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Article

The Evaluation of Green Building's Feasibility: Comparative Analysis across Different Geological Conditions

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Abstract: Green building materials have nontoxic properties and are made from recycled materials. This means they are, in most cases, created from renewable resources in comparison to non-renewable resources. This research aims to further improve the justification of green buildings and their materials. This is undertaken to determine the validity of such construction techniques. This research utilizes both qualitative and quantitative methods through five Australian case studies. The case studies, which are based on new and redeveloped structures, are selected via different geological locations and are evaluated via logical argumentation along with correlation research. Further, the research will address the problem by identifying a variety of green building materials that can be used to substitute non-green building materials. With careful comparisons among the five buildings, the green signs and implementation advantages and disadvantages will be evaluated. The result of this comparison will assist in improving the current education around the topic of green building and benefit the overall response to positive change within the construction industry. Although green building initiatives are not difficult to apply, they can be cost efficient. To maximize their cost efficiency, these initiatives need to be fully adopted. This includes the adaptation of specific building orientation, design, and sealing off penetrations to greatly improve passive heating and cooling. Further, the use of rainwater tanks also assists with energy efficiency by reducing the amount of mains water used. The utilization of natural lighting along with an advanced solar power system would further reduce the overall energy usage.

Keywords: Nationwide House Energy Rating Scheme (NatHERS); green buildings; green building materials; energy efficiency

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1. Introduction

Green building is defined as "the design, construction, and operational practices that significantly reduce or eliminate its negative impact on the environment and its occupants" [1]. The impacts (both on the environment and humans) of current building materials come about from the reduction in limited material sources, excessive energy use, and the buildup of waste in landfills [2]. The actions creating these issues involve the mining and collection of standard building materials, the preparation and production, the transportation, and the overwhelming creation of construction waste [3]. Therefore, the green building itself is becoming an increasingly necessary focus throughout construction as accusations aimed at the industry are at an all-time high. These range from extreme use of global resources at all stages of building construction to high levels of pollution throughout the neighboring environment [4]. Using green building materials to mitigate the environmental impacts of the industry has already begun; however, the information available on the topic is still in its developing stages. This is creating an effect where, due to limited information, individuals such as building owners, architects, engineers, and manufacturers are interested in conserving the environment, but are not interested in using green materials to do so.

The general understanding is that in using green building materials, they are using materials that look unappealing and cheap, and perform poorly in comparison to their counterparts [5]. This, in turn, creates a demanding need across the industry to research both green building and green building materials. It will enable individuals like those identified above to increase their understanding and grasp the importance of the benefits of using green building materials in comparison to standard building materials.

Green building materials have nontoxic properties and are made from recycled materials. This means they are, in most cases, created from renewable resources in comparison to non-renewable resources. Additionally, they can be recycled, and all share characteristics of being both energy and water efficient. The use of these materials shares distinct benefits in contrast to standard building materials such as the ability to conserve energy, diminished upkeep/repair costs throughout the building's lifecycle, increased adaptability through the design stages, positive health and output for building owners, and reduced costs.

Research Objectives

The construction industry should aim to preserve the environment and prepare a sustainable future for the generations to come. The processes, methods, and materials used in the industry should be developed for the global introduction of green building and enabled as a compulsory focus throughout each stage of construction. However, the past and present state of using construction materials has been ultimately leading to future resource starvation, climate change, and negative impacts on human health. The environmental burden of these materials being produced and manufactured is swiftly becoming a critical problem. The corresponding learning that would facilitate people to react strongly and positively to the current effects on the environment is still developing. Incomplete, old, and false information disturb the successful advancement of green building.

Based on data obtained by [6], the consumption of construction materials over the last fifty years has grown significantly. Environmental pressure regarding energy consumption, waste, and greenhouse gas emissions all increased over the period 1996 to 2022. Energy consumption increased by 31%, waste production increased by 163%, and greenhouse gas emissions increased by 20%. These increases in environmental pressure largely involve the construction industry and can be widely reduced with the improvement in green building material knowledge and the substitution of non-green building materials.

This research will address the problem by identifying a variety of green building materials that can be used as a substitute for non-green building materials. With suggestions, alternatives, comparisons, advantages, and disadvantages, this will assist in improving the current education around the topic of green building and benefit the overall response to positive change within construction. To further support this research, the following question will be addressed: "What building methods and materials can be universally used in the future of construction to combat resource starvation, climate change, and negative impacts on human health?". The novelty of this research includes a survey of five Australian buildings (both new and redeveloped structures) to examine their overall green impact. All of these structures have their own unique geological and environmental conditions and thus their comparison and subsequent results are novel in that they show different green impacts across different geological conditions.

2. Literature Review and Background

2.1. Implementation of Green Buildings

With the rapid development of climate change, resource starvation, and negative impacts on human health, the need to implement green building materials as common practice is becoming critical. Figure 1 represents the general influences of green buildings.

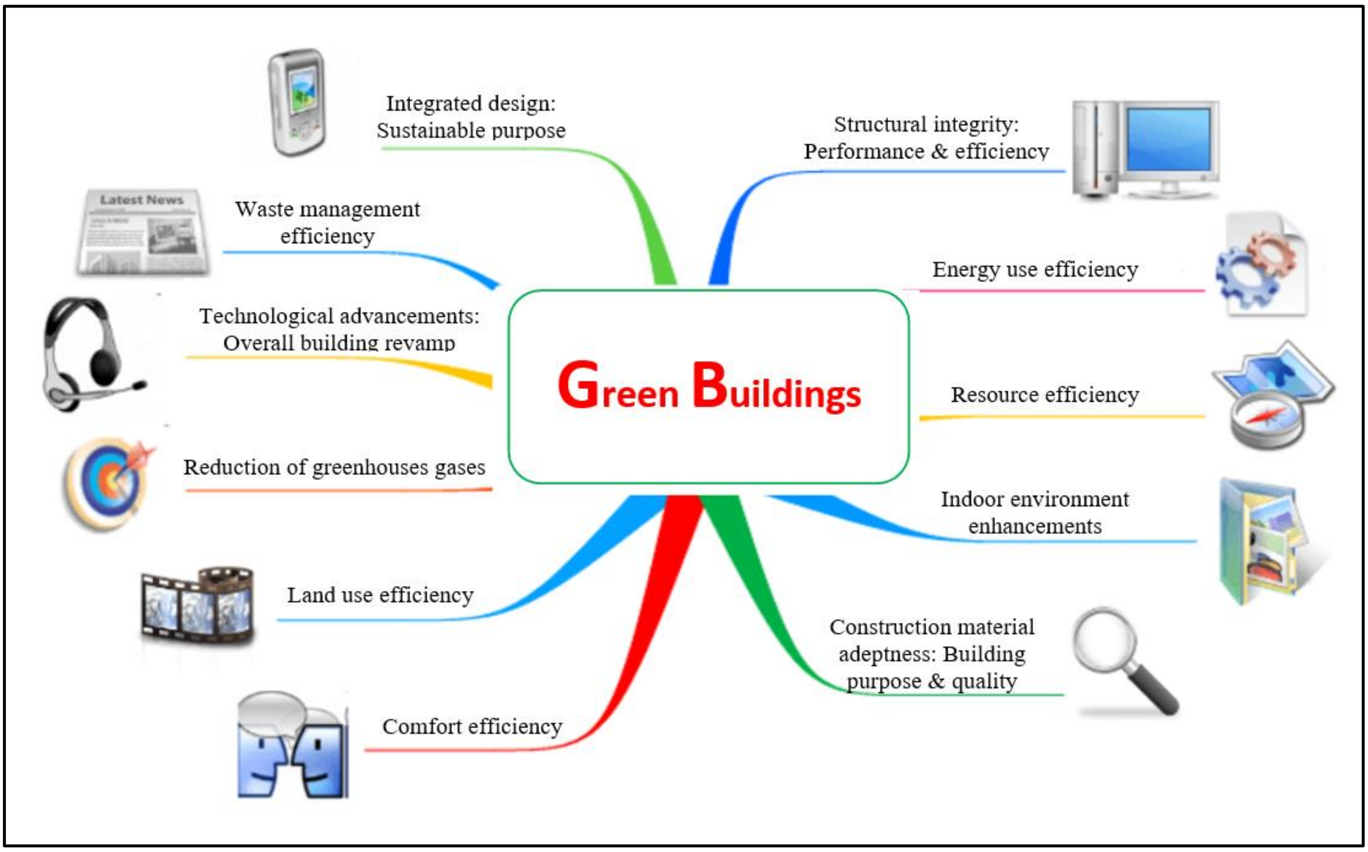

Figure 1. General dimensions of green buildings.

As can be noticed from Figure 1, the general dimensions of green buildings are many, but most focus on improving energy efficiency. To evaluate the feasibility of green buildings, there are many factors to consider. As shown in Figure 1, these factors range from integrated design (following sustainable design principles) to construction adeptness. Materials are one key area where high energy efficiency can be achieved for buildings. Ref. [7] identified that the standard building materials used to provide infrastructure, products, and equipment still have enough global supply to meet the current demand. However, the impacts created on the environment through the production of more materials, which are primarily related to energy, are swiftly becoming crucial. This is supported by [3], who suggested that environmental crises are creating the need for human beings to adjust how they plan, design, and construct buildings, especially regarding building materials. With the suggestions made by the researchers, it can be argued that there is an overwhelming need within the construction industry to adjust building methods with a particular focus on the materials being used. This is further supported by [8], who put forward the idea that the current methods and use of materials are consuming extreme shares of resources and without proper focus on a green building can detract from both the environment and budgets.

Further, the authors in [5] claimed that this issue with current methods and material use arises because the corresponding learning that would facilitate people to react strongly and positively to the current effects on the environment is still developing. Incomplete, old, and false information disturb the successful advancement of green buildings. To further evolve their claim on the present state of green building within construction, it is suggested in [5] that, generally, building owners, architects, engineers, and manufacturers are interested in conserving the environment; however, they are not interested in using green materials to complete their projects. The adverse understanding is that green materials look awful, are cheap, and perform poorly. Through the analysis of the ideas outlined in [5], it can be posited that for green building materials to be implemented as common practice across the industry, there also needs to be more in-depth research and analysis of green buildings. This is because the current situation is causing some individuals with influence in the industry to have knowledge based on poor education.

Although the transition toward a future of total green building is progressing slowly, many individuals across the globe are doing their best to spread the word on both the benefits of the green build switch and the negative impacts occurring with common practice. Ref. [9] identified that the concept of green building is becoming a revolution, not only evolving in a few countries, but many across the world. They claim that the revolution has been influenced by an awakened perspective on how infrastructure uses resources, impacts the environment, and affects human beings. Ref. [10] supported this claim by suggesting that over recent decades, the enthusiasm for creating more sustainable buildings has grown quickly. With the input made by the researchers, it can be argued that although green building is still far from where it needs to be, it is gaining increased exposure and evolving across the globe. With more in-depth research on specific ideas centered around the topic, with a focus on the various materials used, there can be further development of the revolution. In one of Yates' previous books, he identifies some of the probable negative impacts involved with common practice. Ref. [11] claimed that many individuals with knowledge in the given area have predicted that China alone will be responsible for more than half of the new buildings being constructed within the next decade. Therefore, without an elevated focus on green building by both China and the rest of the world, the practical chance of tackling climate change will be severely diminished. Ref. [12] addressed the issue by claiming that the world needs to recognize the inefficiency of the construction sector and its need to be better managed. Refs. [13,14] further supported the claim by stating the faults attributed to the construction industry, which have been recognized by leaders around the globe. Finite resources are being used too quickly, buildings are being constructed as if they are disposable, and the value of money saved has been more than the value of future generations' lives. Through the researchers' ideas, it can be argued that the lack of knowledge of green building has contributed to the lack of care across the entirety of the industry.

2.2. Present Green Building Processes

As green building is slowly developing and being integrated into the construction industry, there is a need to identify which materials are currently being used in single-dwelling construction and analysis of the quality of information. Ref. [15] suggested stone fits as a green building material for a variety of reasons. The claim is that stone is a natural resource that has an exceptionally long lifecycle, with the addition that its use has been explored in a variety of ways within residential housing. Ref. [5] agreed; however, in contrast to [16], they outlined a negative association with the material. Spiegel identified that stone is a green building material that has durability, is load-bearing, and can provide thermal mass. It is also considered both reusable and recyclable; however, its negative aspect is that excess amounts are generally crushed and placed in landfill. Ref. [17] addressed stone well by examining not only the advantages associated with the material, but the disadvantages as well. The information is good, but there is a need for more in-depth research on the material with performance statistics and levels of waste produced, and, in addition, there needs to be research to examine its natural occurrence.

Ref. [18] identified eco-roofing, which is composed of plants, soil mix, filter fabric, water retention, drainage, root barriers, waterproofing, and insulation. They address the usefulness of eco-roofing by suggesting that it serves not only to be aesthetically pleasing, but also to support climate stabilization. Additionally, it is advantageous by protecting the waterproofing and removing the need for other non-environmentally friendly methods of roofing such as tiles. Ref. [19] expanded on the ability of eco-roofing by claiming that it has a positive impact on the environment as well as benefitting the interior structure of the building. Additionally, it provides protection from radiation, which is the most important factor when accessing passive cooling. Through the suggestions made by the researchers, it can be argued that the eco-roof method is a sound alternative to standard roofing as it has numerous benefits on not only the climate, but the structures to which the roofs are attached; however, there needs to be further research conducted into the disadvantages associated with the method, and it needs to be properly contrasted against alternative methods of roofing such as tiling, metal sheeting, and shingles.

The next material that arises in the literature is hemp concrete, otherwise known as 'hempcrete'. Ref. [20] identified that hemp is an extremely durable plant that requires unique processing to transform it into a usable building material. After its unique processing period, it is generally mixed with lime to create strong, yet lightweight insulating concrete. Refs. [20,21] further investigated this material in broad depth and found that hemp concrete is classified as a non-load-bearing material that it is generally used in conjunction with wood, steel, and concrete frameworks. Additionally, after testing, the authors in [22] were able to show that hemp concrete does indeed fit the characteristics of green building material; however, the quality of its environmental friendliness can be improved by reducing the impact caused by the binder. From the information provided by the researchers, we can argue that hemp concrete, or 'hempcrete', is a viable choice for a concrete alternative; however, with its non-load-bearing classification, research will have to be conducted to address the environmental impacts of having to be almost always used with a frame, i.e., steel, wood, or concrete.

Another material that continues to present itself in the literature is bamboo. Ref. [23] suggested the use of the material as a high-quality alternative to wood because of its strong properties, lightweight nature, and load-bearing characteristics. It is commonly used within single-dwelling construction and is available to use without processing and finishing. In addition, the use of bamboo in structural housing is simple, as the material is resilient to both wind and earthquake forces and is easily repaired. Ref. [24] expanded on the link between green building and bamboo by claiming that, due to its favorable mechanical properties, high flexibility, fast growing rate, low weight, and low costs, the material has extremely diverse opportunities in the future. The suggestions made by the research provide a sound argument for bamboo and its ability to be classified as a universal green building material. However, the literature lacks the identification of key statistics when matching bamboo against its counterparts. There is a need for further research to identify how bamboo compares to other commonly used materials in the same category, e.g., wood.

Ref. [25] proposed clay plastering as an alternative to standard plastering. It does not need decoration as it is generally finished in several soft colors, and the product itself is made from straw and cellulose, which are both renewable resources. Ref. [26] expanded on the use of clay plastering by suggesting that it is an effective alternative to standard plastering, as it can withstand severe temperature changes over various regions whilst keeping the structure dry. However, in contrast to [27], the researchers in [28] identified that clay plastering is subject to rather quick water erosion. Based on the information presented in the literature, it can be argued that clay plastering is a decent alternative to standard plastering; however, [29] does not address how much clay is used by this product. In addition, [15] identified a key problem associated with the material and its susceptibility to water erosion. There is a need for additional research that compares clay plaster against standard plaster and investigates whether the issue of water erosion can be fixed or mitigated.

Moreover, other methods of sustainable construction such as Strawbale are also being considered for green buildings. Ref. [30] identified that Strawbale construction enables the ability for unique environmentally friendly buildings, it has a variety of uses within the construction (walls, roofing), and can also be used in cohesion with other green building materials as a binder (mud brick, earth). Ref. [31] expanded on the effectiveness of the material by addressing its load-bearing characteristics and claimed that Strawbale has consistently been one of the best economical building materials. Additionally, the authors in [31] claimed that Strawbale construction in housing has grown in its popularity and respectability within an industry known to be disbelieving in the effectiveness of green building materials. Through the arising knowledge of the researchers, it can be argued that Strawbale is an effective alternative for standard wall construction with its ability to be renewable, cheap, and load bearing. However, there is a need for additional research investigating the negatives associated with the material and how it responds to various climates.

2.3. Comparison of Green Practices against Traditional Construction

After reviewing the research and identifying a variety of green building materials currently being used, it is necessary to review the information that compares those materials against conventional building materials. Ref. [32] addressed the comparison of stone vs. wood, steel, and concrete regarding house design by claiming that deterioration is to be expected in the form of replacement and repair for the standard building materials; however, in contrast, stone generally requires very little maintenance and rehabilitation. Additionally, stone has far superior water resistance in comparison to its counterparts. Ref. [33] expanded on stone with a study identifying the energy consumption of stone vs. concrete housing. The results they obtained demonstrated that a typical concrete house consumes multiple times more energy than a house made with stone. Furthermore, in [34], the authors were able to determine that the transport impact of stone vs. concrete was far less, with the environmental effects being 480% lower. From the research, it can be argued that stone is a better alternative to concrete, wood, and steel when considering durability, maintenance, energy usage, and environmental impact. However, there is a need to further investigate the negatives associated with the material, its use within various forms of housing design, and the economic costs.

The next material that presented itself within the literature was green roofing. It is necessary to review the information that compares green roofing and conventional roofing methods. Ref. [35] opened their suggestions with an economical comparison by identifying that the net present value (NPV) of green roofing throughout 40 years is significantly less than standard roofing (tiles, shingles, and metal sheets) with a figure of 20.3 to 25.2%. Additionally, the researchers identified that the annual benefit of using green roofing vs. standard roofing is between AUD 895 and AUD 3392. Ref. [36] expanded on the comparison of green roofing and conventional roofing by identifying that green roofing causes more embodied energy compared to standard roofing, although the energy consumption figures within green roofing homes are significantly lower. Moreover, it can be argued that green roofing has greater upfront costs compared to standard roofing, but over long periods, it is economically superior. Additionally, regarding energy usage and consumption, green roofs create more embodied energy, but can mitigate this negative effect through less overall energy consumption. This poses the need to further research different aspects of green roofing such as heat transfer, environmental impact, and water management to fully understand and determine whether it is more appropriate than standard methods of roofing.

The third material that arose within the literature and needs comparison is hemp concrete. Ref. [37] identified that, compared to standard construction materials used in walls, hemp concrete has a significantly lower impact on the environment and also aids in the reduction of climate change. Ref. [38] developed the comparison by claiming that hemp concrete has better thermal insulation and acoustical insulation, lower impacts on the environment, and minimizes the stages involved in timber frame construction. From the information provided by the researchers, it can be argued that hemp concrete is superior to other conventional wall materials in terms of environmental impact, pollution, and insulation. However, there is a need for further investigation into the costs and waste associated with the product.

Bamboo is the fourth material that commonly presented itself within the literature and needs comparison with conventional building materials. Ref. [39] address the topic by making the first comparison to other materials used in housing (wood, steel), claiming that bamboo has preferable levels of ventilation and shade when compared to other materials; therefore, it can be used in all areas across the globe. Refs. [40–42] expanded on the comparison of bamboo by identifying that not only does the material have environmental and technical advantages, but it is also favorable economically, as it is among one of the cheapest materials used in building. Through the research, it can be argued that bamboo is a cheaper alternative to a variety of construction materials and that it has less impact on the environment. However, the researchers lack specific information on bamboo comparison, which creates the need to further investigate how it compares to its counterparts regarding energy usage, climate change, and specific impacts on the environment.

The next material that was identified within the literature is clay, which is commonly distinguished as the green building alternative to standard wall plastering [41]. Throughout the literature, some comparisons enabled the understanding of the effectiveness of clay plaster as a green building material. Refs. [43,44] claimed that clay used as wall plaster had large levels of reactivity with the ozone and also the lowest 'ozone-initiated reaction product emissions' in comparison to its non-green building counterparts. Ref. [39] expanded on clay plaster comparisons by identifying the results from their testing display that showed that the environmental performance of clay is exceptionally superior to that of standard wall plasters because its production is based on straightforward processes that use small amounts of energy. By analyzing the information put forth by the researchers, it can be argued that clay plaster is a better alternative to standard wall plasters (in certain categories) as it can improve indoor air quality within homes and also uses far less energy in its processing. However, the information only covers air quality and environmental impact, and for the research, there needs to be an investigation into the costs and a more specific identification of statistics related to energy production.

The last material that was examined within the literature was Strawbale, along with the information provided on its comparisons to other non-green building load-bearing materials. Ref. [44] conducted a study into the effectiveness of Strawbale as a building material and was able to identify that it is a 'natural and breathable material that creates a solution for individuals who believe the use of paints, chemicals, and glues within standard building materials negatively impacts human health'. In addition, in [39], it was identified that Strawbale can save more than 5900 kg of CO_2 in comparison to standard brick masonry throughout the construction process. This is supported by [37], which expanded on the comparisons and advantages of Strawbale housing. The authors claim that Strawbale construction performs far more approvingly when compared to other wall designs, and, in addition, the material is superior to other standard materials in its waste reduction as it can either be recycled or used as mulch. From the points put forth by the researchers, it can be argued that Strawbale not only reduces the impacts on human health, but also has minimal environmental impact and waste reduction compared to its non-green building counterparts. Although the information provided by the researchers makes Strawbale look appealing as a green building material, there is a need to investigate the costs and specific statistics associated with waste reduction.

2.4. Overall Values of Green Buildings

After reviewing the literature that identifies types of green building materials and their comparisons to conventional building materials, it is essential to analyze the information that shows the benefits of using green building materials regarding cost, waste, energy, air pollution, environmental impact, and effects on human health. Ref. [37] started the review by claiming that there is a common misconception that green buildings cost 5% to 15% more to construct compared to standard buildings. They identified that this figure has not been supported by any recent research and that there is a need for it to be challenged. Ref. [45] supported such a claim and further expanded on it to suggest that cost advisors in the building industry severely overestimate the central costs of green building and critically underestimate the possible cost savings. This is supported by the researchers in [28], who claimed that green building benefits (in comparison to conventional methods) from lifecycle cost savings and that some aspects of green building design are more cost efficient. From the information put forth by the researchers, it can be argued that green building is commonly associated with higher costs throughout the life of a project; however, these may be misconceptions because of the lack of high-quality recent material. It poses the need to further investigate the costs associated with green buildings and how they differ from standard buildings.

The next beneficial area of green building that presents itself in the literature is environmental impact and climate change. Ref. [38] suggested that units of energy that are created by green building materials expel the energy generated by fossil fuels, which leads to less of an impact on the climate. In addition, the authors in [38] identified that green building design considers not only the potential effects buildings have on the environment, but also the effects on the health of human occupants. This is supported by the studies in [19,45], which asserted that green building design uses resources such as materials, energy, water, and land far more effectively than that of conventional building design. Furthermore, green building design has positive effects on human health through improved air quality and natural lighting. Through such claims, it can be argued that green building design and the use of green building materials perform better than conventional building design in the areas of energy usage/consumption, impact on human health, and resource usage. However, there is a need to further research the statistics associated with these categories to fully gauge how efficient green building is.

Another beneficial area that presents itself in the literature is green building energy consumption. In [30], the authors conveyed that within their testing, they found that energy usage within green buildings decreases by about 30% compared to standard buildings. This is supported by those in [38], who asserted that green buildings, in comparison to conventional buildings, save 30% to 55% in energy depending on the certification level. From the claims made by the researchers, it can be argued that green buildings generate a minimum of 30% in energy savings compared to standard buildings, and that figure can improve depending on the type of green building. The research is good, although there is a need to identify what type of green buildings and standard buildings were used to determine the statistics, and additional research is necessary to identify whether certain materials played a variable part in that 30%.

However, the ever-evolving nature of the green practices involved in the design requirements is making them increasingly difficult to comprehend and implement. This subsequently leads to a lack of awareness among building designers. To overcome this problem, this research will assess five geologically different buildings to better understand the feasibility of green building process adaptation.

3. Research Development and Process

The analytical approach of the research is a combination of qualitative and quantitative research in which case studies, logical argumentation, a detailed literature review, and statistics summarized in numerical form will be used. For the qualitative approach, the research will attempt to study a variety of situations in which green-constructed houses have been matched against standard-constructed houses and investigate the advantages and disadvantages of each. Additionally, the research will compare the material used within the chosen case studies and incorporate logical arguments and a detailed literature review to identify why green buildings are superior. For the quantitative approach, the research will also study a variety of situations in which green materials are matched against conventional building materials and then characterize the data in numerical form to develop a stronger argument in favor of the use of green building materials. To assist with this research, the following key areas were investigated in order to:

- Identify a variety of green building materials that can be used at various stages of the construction process.
- Investigate the key green building materials.

- Compare and contrast the identified green building materials with standard building materials.
- Address the advantages and disadvantages of using green building materials.
- Outline how the identified green materials combat resource starvation, climate change, and negative impacts on human health.

Methods and Data Sources

For this research, case studies, logical argumentation, and a detailed literature review have been chosen to investigate the topic of green building and answer the research question. For the case study method, the plan was to obtain data through the document analysis of multiple case studies and explain the benefits of using green building design in comparison to conventional building design. To ensure unbiased selection, the five case studies were selected randomly and covered different geological conditions. These case studies ranged from redevelopment, to minor renovations, to major redevelopment. Their selection was primarily based on various sustainability optimizations that could assist designers in green building design, that is, to determine the optimal solutions for green building design. The uniqueness in selecting the types of buildings in the five cases is based on different geological conditions, which subsequently leads to different environmental conditions that are subject to different green design requirements. This is based on each state of Australia and aligning their green design requirements to the NatHERS ratings.

For the logical argumentation, the research will attempt to identify the principles associated with green building materials and determine their relationship in minimizing resource starvation, environmental impact, and negative impact on human health. The advantage of this method is that the principles can be presented and the argument for answering the research question can be logically identified. The reason for choosing this method is that it largely involves logical thinking and makes for an extremely sound argument.

4. Findings and Analyses

The results and discussion sections feature five separate case studies that analyze and identify construction projects that have been prioritized using green building initiatives. These are Fitzroy North, Victoria; Curtin, Australian Capital Territory; Birkenhead, South Australia; and Caloundra, Queensland. The results section is an attempt to address the green building changes made within these projects and how they compare to standard building designs. The main focus was to individually identify these changes and then specifically outline how they benefitted the home. Additionally, the builder, designer, size, size of land, cost, and thermal comfort ratings are all established in the case study. The discussion section delves into each of the case studies and addresses the most important aspects of each. The main purpose of the discussion section is to make conclusions and summarize the entirety of the findings within the case studies.

4.1. Fitzroy North

The first case study that is featured is a two-story terrace located within the inner Melbourne suburb of North Fitzroy. The house is an east–west-facing structure that was subject to a major, yet challenging, renovation to improve its overall environmental friendliness. Table 1 shows the overall energy representations of this building.

Table 1. Fitzroy North building's overall energy representations.

Building size	125 m^2
Size of land	190 m^2
National Construction Code energy efficiency rating	3.2 stars—Rated out of 10 using the NatHERS

Table 1. *Cont.*

Thermal comfort rating	*Original house NatHERS 1.8 stars:* Heating 370 MJ/m^2/year Cooling 36 MJ/m^2/year Total 406 MJ/m^2/year *Complete house post renovation NatHERS 3.2 stars:* Heating 232 MJ/m^2/year Cooling 18 MJ/m^2/year Total 250 MJ/m^2/year
Green building features	2000 L steel rainwater tank Argon-filled double glazing Clerestory windows Concrete slab with cement replacement and recycled aggregates Double-glazed skylight with toughened low e-glass Energy-efficient appliances Evacuated tube solar hot water system Glass wool batts insulation Insulative paint additive Light-emitting wall-hung toilet suite and taps Natural rubber floor tiles and low volatile organic compound (VOC) adhesive Reclaimed kitchen benchtop and cabinetry Solar photovoltaic (PV) panels Zero-VOC paint

The Fitzroy North building's energy efficiency recommendations are as follows:

- Design response: Before the renovation, the home featured a corridor leading to a living area and a kitchen. The setup was unwanted by the owners, so to combat this, a bathroom was constructed in place of the kitchen area. In addition to this, the focus on green building alternatives allowed for a wide range of features to be installed. Some of these include double-glazed windows/doors, LED lighting, brand new insulation, and solar power. The remainder of the home was largely untouched to preserve the original heritage aspects of the structure.
- The green building improvements were carried out as per below:
    1. Energy-saving lighting: The old home comprised all standard globes; however, with the renovation, all lighting within the home was upgraded to feature light-emitting diodes. The watt range varied based on the room required to light, with the average being 12 watts. This enabled sufficient and efficient active lighting where necessary while maintaining below-average energy consumption.
    2. Insulation: The renovation upgraded the roofing and walls of the home with sufficient glass wool batts primarily made up of recycled materials. The roof insulation rating was 4, while the wall insulation rating was 3.5. The overall quality of the home improved as the ability to keep it warm during colder periods increased.
    3. Passive heating and cooling: The old home featured a brick wall on the side of the house and inefficient window locations to enable access to natural lighting. The renovation saw north-facing windows installed to allow a greater amount of natural light to enter the home. This installation brought about a higher quality of temperature control and allowed for passive heating. Additionally, the brick wall mentioned above is now showcased within the kitchen and dining space as it enables thermal mass and both passive heating and cooling. The original requirements for active heating and cooling have significantly diminished with the inclusion of multiple screened windows, plant locations, and blinds to regulate access to sunlight when necessary.

4. Solar hot water and solar photovoltaic (PV) system: The old home originally had an 835-watt grid-connected solar photovoltaic structure in place. The renovation saw this upgraded to a 1.185-kilowatt system. Additionally, with the renovation, two 175-watt solar panels were placed on the roof to assist with the overall passive energy availability of the home. Lastly, the previous hot water system was replaced with a new solar hot water system to enable further reductions in gas usage.
5. Sustainable materials usage: Rather than using completely new materials, the renovation made use of a large range of sustainable building materials. The benchtop and cupboards were predominately made up of excess materials from a different demolition, while the shelving was constructed through recycled timber. Additionally, the sink in the bathroom was repaired and remodeled, while the porch was made up of Green Element's excess stock. The most influential sustainable material usage was the creation of the slab. Its contents were made up of 60% recycled materials and 30% cement substitute. The use of the substitute saved over a tonne of CO_2.
6. Water saving: The old home had no equipment or processes in place to save water and reduce active water usage. The renovation included a brand new 2000 L water tank located outside to store rainwater. The plumbing is connected to the garden (for plants), toilet, and laundry. In addition to the rainwater tank, a 4-star water-efficient toilet and 3-star faucets were set up in the toilet and bathroom/kitchen, respectively. This variation has enabled the owners to save over 100 L of water per day compared to the previous formation.
7. Windows and glazing: The old home featured standard windows and doors throughout. These were removed and replaced with double-glazed glass. In addition to this, a double-glazed skylight was installed in the bathroom to allow for more natural lighting. Through the window/door variations, the renovated home has significantly less usage of active lighting.

Pre-renovation, the home was of standard building design, not incorporating any form of green building initiatives. The owners sought a renewed experience and outlined a variety of changes they wished for mainly focusing on energy efficiency and environmental friendliness. A major upgrade was the floor tiling, which was made of rubber. Its ability to regulate temperature and its environmental sustainability proved to be considerably better than that of standard floor tiling. The appliances within the home were all upgraded along with the renovation to fit the environmentally friendly standard. The inclusions were a brand new energy-efficient television and a refrigerator featuring 6-star and 4-star ratings, respectively. Additionally, an induction stovetop was installed, which is widely recognized as faster, safer, and more efficient in comparison to standard stovetops.

4.2. Curtin

The second case study that is featured is a two-story dwelling located within the inner suburbs of Canberra. Situated in Curtin, the house has been subject to renovation that completely remodeled its previously barren state and was transformed into a home that is sustainable, energy efficient, and environmentally friendly. Table 2 displays the overall energy representations of the Curtin building.

Table 2. Curtin building's overall energy representations.

Building size	228 m^2
Size of land	825 m^2
National Construction Code energy efficiency rating	$7\frac{1}{2}$ stars—Rated out of 10 using the NatHERS

Table 2. *Cont.*

Thermal comfort rating	*NatHERS rating* $7\frac{1}{2}$ *stars* Heating 65.6 $MJ/m^2/year$ Cooling 17.3 $MJ/m^2/year$ Total 82.9 $MJ/m^2/year$
Green building features	Bamboo flooring Double-glazed windows and doors Effectively sealed building with minimal gaps Evacuated tube solar hot water system Hydronic heating Light-emitting diode (LED) lighting Low-VOC paint and finishes North-facing design Rainwater tank Reconstituted timber cladding

The Curtin building's energy efficiency recommendations are as follows:

- Design response: Before the renovation, the house featured a central staircase that was extremely inefficient when managing heat flow. Rather than maintaining heat within the home, the staircase enabled heat to travel upwards, leaving the bottom floor cold and completely deprived of warmth. The response and improvement of green buildings within the home saw the old staircase removed and a new one built on the east side of the home. This allowed for better management of the heat flow and enabled the residents to capture the warmth rather than release it. The kitchen moved from the southeast area of the home into a more central position that faces north. Its key feature is two double-glazed doors that allow for more natural lighting and heat to enter the home. The lounge was transferred to the southeast in place of the previously located kitchen. It faces south, with direct access to the backyard and features double-glazed sliding doors for natural lighting and heat. The upstairs area was maintained in its original form; however, the roof was reconstructed to become an eco-roof. This prompted significantly lower energy consumption of the home and enabled large monetary savings in comparison to a standard home. The entire renovation focused on the key objective of ensuring that the house was reconstructed to become a compact, sealed building without needless ceiling insertions and holes throughout the home to better manage the flow of heat. The objective enabled the most efficient passive heating and cooling possible by using green building initiatives.
- The green building improvements were carried out as per below:
    1. Active heating and cooling: The old home featured an extremely inefficient heater on the bottom floor and a reverse split system on the second floor. Due to the nature of Canberra's winter temperature, a new and improved active heating system was necessary. The renovation saw the installation of a highly effective hydronic heating setup that acts through a gas boiler and radiator. For active cooling, the builder implemented ceiling fans that increase the flow of cool air around the home.
    2. Building materials and insulation: The old home was of brick veneer, although not entirely energy inefficient, and there were selected areas that required change. The renovation saw the removal of bricks at various sections of the structure, which were replaced with restored timber weatherboards in the form of cladding. This replacement enabled the home to use a material that has a lower impact on the environment while reducing embodied energy. In addition to this, the renovation featured a change to the existing wall insulation that included R3 recycled polystyrene, R2 polyester batts, and R5 wool cells. The change restricts the flow of heat during winter to maintain warmth within the home, whereas the old design lacked the insulation required to do so.

3. Energy-saving lighting: The lighting within the home was upgraded to efficient light-emitting diodes. This allows for active lighting throughout the home where required, while committing to just 8 watts.
4. Passive heating and cooling: The old home lacked the basic design that enabled high-quality passive heating and cooling. The renovation saw the inclusion of exceptional window design and placement to increase the ability of natural light to enter the home. This caused a reduction in the usage of artificial lighting and increased the performance of passive heating. Additionally, all windows and doors were set up with double glazing to prompt heat flow from natural light.
5. Solar hot water and solar PV system: The old home featured an old electric hot water system that consumed unnecessary energy. The renovation saw the inclusion of a brand new solar hot water system, which increased the overall efficiency of water use and reduced the usage of the booster. In addition to this, the builder was unable to include solar panels in the build due to the design of the old home; however, to combat this, the overall efficiency of the home was developed to minimize costs.
6. Sustainable materials usage: The excess materials from the pre-renovated home were given away to individuals who needed them; otherwise, the rest were used to renovate the new home.
7. Water saving: The old home lacked any form of water-saving features. Therefore, considering Canberra's uncharitable rainfall, the renovation saw the inclusion of two 5000 L rainwater tanks, which were both directly connected to the toilet and laundry room. This reduced the amount of active water usage and enabled the recycling of water to the present.

The owners were looking to improve the home through better temperature control in winter and increasing the availability of natural lighting. The need for a sustainable home meant that passively heating the dwelling would be a necessary fundamental achievement. This meant outlining objectives to ensure that the building would be clear and linked to the surrounding environment. Pre-renovation, the home boasted a 5-star NatHERS rating; however, through the renovation, this figure was able to be improved to 7.5 stars. The electricity usage was far higher than the average Australian home, yet with the renovation, the household electricity usage was cut in half. As outlined above, the house went through a variety of green building changes that ultimately increased its efficiency and effectiveness as a green building structure.

4.3. Birkenhead

The third case study that is featured is a single-story two-bedroom home located in Adelaide, South Australia. Before the renovation, it was a below-par insulated stone structure where the temperature within the home was extremely hard to regulate. The renovation planned to completely remodel the previous structure and create a newly formed energy-efficient home. Table 3 illustrates the overall energy representations of the Birkenhead building.

Table 3. Birkenhead building's overall energy representations.

Building size	125 m^2
Size of land	330 m^2
National Construction Code energy efficiency rating	7.9 stars—Rated out of 10 using the NatHERS

Table 3. *Cont.*

Thermal comfort rating	*Original house NatHERS 1.5 stars:* Heating 410 MJ/m^2/year Cooling 52 MJ/m^2/year Total 462 MJ/m^2/year *Complete house post renovation NatHERS 7.9 stars:* Heating 21.4 MJ/m^2/year Cooling 23.4 MJ/m^2/year Total 44.8 MJ/m^2/year
Green building features	Ceiling fans with no other mechanical heating or cooling Double-glazed windows Drought-tolerant garden Heat pump hot water system Insulation, R2.2 insulation in all walls, and R6 bulk insulation in the ceiling LED lighting Monitoring systems to track internal temperature, humidity, energy consumption, and solar PV production Passive design Rainwater trans with a total capacity of 7000 L Reverse brick veneer Sealed building fabric Solar PV panels Structural insulated panels (SIPs) Thermal mass Zero-VOC paint and floor treatments

The Birkenhead building's energy efficiency recommendations are as follows:

- Design response: The home was initially drafted to house two individuals; therefore, the amount of space available to renovate was restricted. Additionally, the renovation had its share of tests that needed to be overcome. The main issue that arose was the council putting forth a requirement of two off-street car spaces (one being sheltered). With already limited space to work with, it was a strain for the designer to include the spaces. However, overall, the response was effective. The owners sought to achieve the objective of making energy-efficient and environmentally friendly structures with limited spending and space. The builder and designer made good use of the area and boosted both solar and winter warmth potential, while various windows were inserted to enable maximum natural lighting. Overall, the response was well organized and displayed the effectiveness of green building initiatives.
- The green building improvements were carried out as per below:
    1. Energy-saving lighting: The lighting within the home was upgraded throughout with LEDs. The owners decided to remove all downlights from the structure as they did not want any issues with the ceiling insulation. Additionally, the design of the home enabled more than satisfactory natural lighting; therefore, the need for active lighting and energy use was modest.
    2. Sealed building fabric: The renovation patched up the majority of the penetrations and unnecessary voids within the home. Thermal imaging analysis conducted on air pressure testing concluded that the structure brought about 3.6 air changes p/hour at 50 pascals (PA). The standard Australian home brings about 19 air changes p/hour; this means the home is well above the average at 15 ACH less. This is beneficial, as well-sealed homes reduce carbon emissions and energy bills by up to 25% and ensure homes maintain the heat in colder seasons.
    3. Solar hot water and solar PV system: The old home lacked any form of solar power and/or heating. One of the owner's objectives was to ensure sufficient energy availability through natural methods; therefore, to solve this, a 3.5-kilowatt solar PV was installed on the roof. This allows for more energy to be available than necessary

and has completely removed the need for active energy use. Additionally, a solar hot water system was introduced to steer away from the older gas water heater.

4. Thermal mass: The old home could not maintain and regulate temperature when required. The renovation increased the internal thermal mass of the home by constructing two recycled brick walls in two separate areas of the home. The method of reverse brick veneer was used, which shows the bare brick wall on the inside of the home. This drastically improved the ability of the home to manage heat and cold while looking modern and unique.
5. Wall construction: The renovation required the addition of new walls and the owners insisted on using green building materials for its construction. The solution was to use SIPs, otherwise known as structural insulated panels. These are high-performing panels that are made of foam in between exterior sheathing. The overall result is a durable, cost-efficient, and environmentally friendly building material that can increase the effectiveness of passive heating and cooling.
6. Water saving: The old home neglected water saving and unnecessarily used water regularly. To combat this, the builder installed two rainwater tanks of 5000 and 2000 L, totaling 7000 L. These tanks were connected to all water sources within the home. The overall effect caused significant reductions in water usage and cut the owner's water bills by over 60%.
7. Window glazing: The old home featured standard windows and doors throughout. The renovation saw that all windows and glass-fitted doors were replaced with double-glazed aluminum. Additionally, two new north-side windows were created to allow for easier access to natural lighting while ensuring enough shading to prevent unwanted sun in summer. The upgrades of the windows and glass doors enabled the home to receive sufficient amounts of natural lighting whilst reducing the need for active lighting.

The owners were looking to renovate the home using green building initiatives. The main goals were to revitalize the structure through passive heating and cooling, material choices, and design. In addition to this, they commented on the claim that eco-housing costs far more than conventional builds and wanted to prove the stereotype wrong. The home before the renovation was a standard design that had zero focus on green building initiatives. The renovation saw the inclusion of several green building upgrades. The focus on enabling efficient passive heating and cooling worked well, as the new home requires a very small amount of active heating and cooling. The structural insulated panels were the big takeaway from the project, as the material heavily contributed to the home's environmental friendliness.

4.4. Caloundra

The fourth case study that is featured is the development of a new display home that showcases the potential of using green building design. Its design and model were solely constructed to identify the benefits of using an environmentally sustainable build. When compared to a home of conventional design, it performs well above standard. Table 4 shows the overall energy representations of the Caloundra building.

Table 4. Caloundra building's overall energy representations.

Building size	150 m^2
Size of land	320 m^2
National Construction Code energy efficiency rating	10 stars—Rated out of 10 using the NatHERS
Thermal comfort rating	*NatHERS rating 10 stars* Heating 4.2 $MJ/m^2/year$ Cooling 5.1 $MJ/m^2/year$ Total 9.4 $MJ/m^2/year$

Table 4. *Cont.*

Green building features	Concrete slab Energy-saving windows Energy-efficient appliances Insulation Lightweight construction Rainwater tank Reverse brick veneer Solar PV panels

The Caloundra building's energy efficiency improvements are as follows:

- Design response: The design was shaped to suit the needs of a small family. It includes three bedrooms, two bathrooms, and a garage. Considering the focus of the build was to demonstrate the benefits of green building, the home is a lightweight construction that is well insulated and saves energy through appliances, windows, and solar power. Additionally, the water sources in the home all have well-above-average water efficiency labeling and standard ratings. Many of the walls in the home were designed as reverse brick veneer. It is featured in the home to increase the ability to manage temperature and boost thermal mass. The main reason behind the decision to use reverse brick veneer was so that the bricks can store heat during the colder periods of the year. The materials used throughout the home were predominately made of recycled material. Those that were not recycled were all materials that can recycle themselves. The house itself can be deconstructed and all of the materials can be reused.
- The green building inclusions were set out as below:
    1. Concrete slab: The creation of the concrete slab was extremely precise in its vertical and horizontal measurements. It also required its mass to be perfect to achieve its NatHERS 10-star rating. The slab rests on waffle ponds, which creates air pockets. This allows for insulation to be present and regulates the temperature within the home.
    2. Energy-efficient appliances: The home was fitted with highly energy-efficient appliances that consume less energy than standard appliances. Additionally, ceiling fans circulate air through the home and into the vents to produce cool wind flow and reduce the need for air conditioning.
    3. Energy-saving windows: The windows and doors within the home were all fitted as low-E glass, which is essentially glass that has been coated with a substance to reflect energy. Its purpose is to maintain energy within its original location. Additionally, the windows were placed in a calculated manner to ensure the best natural lighting is available.
    4. Insulation: There was a heavy focus on ensuring that the home was well insulated. This is one of the major factors in the achievement of the 10-star NatHERS rating. The outer walls featured R1 wrap and R2 batts, while the roof featured R3 batts and a tier of R1.5 glass wool. Insulation plays an important part in enabling the home to maintain its desired temperature without active heating or cooling.
    5. Lightweight construction: The construction of the home was composite, meaning that an array of different materials was used to complete the project. In cohesion with the reverse brick veneer, a variety of lightweight materials were used such as timber obtained through environmentally friendly methods. The decision to use lightweight materials reduces the overall embodied energy of the home.
    6. Reverse brick veneer: Reverse brick veneer builds have been common among much newer sustainable construction builds. Its ability to provide thermal mass in a structure is invaluable and enables the home to reject unwanted heat from the exterior while maintaining any heat from the interior.

7. Solar photovoltaic system: The installation of a 1.5-kilowatt solar photovoltaic system has enabled the home to generate more energy through natural sources than the required amount for a small family occupation. This lowers the cost of actively using electricity in a home and is a far better alternative to standard electricity systems.
8. Water saving: The home had a 5000 L rainwater tank installed to collect and use water where necessary. This enables reductions in active water usage as it is connected to the toilets, laundry, and gardens.

The purpose of the home was to demonstrate the effectiveness of building with green initiatives. The owners, along with the builder, set out three major objectives to be achieved to ensure the home would be a suitable example for all sustainable homes. These were a 10-star NatHERS rating, net zero energy usage through more production than consumption, and successfully exhibiting the effectiveness of building using environmentally friendly methods. The home is considered a benchmark in green building. The 10-star NatHERS rating is no easy feat and was made possible through the three objectives (specified during the planning of the build) being successful. The most interesting aspects of the build were the reverse brick veneer construction and the insulation choices. Both of these initiatives enabled the home to increase its ability to retain heat during the winter and cool the home during the summer. The home is the perfect example when identifying green builds that can be cost efficient.

4.5. Darwin River

The final case study that is featured is the development of a two-story home built to withstand the hot climate of the Northern Territory. The home displays a variety of remarkable green building initiatives that have been incorporated to achieve comfort, low maintenance, and energy efficiency. Table 5 shows the overall energy representations of the Darwin building.

Table 5. Darwin building's overall energy representations.

Building size	177 m^2
Size of land	80 hectares
National Construction Code energy efficiency rating	$6\frac{1}{2}$ stars—Rated out of 10 using the NatHERS
Thermal comfort rating	*NatHERS rating $6\frac{1}{2}$ stars* Heating 0.6 MJ/m^2/year Cooling 211.8 MJ/m^2/year Total 211.9 MJ/m^2/year
Green building features	Solar hot water system Solar photovoltaic system Wastewater management Renewable energy production Greenhouse gas reduction

The Darwin building's energy efficiency improvements are as follows:

- Design response: The home was designed to cater to the needs of the couple that owned the home. This means that processes were put in place to combat the hot temperatures of the location along with the risks that were present. Additionally, the couple wanted green building initiatives to be used throughout the construction of the home. The designer and builder worked together to meet the needs of the owners and ultimately included passive design, recycled materials, passive cooling, water saving, natural lighting, and greenhouse gas reductions.
- The green building inclusions were set out as below:

1. Embodied energy reduction: The area is highly susceptible to fires and termite attacks; therefore, the construction of the home used no timber. The alternative chosen was steel and cement sheeting, which are both long-lasting materials that will inevitably lower the embodied energy.
2. Greenhouse gas reduction: Since the home uses all renewable energy, the home's average greenhouse gas emissions are far lower than that of the standard Australian home. The solar power features of the home completely reduce the need for active energy usage.
3. Reducing mains water usage: When constructing the home, the owners chose not to connect the water main. Instead, rainwater is used for all of the necessary water through three rainwater tanks and the roof. The entire storage possible for rainwater is 100,000 L and it is processed through filtering when required to drink. Not connecting the main is an effective method to completely cut out active water. However, when there is a lack of rain, it could pose issues of water insufficiency.
4. Renewable energy production: The entire home (except the gas stove and oven) uses renewable energy sources. In this case, the renewable energy is solar power. Solar power is an important feature, as the climate is more often warm with the sun shining than cold, and, therefore, the home receives enormous amounts of power.

The owners of the land wanted to build an environmentally friendly home that was resistant to the hot Northern Territory climate. This required several different ideas and methods to create a completed product. The main goals were to ensure green building initiatives were used, fire and termite risks were mitigated, and the passive cooling was of the highest quality. The home is a perfect example of a structure that features green building initiatives in a warm climate. Its more interesting features are the complete disregard for mains water use along with being entirely solar powered. Both features are essential aspects of green buildings and are perfectly highlighted within the case study. Any home that can function solely on renewable energy performs well and is cost effective.

4.6. Overall Result Deliberation

This paper examined five case studies that included two types of homes. The first were homes that were built with a standard building design and then renovated with green building initiatives. The second were homes that were built brand new and planned to demonstrate the effectiveness of green building design. In the Fitzroy North building, its improvements ranged from passive heating and cooling to solar photovoltaic systems and insulation; in the Curtin building, the structure was a renovated two-story home that focused on improving temperature control during colder periods and increasing the availability of natural lighting. For the Birkenhead building, the overall aim was to make the structure energy efficient with limited area and spending. The Caloundra building, on the other hand, featured the development of a new display home that focused on displaying the potential of construction with green building initiatives. Finally, the Darwin River building presented a two-story home development that focused on passive cooling and water saving. All of these structures included various green building inclusions ranging from solar hot water systems to energy-efficient appliances. Their inclusion aimed to reduce embodied energy and greenhouse gases through the use of renewable sources of energy. Such improvements not only added value to each building, but also show how such design considerations can be incorporated into future construction builds.

5. Conclusions

This paper focused on green building initiatives present within the construction industry. Its purpose was to improve the overall understanding of green building construction methods and sustainable building materials. This was undertaken whilst addressing alternatives to standard construction methods through contrast and comparison. A comprehensive literature review was conducted on green building to identify the present knowledge on the topic along with various contributions made to the subject. The themes presented in the review attempted to outline the context of green building and lay out the current knowledge of the topic.

Further, five case studies were identified and analyzed to showcase the effectiveness of green buildings. Their selection was primarily based on the various sustainability optimizations that could assist designers in green building design— that is, to determine the optimal solutions for green building design. The structures selected were based on different geological conditions that subsequently involve different environmental conditions, and, thus, are subject to different green design requirements. This is based on each state of Australia and aligning their green design requirements to the NatHERS ratings. Each study demonstrates how different areas and climates can adapt and produce structures that focus on green building initiatives. The main conclusions of this study are as follows:

(a) Green building initiatives are not difficult to apply. When building with green initiatives, several small changes can be made to the home that enormously change its environmental friendliness and energy exertion. An example of this is installing rainwater tanks to limit the amount of active water use.
(b) Green building initiatives can be cost efficient. As witnessed through the case studies, most of the cost effectiveness does not occur with the method or material itself, but in the saving that is applied when the method or material is used.
(c) Natural lighting plays a large role in the amount of active lighting used within a home. Effective natural lighting within a home due to the orientation and types of windows greatly reduces the need for active lighting. The result of superior natural lighting is reduced energy usage.
(d) The orientation, design, and sealing of penetrations greatly improve passive heating and cooling. Self-explanatorily, this area of the green building enables the home to passively heat and cool itself, which, in turn, reduces the amount of necessary active heating and cooling, ultimately seeing reductions in energy and greenhouse gas emissions.
(e) The use of rainwater tanks reduces the amount of mains water used when connected to key areas of the home (toilet, laundry, garden). The inclusion of a rainwater tank reduces active water usage and enables cost savings.

There is potential for further research into green building. The green building design process is often neglected throughout the industry due to the lack of information available. For example, solar power requires more in-depth research to determine its long-term cost benefit. Although the use of solar power is initially promising, its long-term effects such as waste need further consideration. Nonetheless, overall, testing the effectiveness of various green building initiatives and their overall cost in comparison to standard methods is necessary as the basis of a long-term and ongoing feasibility process.

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