance in the energy category provides a specific area for improvement. Projects can learn from this example to enhance their strategies related to energy efficiency and sustainability. Overall, this information positions the Upminster project as having areas for improvement, particularly in the energy category, and provides insights into potential focus areas for future green building initiatives.

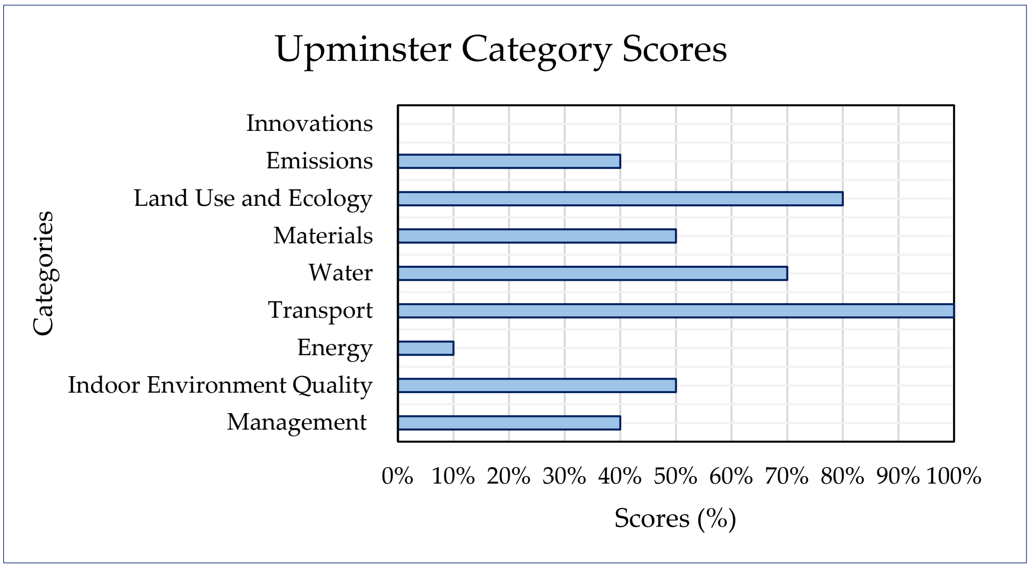

Figure 8. Upminster four-star minimum scoring per category.

The buildings in the four-star category achieved an average score of 49 out of 100 points. This signifies a moderate level of adherence to green building criteria. The average score serves as a benchmark for evaluating the overall performance of these buildings. The mention of "targeted few categories in scoring points" implies that these buildings might not have fully explored or implemented a comprehensive set of green design alternatives. This limitation could be a result of various factors, such as budget constraints, design choices, or a lack of awareness regarding certain green building practices. Despite the limitations, there is an indication that the energy category was a primary focus. However, even in this category, the buildings did not achieve the maximum points possible. This suggests that while energy efficiency measures were considered, there might still be room for improvement or more innovative solutions. Regardless of the efforts in the energy category, challenges persisted in obtaining the highest possible score. This could be due to the complexity of the criteria, technological limitations, or other factors. The data provide insights for future green building designs in the four-star category. It highlights the importance of diversifying strategies across multiple categories to achieve a more holistic and optimized green building.

In summary, the average score, emphasis on the energy category, and challenges in achieving maximum points collectively offer valuable information for evaluating and improving the sustainability performance of four-star-rated buildings.

4.4. Case Studies Targeting Five-Star Rating

The case studies in Table 3 achieved five-star ratings, indicating a higher level of adherence to green building criteria compared to the four-star category. A five-star rating suggests a more advanced and sustainable approach to building design and construction.

Table 3. Case studies of five-star-rated buildings [34].

Five-Star Projects	Categories									
	Management	Indoor Environment Quality	Energy	Transport	Water	Materials	Land Use and Ecology	Emissions	Innovation	Total Points
Green Building at Karl Bremer Hospital Bellville, Cape Town, SA	✓	✓	✓	✓	✓	✓	✓	✓	✓	**73**
The Lakeside Offices Centurion, Gauteng	✓	✓	✓	✓	✓	✓	✓	✓	✓	72
Vodacom Century City Boulevard, Cape Town	✓	✓	✓	✓	✓	✓	✓	✓		67
No.1 Mutual Place Rivonia Road, Sandton	✓	✓	✓	✓	✓	✓	✓	✓	✓	66
Sanral Southern Region/Baywest Office, Baywest City, Port Elizabeth	✓	✓	✓	✓	✓	✓		✓	✓	66
BMW (SA) Head Office Refurbishment, Midrand	✓	✓	✓	✓	✓	✓	✓	✓		66
National English Literary Museum, Grahamstown, Eastern Cape, SA	✓	✓	✓	✓	✓	✓	✓	✓		65
Centurion Square Centurion, SA	✓	✓	✓	✓	✓	✓	✓	✓		64
1 Mutual Place, Rivonia Road, Sandown	✓	✓	✓	✓	✓	✓	✓	✓		64
Nedbank Menlyn Maine Bancor Ave, Waterkloof Glen	✓	✓	✓	✓	✓	✓	✓	✓		64

Table 3. *Cont.*

Five-Star Projects	Categories									Total Points
	Management	Indoor Environment Quality	Energy	Transport	Water	Materials	Land Use and Ecology	Emissions	Innovation	
Homechoice, Wynberg, Cape Town	✓	✓	✓	✓	✓	✓	✓	✓		63
Sisonke District Offices Margaret Street, Ixopo, SA	✓	✓	✓	✓	✓	✓	✓	✓		63
144 Oxford, Melrose, Johannesburg	✓	✓	✓	✓	✓	✓		✓	✓	62
Nedbank Menlyn Maine Falcon, Waterkloof Glen, Pretoria, SA	✓	✓	✓	✓	✓	✓		✓	✓	62
Tswhane House, Madiba Street, City of Tshwane	✓	✓	✓	✓	✓	✓	✓	✓		61
Boogertman Johannesburg Interior, Block C Main Road Bryanston	✓	✓	✓	✓	✓	✓	✓	✓	✓	61
4 Bucksburn, Bucksburn Road, Newlands, Cape Town	✓	✓	✓	✓	✓	✓	✓	✓	✓	61
Standard Bank Nelspruit Crossing, The Crossing Centre, Nelspruit	✓	✓	✓	✓	✓	✓		✓	✓	61
Victoria Wharf Shopping Centre, V&A Waterfront	✓	✓	✓	✓	✓	✓	✓	✓	✓	60
Growthpoint Ridgeview Office Development, Umhlanga Ridge	✓	✓	✓	✓	✓	✓	✓	✓		60
Millennia Park Stellenbosch, SA	✓	✓	✓	✓	✓	✓	✓	✓	✓	60

Note: The ticks represent the scoring for each of the categories, i.e., for each of the projects.

Management, indoor environment quality, and energy highlight the key areas of emphasis in the design and optimization process. These categories are critical for achieving a high level of sustainability and occupant well-being. The arrangement of case studies from maximum to minimum points provides a clear hierarchy of performance. This ranking is insightful for understanding which projects excelled in implementing green design alternatives and which ones had room for improvement. By illustrating which projects targeted the most green design alternatives, the data serve as a benchmark for evaluating the extent of sustainable practices adopted in each case study. This information is valuable for both designers and stakeholders interested in green building practices.

The data on green design alternatives and optimization focus offer insights for future building designs aspiring for five-star ratings. Understanding the emphasis on specific categories can guide designers in prioritizing aspects that contribute significantly to achieving a higher rating. The emphasis on five-star ratings, focus on key categories, and the ranking of case studies based on points provide a comprehensive view of the commitment to sustainability in the considered projects. This information can contribute to the knowledge base for advancing green building practices.

Karl Bremer Hospital's attainment of the maximum number of points in Figure 9 (73 out of 100) positions it as a leader among the considered case studies. This exemplary performance reflects a strong commitment to implementing green design alternatives and optimizing key categories. Management, indoor environment quality, and energy are their major scoring categories, which highlights the specific areas of emphasis. These categories are crucial for achieving high sustainability standards, ensuring efficient building management, providing a healthy indoor environment, and optimizing energy use. Karl Bremer Hospital, by achieving the highest points, serves as a benchmark for other projects aspiring to attain a five-star rating. Designers and stakeholders can look to this project for insights into effective strategies and practices that contribute to superior green building performance.

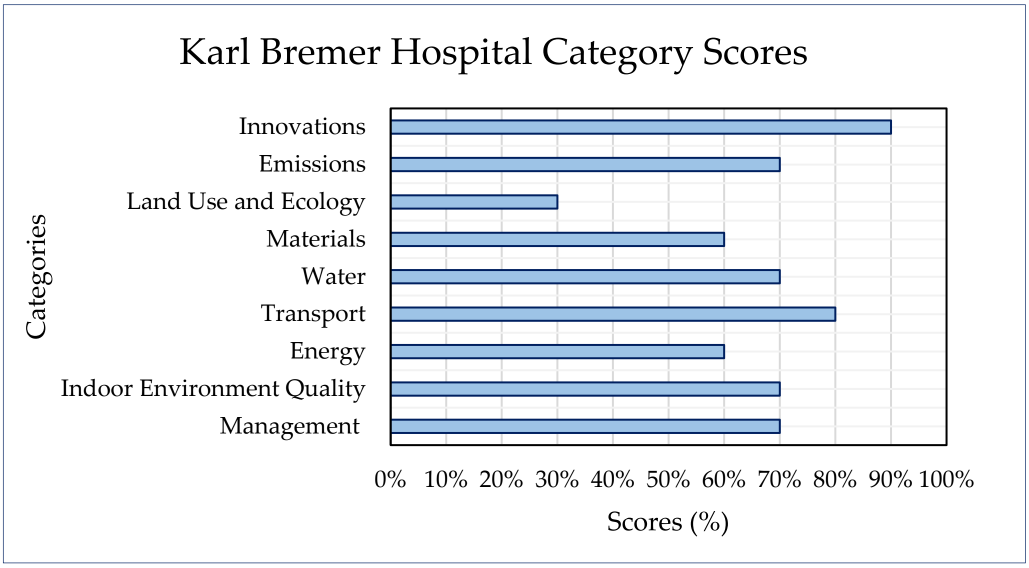

Figure 9. Karl Bremer Hospital five-star maximum scoring per category [1].

The fact that the project targeted major scoring categories suggests a holistic approach to green building. Karl Bremer Hospital demonstrates a comprehensive commitment to sustainability. The success of Karl Bremer Hospital offers an opportunity for knowledge transfer within the industry. Lessons learned from this project can be shared to inspire and guide future green building initiatives. The focus on management, indoor environment quality, and energy recognizes the interconnectedness of these categories. A balanced approach that considers various facets of sustainability contributes to the overall success of the project. Karl Bremer Hospital's outstanding performance in achieving the maximum points for a five-star rating positions it as a noteworthy example in the realm of green building. The lessons learned from this project can contribute to advancing sustainable practices in future building designs.

The performance of the Millenia Park project in KZN, South Africa, which achieved the fewest points in the five-star category, provides insights into certain aspects of its green building strategies. With a score of 60 out of 100 points as in Figure 10, Millenia Park's performance indicates a moderate level of accomplishment in green building practices. However, the fact that it achieved the fewest points among the considered five-star projects suggests that there are areas for improvement. Energy optimization is a critical aspect of green building, impacting both environmental sustainability and operational costs. The lower emphasis on this category suggests a potential area for improvement or a focus for future green initiatives. While energy was the least targeted category, the mention of management and indoor environment quality being average indicates a more balanced performance in these areas. This balanced approach can contribute positively to the sustainability of the project.

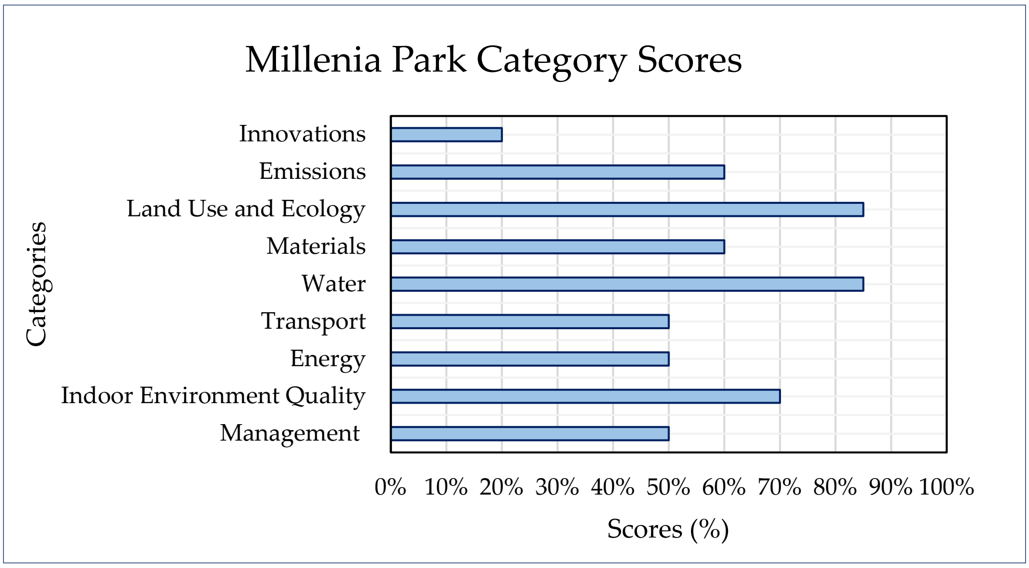

Figure 10. Millenia Park five-star minimum scoring per category [1].

The fact that Millenia Park received the fewest points does not necessarily imply failure but rather points to untapped opportunities. There is potential for optimization, particularly in areas where the project scored lower, such as energy. Millenia Park's performance, even if not the highest, serves as a learning opportunity for future projects. Understanding the challenges faced by this project can guide designers and stakeholders in avoiding similar pitfalls and enhancing their green building strategies. The acknowledgment of management and indoor environment quality as average suggests a holistic consideration of multiple sustainability aspects. Even with room for improvement, a balanced focus on various categories aligns with the principles of comprehensive green building. Millenia Park's achievement of the fewest points in the five-star category signals a need for a closer examination of its energy optimization strategies. This project, like any other, presents opportunities for learning and refinement, contributing to the ongoing evolution of green building practices in the region.

The average score of 64 out of 100 points for the five-star-rated buildings provides valuable insights into the overall green building landscape in the considered case studies. The fact that the average score is 64 indicates that, on average, the five-star-rated buildings performed above the midpoint in terms of green building criteria. This suggests a relatively high level of commitment to sustainable and environmentally friendly practices in these projects. Projects scoring well across multiple categories demonstrate a commitment to a holistic and well-rounded sustainability strategy. Despite the above-average performance, the mention that "green design alternatives were average on these buildings and could not be optimized to their maximum" suggests that there might be challenges in fully optimizing green design strategies. Identifying and addressing these challenges could lead to higher scores and more sustainable buildings. The observation that the IEQ category "reigned supreme" indicates a particular strength in focusing on indoor environmental quality. This could be due to the recognition of the impact of indoor spaces on occupants' well-being and productivity. While the average score is commendable, there is still room for improvement, especially in optimizing green design alternatives.

Understanding the specific challenges or limitations that prevented maximum optimization could guide future projects in overcoming similar obstacles. Achieving maximum points in every category might involve trade-offs, and projects need to find a balance that aligns with their specific goals and constraints. It is not just about scoring highly but doing so in a way that meets the project's unique requirements. The findings indicate a positive trend with the average scores increasing from the four-star to the five-star category. This suggests a commitment to continuous improvement and a willingness to adapt to evolving green building standards and practices. The average score of 64 for the five-star category reflects a strong commitment to green building principles. However, the observation that optimization could be improved suggests that there are opportunities to push the boundaries of sustainability further in future projects. The dominance of IEQ indicates an awareness of the importance of the indoor environment in creating truly sustainable buildings.

4.5. Case Studies Targeting Six-Star Rating

The case studies in Table 4 have attained the highest six-star ratings, signifying the pinnacle of green building certification. A six-star rating indicates an exceptional commitment to sustainability and environmental responsibility. Management, indoor environment quality, and energy, among other categories, have been the focus of optimization and scoring in each of the six-star projects. These categories reflect a holistic approach to sustainable building design, encompassing factors related to management, indoor environment quality, and energy efficiency. The case studies are rated from maximum to minimum points, illustrating which projects targeted the most green design alternatives for optimization. This ranking provides a clear understanding of which projects excelled in incorporating green design alternatives, offering insights into best practices and potential benchmarks for future projects. The case studies concentrated on specific categories for optimization and scoring, such as management, indoor environment quality, and energy. This indicates a targeted approach to achieving green building certification in these areas, reflecting priorities in sustainability and occupant well-being. A detailed examination of the case studies in Table 4 emphasizes their achievements in specific categories, providing a structured view of their optimization efforts for green building certification. This underscores the exceptional commitment and holistic approach of six-star-rated projects in achieving green building certification. The detailed examination and ranking of optimization efforts provide valuable insights for stakeholders and industry professionals in advancing sustainable building practices.

The Hotel Verde project in Cape Town, SA, stands out among the case studies in the six-star category, achieving the most possible points, with a remarkable score of 92 out of 100. This exceptional performance is a testament to the project's robust commitment to green building principles and sustainability. The key focus areas for optimization in this project include management, indoor environment quality, and energy, reflecting a comprehensive approach to sustainable building practices. The project attained the maximum achievable points, demonstrating an outstanding level of adherence to green building criteria. The major scoring categories for the Hotel Verde project include management, indoor environment quality, and energy. These categories emphasize a holistic approach that considers aspects of efficient project management, superior indoor environmental quality, and energy conservation. Achieving the highest score indicates that the Hotel Verde project has implemented exemplary practices in sustainability and environmental responsibility. The Hotel Verde project serves as a benchmark for other projects aspiring to achieve a six-star rating, providing insights into best practices and optimization strategies. The focus on multiple key categories reveals a commitment to a holistic approach to sustainability, addressing various aspects of building design and operation.

Table 4. Case studies of six-star-rated buildings [34].

Six-Star Projects	Categories									
	Management	Indoor Environment Quality	Energy	Transport	Water	Materials	Land Use and Ecology	Emissions	Innovation	Total Points
Hotel Verde Cape Town Airport Industria, Cape Town	✓	✓	✓	✓	✓	✓	✓	✓	✓	**92**
Vodafone Site Solution Innovation CENTRE, Midrand, Gauteng, SA	✓	✓	✓	✓	✓	✓	✓	✓	✓	86
Central Building Fir Street, Observatory, Cape Town	✓	✓	✓	✓	✓	✓	✓	✓	✓	76
Old Warehouse Fir Street, Observatory, Cape Town	✓	✓	✓	✓	✓	✓	✓	✓	✓	76
WWF-SA: Braamfontein Braamfontein, Johannesburg	✓	✓	✓	✓	✓	✓	✓	✓		76
Belgotex Floorcoverings (Pty) Ltd. Willowton, Pietermaritzburg	✓	✓	✓	✓	✓	✓	✓	✓	✓	76
Woolworths Food Store: Palmyra Junction, Claremont, Cape Town	✓	✓	✓	✓	✓	✓	✓	✓	✓	75
The Product Testing Institute, Coega IDZ, Nelson Mandela Bay	✓	✓	✓	✓	✓	✓	✓	✓	✓	75

The visual representation in Figure 11 provides a graphical overview of how points were distributed across different categories, offering stakeholders and professionals a clear understanding of the project's strengths. In summary, the Hotel Verde project has set a high standard for six-star-rated buildings, showcasing outstanding achievements in key optimization categories. Its success serves as an inspiration and reference for the industry, promoting sustainable building practices and contributing significantly to the green building landscape.

The Product Testing project in Nelson Mandela Bay, South Africa, achieved a respectable score of 75 out of 100 points in the six-star category. While it received the fewest points among the six-star-rated buildings, this score still reflects a commendable commitment to green building principles. The Product Testing project achieved a total of 75 out of 100 points, indicating a substantial effort in incorporating green design alternatives. The management category was identified as the least targeted one in terms of optimization. This suggests that there may be opportunities for improvement in project management practices to enhance sustainability. Despite management being the least targeted category, the energy and indoor environment quality categories were above average. This indicates a strong focus on energy efficiency and creating a healthy indoor environment. The project's approach to reducing unwanted heat gain through interventions like vertical shading fins on the East/West sides demonstrates a strategic focus on energy efficiency. Allowing ample daylight penetration while reducing heat gain signifies a conscious effort to leverage natural light, contributing to energy savings and occupant well-being. The reduction in heat gain not only contributes to energy efficiency but also results in decreased electricity usage for cooling purposes, aligning with green building goals. The mention of specific interventions, such as shading fins, provides a glimpse into the project's unique strategies for achieving sustainability goals.

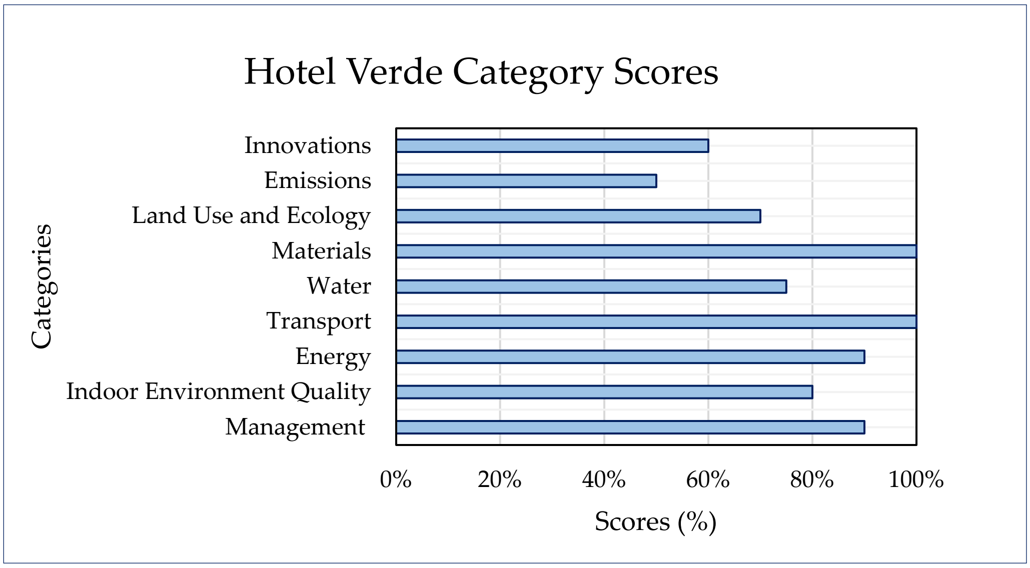

Figure 11. Hotel Verde six-star maximum scoring per category.

While the Product Testing project in Figure 12 may have received fewer points compared to other six-star-rated buildings, its above-average scores in crucial categories and specific interventions showcase a commitment to green building practices. This analysis provides valuable insights for both the project itself and the broader industry, offering opportunities for learning and improvement in sustainable building design and operation.

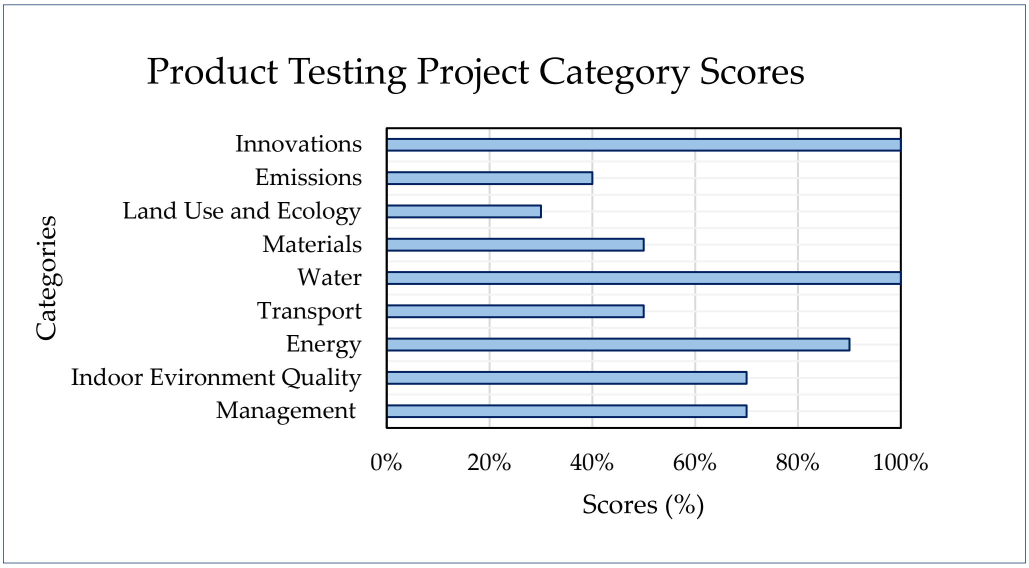

Figure 12. Product Testing project five-star minimum scoring per category.

The high average score of 79 indicates that six-star-rated buildings, on average, targeted many categories to score points. This reflects a comprehensive approach to green design and optimization. The analysis suggests that six-star-rated buildings not only targeted multiple categories but also successfully implemented green design alternatives.

This implementation is crucial for achieving the highest level of sustainability. The indication that buildings could be optimized to their maximum in terms of green design alternatives is a positive outcome. It suggests that these projects went beyond mere compliance and strived for excellence in sustainability. The statement that all three categories (management, indoor environment quality, and energy) reigned supreme in this rating underscores the holistic approach taken by six-star-rated buildings. This balanced focus on different aspects contributes to overall sustainability. Achieving high scores in all three categories suggests a holistic sustainability approach. This likely involves a combination of efficient project management, a focus on creating a healthy indoor environment, and strategies for optimizing energy usage. Six-star-rated buildings serve as leaders in the green building space, setting benchmarks for others to follow. Their success in optimizing across various categories showcases a commitment to environmental responsibility and occupant well-being.

The information on the average scoring provides valuable insights for the broader industry. Other projects, aspiring for the highest green building ratings, can learn from the strategies and practices implemented by these six-star-rated buildings. The high average score of 79 for six-star-rated buildings indicates a commendable achievement in green building practices. This analysis not only celebrates their success but also provides a basis for knowledge transfer and continuous improvement within the field of sustainable architecture and construction.

The information presented in Figure 13 outlines a temporal progression of green building initiatives in the case studies, particularly in South Africa. The case studies span the period from 2013 to 2019, indicating a historical perspective on the evolution of green building projects in South Africa over a six-year period.

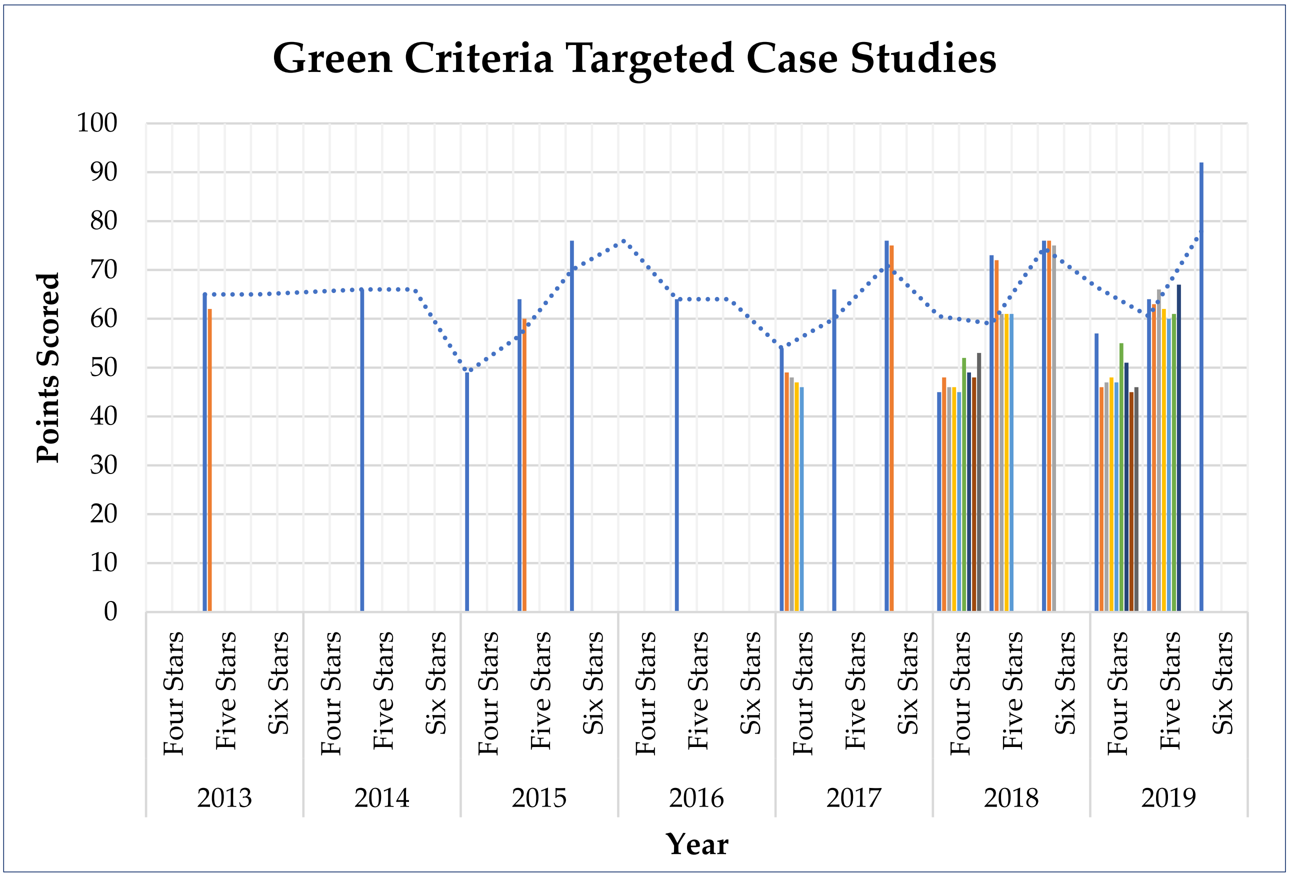

Figure 13. Case studies targeting green criteria from 2013 to 2019.

1. The gradual progression through the years suggests a growing awareness and engagement with green criteria among practitioners. More projects have targeted and achieved green building certification, as reflected in the increase in the number of certified projects over the years.
2. Collaboration and Involvement of Specialists: The note about increased collaboration with specialists implies a maturing industry where practitioners are seeking expertise to meet green criteria. This collaboration involves various professionals, including architects, engineers, sustainability consultants, and others, reflecting a multidisciplinary approach to green building design.
3. Surge in Four-Star Ratings (2017–2018) and Future Trends: Projects targeting four-star ratings in 2017–2018 suggests a period where green alternatives might have been limited or in the early stages of implementation. However, the anticipation is that, with technological advancements and innovation, more projects in the coming years are likely to target higher ratings (five-star and six-star). This reflects an optimistic view of the industry's trajectory toward more sustainable and advanced green building practices.
4. Significant Increase in 2018 and 2019: The data indicate a substantial increase in the number of projects achieving green criteria in 2018 and 2019, with 34 out of 57 projects achieving certification. This represents a 61% increase since 2013. The notable surge in these two years could be attributed to a combination of increased awareness, supportive policies, and a more mature understanding of green building practices.
5. Technological Advancements and Innovation: The reference to technological advancements and innovation as drivers for targeting higher star ratings aligns with a global trend. As technology evolves, it provides more sophisticated and efficient solutions for sustainable building design, influencing the choices made by practitioners.
6. Industry Shift towards Higher Ratings: The observation that more projects are likely to target five-star and six-star ratings in the future signals a positive industry shift towards more ambitious sustainability goals. This could be attributed to a combination of market demand, regulatory incentives, and a deeper understanding of the long-term benefits of high-performance green buildings.

In summary, the data suggest a positive trend in the South African green building landscape, with increasing engagement, collaboration, and a shift toward higher certification ratings driven by technological advancements and innovation.

In the context of green buildings in South Africa, the optimization process of the learning tool, as tabulated in Table 5, can have specific relevance and implications. The process is related to green buildings in the South African context.

Table 5. Analysis of building features for various star-rated buildings.

<table>
<tr><th colspan="6">Building Features and Green Energy Methods</th></tr>
<tr><th colspan="2">Four Stars</th><th colspan="2">Five Stars</th><th colspan="2">Six Stars</th></tr>
<tr><td>(BEST)
Wierda Gables
[35,36]</td><td>(WORST)
Upminster
Essex Gardens
[36,37]</td><td>(BEST)
Green Building at Karl Bremer Hospital
[38,39]</td><td>(WORST)
Millennia Park
[39,40]</td><td>(BEST)
Hotel Verde
Cape Town
[40,41]</td><td>(WORST)
The Product
Testing Institute
[41,42]</td></tr>
<tr><td>• Evaluating indoor air quality to ensure a healthy and productive environment.
• Measuring key factors like temperature, humidity, and air speed to maintain optimal thermal comfort.
• Analyzing the impact of noise to maintain acoustic quality.
• Assessing daylight and artificial lighting levels to prevent fatigue and minimize eyestrain.</td><td>• IEQ testing to recognize the monitoring and control of indoor pollutants to sustain the comfort and wellbeing of building occupants.
• Glare control devices are mandatory in occupied spaces to reduce the discomfort from glare and direct sunlight.</td><td>• Socio-economic category (SEC) achieved.
• All fixtures and fittings discharge into a black water treatment plant.
• Treated black water is used for the supply to the HVAC cooling plant.</td><td>• Uses radiant cooling system—lower energy consumption than conventional cooling systems.
• Use of LED in the parking areas.
• Use of double-glazing, which reduces and regulates thermal loss from the inside and solar heat gain from the outside and acts as an acoustic insulator.</td><td>• Including vertical-axis wind turbines, PV panels installed on both the north-facing roof and façade.
• Energy-generating gym equipment and elevators equipped with regenerative braking.
• A smart building management system (BMS).
• An energy-efficient HVAC system utilizing geothermal ground loops coupled with heat pumps for central heating/cooling and domestic hot water.
• Motion/occupancy-controlled lighting.
• Individual main power isolation switches for each office.
• Demand-controlled ventilation in various rooms.</td><td>• Natural ventilation of research storage area.
• Energy-efficient heating and cooling systems with motion-sensor shut-off.
• Energy-efficient LED lighting and lighting controls.
• Solar hot water generation and renewable energy generated from PV solar array.</td></tr>
</table>

The analysis of the projects in the context of green buildings in South Africa is explained below [43]:

1. Localized Case Studies (57 in South Africa): The fact that 57 case studies are examined specifically in South Africa indicates a localized approach. The challenges and opportunities for green buildings in South Africa can differ from global contexts, considering factors such as climate, available resources, and regional regulations. Analyzing these case studies provides insights tailored to the South African context.
2. Green Star Rating System: The division of case studies into three sections based on Green Star ratings (four stars, five stars, and six stars) aligns with the Green Building Council of South Africa's Green Star rating system. This system evaluates the sustainability performance of buildings and awards stars based on criteria such as energy, water, materials, and indoor environmental quality.
3. Focus on Energy Efficiency: The emphasis on energy in each case study aligns with the broader sustainability goals of South African green buildings. Given the country's energy challenges and the importance of sustainable energy practices, optimizing energy efficiency is a critical aspect of green building design.
4. Intervention Strategies for Green Criteria: South Africa, like many regions, has specific green building criteria influenced by local environmental concerns and regulatory frameworks. The intervention strategies outlined in Figure 5 would likely address these localized criteria, aiming to achieve sustainability objectives relevant to the South African context.
5. Benchmarking and Compliance with Local Standards: The process includes benchmarking, which is crucial for comparing the performance of South African green buildings against local standards and compliance requirements. This ensures that the optimization aligns with and contributes to the advancement of South Africa's green building industry.
6. Climate Considerations: The South African context includes diverse climates, from arid regions to coastal areas. The optimization process may consider how green building strategies vary based on climate, addressing issues such as water conservation in arid regions or coastal resilience in the face of climate change.
7. Local Innovation and Best Practices: By focusing on case studies in South Africa, the learning tool can capture local innovation and best practices. This contributes to a growing body of knowledge specific to the South African green building landscape, fostering a more sustainable and resilient built environment.

In summary, the optimization process, when applied to green buildings in South Africa, informs intervention strategies to address local criteria, comply with standards, and leverage best practices. It contributes to the development of a context-specific knowledge base, advancing sustainability in the South African built environment.

5. Future Development of the Model and Evaluation Criteria

To ensure the effective testing of practitioners, considering all levels of Bloom's domains, it is crucial to align the assessment method with the exercises and techniques used. The following assessment criteria should be considered when evaluating practitioners at the design stage of the building:

1. The extent to which the practitioners can correctly conduct different sections of the design under the functionality criteria of green scoring.
2. The extent of the practitioners' ability to explain the reasons for the targeted green criteria in each section of the building.
3. The extent to which the practitioners are able to analyze the data and results obtained for benchmarking purposes.
4. The extent to which practitioners can select, integrate, and use appropriate software for the simulation of optimization techniques.
5. The extent to which practitioners can draw appropriate conclusions based on the site's conditional assessments in adopting green initiatives.

All the above assessments need to be carried out and checked by the relevant person evaluating the green star criteria internally on behalf of the practitioner's firm or the GBCSA team. The assessment method is aligned to the GBCSA scoresheet.

6. Successes, Effects, and Future Targets

The presented case studies have shown their benefits and impacts on practitioner education in green criteria, as they improves the knowledge of the practitioners involved regarding green building projects.

Based on the experiences, the following can be considered as future targets:

1. Development of a four-star-targeting green building course encompassing the fundamentals of green criteria and potential innovation.
2. Development of a five-star-targeting green building course encompassing the fundamentals of green criteria and potential innovation.
3. Development of a six-star-targeting green building course encompassing the fundamentals of green criteria and potential innovation.

Further development and evaluation of the practitioners' knowledge and understanding of the green criteria modelling through previous projects can be carried out based on the concepts of passive and low-energy design.

7. Conclusions

The problem stated at the beginning of this paper was energy optimization in the life cycle of buildings. To a very significant extent, this is dependent on sustainable design decisions which are taken at the early stages of design. The problem is exacerbated by tight timelines. There is also the need to accommodate multiple conflicting design objectives that are associated with the diverse professional inputs to the final design. Focusing on energy alone as a key element in the enabling of a near-optimal internal environment quality for buildings, this paper recognizes that there are multiple connections between energy and other GBCSA parameters. The complete optimization of any one of the parameters must almost certainly occur at the sub-optimization of one or more of the other parameters. In brief, optimization is a complex, messy problem. The importance of finding best possible solutions to complex problems is presented. The importance of finding these quickly at the earliest possible time in the design process is also presented. This implies facilitating the ability of designers to learn rapidly to finalize decisions through an iterative process. Iterative processes are endemic to learning cycles and knowledge growth. The problem implied is how to accelerate learning based on an understanding of learning cycles. The complexity of interacting multiple variables does not make this easy or quick, which violates the need for rapid early-stage design decisions. While system dynamics is useful in exposing the structure of complex systems, simulation provides the power of machine learning that not only accelerates learning capacity but can also rapidly adjust to the presence of multiple variables. This has been conclusively demonstrated in many fields of human activity, such as biological science, medicine, and the military. Data presented in the paper illustrated the increase in the prevalence of six-star GBCSA-rated buildings. The proposition of this paper is that the deliberate engagement of appropriate algorithms through machine learning can both accelerate and refine early building design decisions for sustainability. Building life cycle decisions are therefore most important at the early stages of the process, which underscores the importance of taking a proactive and well-informed approach during the initial phases of building development, especially concerning energy optimization. This therefore emphasizes the necessity for a thorough comprehension of the intricacies involved in establishing energy-efficient and sustainable buildings.

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Abbreviations

GBCSA	Green Building Council of South Africa
BIM	Building information modelling
BMS	Building management system
BREAM	Building Research Establishment Environmental Assessment Method
GBS	Green Building Studio
HVAC	Heating, ventilation and air-conditioning
IEQ	Indoor environment quality
LED	Light-emitting diode
LEED	Leadership in Energy and Environmental Design
nZEB	Net zero-energy building
PAR	Participatory action research
PV	Photo voltaic
SDG	Sustainable Development Goals
SEC	Socio-economic category
WGBC	World Green Building Council

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