A Comparative Study of Green and Living Buildings

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Abstract

Aim and Objective - Buildings are one of the critical components of the built environment in which every aspect of the building's design and construction will impact the wellbeing of its occupants - how it is built, from which material, the outputs of its usage, and the impact on its surrounding ecosystem. The fast pace of urbanization growth across the globe is resulting into environmental issues such as air pollution, heat, water pollution, noise pollution, waste disposal, social and economic problems. To combat such challenges, the concepts of green and living buildings emerged. This paper covers a comparative analysis of green versus living buildings (in pre-construction, construction, and the post-construction stages).

Design/methodology/approach – The paper provides a summary of the systematic review and critical assessment of literature content using secondary data of studies' findings and systematic database searching techniques. This systematic review only includes peer-reviewed, published journal articles. The report summarizes the results of a comprehensive examination and critical assessment of the relevant literature.

Findings – In this paper results indicated that the green and living buildings concepts are indeed similar in certain aspects but also different in all three stages (1) pre-construction (2) construction) (3) post construction. The study also demonstrates that the built environment is heading towards more living buildings than green buildings for a sustainable environment.

Recommendations for Future Research – There is a potential of further research in the living building in particular, with in-depth analysis and assessments for key strategies such as the pre-construction ecology of the place, construction approach strategy, and post-construction facility management, rather than holistic comparisons. Moreover, more studies devoted to material selection and end-of-life challenges, finding eco-friendly construction materials in developing markets, and how can policy makers provide legislative frameworks for the development of green and living buildings in the urban planning process would be a useful addition to the body of knowledge.

Paper type – Research paper

Keywords

Living Buildings, Green Building, Systematic Review, Comparative Study, Sustainable Construction

1. Introduction

Green buildings are becoming increasingly popular and more evident in developed countries. The term 'green' building refers to the use of environmentally friendly techniques and technology in the design and construction of the built environment (Shams & Rahman, 2017). They deal with ecological issues within or outside the building premises to protect the environment (de Ridder & Vrijhoef, 2008). It is crucial for the human race and the planet's living creatures especially that with the pace of urbanization that generate large quantities of waste (Seider, 2017) and scarcity of resources on earth, green architecture and building is a necessity (Robertson, Franzel, & Marie, 2017). Green Living by ensuring any human actions or activities result in positive impact on planet Earth for future generations to live in without the harmful environmental pollutants and emissions is a responsibility of all inhabitants (Rao, Schreiber, & Lee, 2017). While the Living buildings concept is a newly adopted approach to the design, build and management of buildings, aiming to shift the conventional demand driven supply to an inclusive supply driven demand. This is mainly through developing and delivery a building that is resilient to the ever-changing technology, legislations, regulations and stakeholder demands (Ragheba, El-Shimy, & Ragheb, 2016). However, this paper investigates the legitimacy of the hypothesis living buildings being different from green buildings by providing a comparison to each stage of the building life cycle (1) pre-construction (2) construction (3) post-construction.

Definition of a Green Building

The goal of a Green building is to take responsibility for achieving energy and resource efficiency, realizing long-term economic, environmental, and social health. The terms green building and sustainable construction are sometimes used interchangeably. However, the term sustainable construction is applied from the period of pre-construction to the disposal of the building and focuses on the ecological, social, and economic issues involved with a building. Hence, green building is an integral part of the sustainable construction (Shams & Rahman, 2017). The Green building concept is part of green urban infrastructure classified as an approach towards land use that is strategically planned and designed network of natural and semi-natural areas joined with other environmental features that allows for an ideal ecosystem within an urban area that resolves the current challenges encountered (Vrijhoef & de Ridder , 2007). In UAE, "Green building is the practice of creating a built environment that is resource efficient in terms of energy, water, and materials whilst reducing building-related impacts on human health and the environment throughout the building's lifecycle, through better siting, design, construction, operation, maintenance, change of use and deconstruction" (Prosser, Spisak, & Jose, 2021). Their definition is further aligned with the definition of the Environmental Protection Agency (EPA) which defines Green buildings as "the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction". This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. Green building is also known as a sustainable or 'high performance' building (Phillips & Barker, 2021). Additionally, Green Building as any class of building use that relate to the conscientious handling of its surrounding natural resources and causes little interference to its surrounding environment and use environment-friendly material (Lydon, et al., 2017).

Definition of a Living Building

According to (Lootah, 2011), a building is considered 'Living' when it accomplishes certain requirements such as generating its own energy on-site through renewable sources, seizes and treats its own water, be built from non-toxic and environmental-friendly construction materials, uses brownfields yet remains inspirational to live in by interacting and adapting to external stimuli. The living building is a philosophy that bridges the gap between natural and artificial environments by adopting living building strategies integrated in the building's design, construction, renovation and deconstruction (Refer to tables 3-5 below). The urgency to also increase the performance of buildings has demanded for the adoption of the 'Living Building' concept that stresses on the need for good design, fit for purpose, up-to-date technologically, and altering the way we build increasing the benefits of those buildings to both the developers, end-clients and societies by offering both integrated and sustainable products and life cycle service (Hwang, Zhu, Wang, & Cheong, 2017).

2. Methods

The paper provides a summary of the systematic review and critical assessment of literature content using secondary data of studies' findings and systematic database searching techniques. This systematic review only includes peer-reviewed, published journal articles. The report summarizes the results of a comprehensive examination and critical assessment of the relevant literature.

3. Results

3. 1 Benefits of Green Buildings versus Living Buildings

Green buildings have environmental, economic, and social benefits to key stakeholders. They can bring about energy and water savings, which lower operating costs. Moreover, provide the comfortable environment that can improve social benefits, including the increase in occupants' satisfaction due to the positive impact on their health and productivity (Howe, 2010). Additionally, green buildings lead to enhanced wellbeing, physical, psychological and social health, improved livability due to enhanced amenities with easier maintenance, efficient technologies, improved indoor air quality and reduced noise pollution, less urban heat impact due to more shading and protection techniques from extreme weather. Moreover, enhanced storm water management, water quality and efficiency, groundwater recharge, soil infiltration, enhanced property value and return-on-investment, energy efficiency and savings, healthcare savings and overall ecosystem services. Furthermore, organic and local food production, healthy urban ecology-conserving and efficient use of resources, water and assets (Vrijhoef & de Ridder , 2007), (Hegazy, Seddik, & Ibrahim, 2017). Living buildings (1) improve and protect biodiversity and ecosystems (2) improve air and water quality (3) minimize waste streams (4) preserve and restore natural resources (5) minimizes operating expenditure (6) create markets for green services and products especially real estate assets (7) improve the productivity levels of living building occupants (8) enhance the buildings performance throughout its life cycle (9) elevate the comfort and health levels of occupants (10) increase the esthetical qualities (11) reduce the stress on the existing local infrastructure (12) improve the overall quality of life of humans (Lootah, 2011).

The main components for achieving green building as per (Elshimy, Radwan, Kashyout, & Ashour, 2015), (Duijzera, van Jaarsveld, & Dekker, 2018), (Vrijhoef & de Ridder , 2007) are the following:

Site Selection: the green building must be developed on suitable, thoughtful and efficient sites. It must be located away from wetlands and prefer on brown field sites where usually have infrastructure in place. Choosing a site for people who can use public transportation and bicycles to work, preserve open space, manage stormwater, lessen urban heat island effect, decrease light pollution of the night sky. and minimize parking lots to enhance car-sharing which also lead to decrease emission and reduce the use of gasoline Choosing a proper site will help in reducing environmental impact and enhance the energy performance of new buildings (Dakkak, 2021).

Energy Efficiency: the energy efficiency is an important component in most green building projects. Reducing the energy usage in the green buildings around 20% below the usage of the normal building. A proper selection of energy elements, implement envelope air sealing, duct sealing, appropriate placement of air and vapor blocks, decrease the use of harmful chemicals in building refrigeration and air-conditioning systems will enhance the energy efficiency building and maximizing the use of renewable and green energy (such as solar energy and wind turbines) and minimizing the use of fossil fuels (Bronstein, 2019).

Water Efficiency and Conservation: Green building emphasis on conserving water both indoor and outdoor through controlling and reducing the usage of potable water for landscape irrigation and for building, treating the wastewater on site, and use water-conserving fittings inside the building, to lessen water demand. Moreover, current researches have shown the natural processes can be a very effective methods of filtering and separating contaminants from storm water and waste water which can be reused for irrigation and other purposes (Bauer, Mosle, & Schwarz, 2007).

Materials and Resources: A successful green building selects a proper material/product/system during the design phase-the time. Green building materials cover a massive area of themes and materials, and they are well known as ecofriendly and renewable resources. Some of the effective practices followed are assigning permanent locations for recycling bins in the building, using recycled materials such as recycled concrete, dry wall, fly ash from coal- fired plants and newspapers, use renewable, sustainable materials such as bamboo, cork, linoleum, wheat board or straw board cabinetry. Moreover, repairing and reusing of a building instead of demolishing it or constructing new building which has positive impact in environment. Restoration and recycling the existing building components, also helps minimizes any possible negative impact on the environment and protects natural resources, including the raw materials, energy, and water resources which is essential for new construction. It also helps decrease pollution that might happen due to the by-products from manufacturing extraction, and transportation of raw materials, besides minimizing the formation of solid waste that often ends up in landfills (Bahaudin, et al.), (Akshey , Swati, & Disha, 2018).

Indoor Environmental Quality, Safety, Innovation and Integrated Design: The health and productivity of employees and occupants of any building are significantly influenced by the Indoor Environment Quality (IEQ), and recent studies showed the correlation between improved IEQ and occupants' health and well-being. The impact of poor air quality and lighting levels, the growth of molds and bacteria, off-gassing of chemicals from building materials on occupants is significant. One of the main characteristics of green design is to support the well-being of building occupants by reducing indoor air pollution. This can be achieved by selecting materials with low off-gassing potential, proper ventilation strategies, providing suitable access to daylight and views, and providing for best individual comfort controlling through maintaining thermal comfort standards; and offer daylighting and views to the outdoors (Salem, Bakr, & El Sayad, 2018). Innovation is one of the main elements to create a green building design. This includes a variety of ideas, from environmentally friendly technological developments to socially acceptable innovative routes towards green approach. It would be an element to inspire people and professionals to apply green approach during construction phase and it can provide competitiveness in the construction sector. Rapid changes in the economy and high demands for new green construction investments are essential, but the initial high costs slow the progress. A method to measure the annual innovative variation in construction sector is a complex indicator that ranks countries/economies/projects depends on their environment to innovation and the outputs from implementing innovation. This indicator is called global innovation index (Hamad, 2020).

3.2 Criteria of the living building

The Living Building Challenge is a strategy for defending the ecosystems of natural resources that sustain human health. Instead of concentrating on densely connected neighborhoods, it sets a ban on what seems to be endless outward growth. In this situation, living buildings have a special requirement to restore surfaces and natural functions to harmonious built-environment interfaces (Hamad, 2020). It is a philosophy, certification, and advocacy tool for projects to change into regenerative type (WBDG, 2021). The criteria of the living building are as follows:

Limits to growth: buildings are only permitted to be constructed in this situation on ready-made, gray, or abandoned land (Beardsley, 2019) that does not belong to (1) Wetlands: The spots chosen should be at least 15 meters and up to 70 meters apart (2) Primary dunes: At least 40 meters must separate the chosen places. (3) Old growth forest: At least 60 meters must separate the chosen places. (4) Native Prairie: At least 30 meters must separate the chosen places. (5) Prime farmland (6) Within the100-year floodplain (Hamad, 2020).

Urban agriculture, Habitat Exchange and Human-powered living: Floor area ratios should be utilized as a starting point for calculations to calculate the square meters committed to agriculture, and buildings should incorporate agricultural potential appropriate with their size and density. As part of the habitat exchange in this situation, areas of the same size distant from construction sites should be permanently set aside (Hamad, 2020). There is a 0.4 hectare/1.0-acre minimum offset per project. Communities should be made more walkable. For this effort to succeed, the community's ability to support a car-free lifestyle must be improved (Dittrich, 2001). The proposal should demonstrate at least propose a mobility plan that spans both the inside and outside of the building by following (1) considerations for pedestrian walkways, such as weather protection in front of the road; protected parking for human-powered cars; facilities for promoting bicycles (2) choosing steps in buildings over elevators and advocating for good stairs (3) encourage the adoption of transportation powered by people (4) at least one electric vehicle charging station. Communities should encourage residents to use bicycles, public transportation, alternative fuel vehicles, and car sharing to minimize traffic (Beardsley, 2019).

Water: in many nations around the world, the lack of and poor quality of drinkable water has recently become a severe problem. The living building made the case that every structure, piece of infrastructure, and community should be planned according to the carrying capacity of the land: gathering enough water to satisfy the demands of a certain population while honoring the natural hydrology of the land. The cycle of using, cleaning, and reusing water can go on forever. Creative reuse and water saving are essential. Net positive water: Building water should be used and released in accordance with the water flows on the construction site and in the area around it. It should be underlined that all water needed must be obtained naturally, either through the collection of rainfall or other closed-cycle water sources, or through the recycling of water used in the structure (Hamad, 2020). Without the use of chemicals, water should be sufficiently purified. Additionally, all stormwater runoff, including gray and black water, should be treated, and controlled through infiltration or reuse (Beardsley, 2019).

Energy: building orientation, glazing choice, and the use of climate-appropriate building materials are some examples of design features that lower overall energy requirements in a living structure. The energy consumption of a building can be further decreased through passive heating and cooling, as well as natural ventilation with intelligent controls. The production of renewable energy on-site enables the remaining energy needs to be partially satisfied by non-fossil fuel energy, decreasing the need for conventional sources. In this situation, the living building demands a secure, dependable, and decentralized power system that can meet internal and external demand without the drawbacks of fuel combustion. Net positive energy: Net annual energy requirements should be met entirely by on-site renewable energy sources, with no on-site combustion. In this situation, onsite clean energy storage should be utilized for resilience (Beardsley, 2019).

Health and Happiness: the health and comfort of building occupants are protected by good indoor environmental quality in dwelling structures. High-quality indoor settings increase output, raise a building's worth, and lessen owners' and designers' liability (Beardsley, 2019). In this situation, rather than addressing all potential ways that an interior environment could be impaired, the health and happiness petal in the living building challenge concentrates on the fundamental environmental conditions that should exist to generate healthy and highly productive environments (Hamad, 2020). Numerous interior environments are harmful to a person's health and productivity. Because increasing well-being in the physical environment is typically energy intensive, there is a relationship between lower comfort and increased environmental consequences.

Civilized and Health Interior environment: Windows that can be opened and closed to let in natural light and ventilation are required in every occupied section of the building (Beardsley, 2019). Health interior environment requirements should be met by living structures to promote good indoor air quality. Hence, entrances must be provided by a separate entry space with an interior dirt track-in system and an external dirt track-in system. Additionally, each kitchen, restroom, copy room, janitorial closet, and location used to store chemicals must have its own ventilation system that exhausts to the outside air. Furthermore, equipment should be placed to monitor CO2, temperature, and humidity levels, and ventilation rates should be planned to adhere to ASHRAE guidelines. Also, smoking should not be permitted inside the structure and use cleaning supplies bearing the "EPA Design for the Environment" mark (or international equivalent) (Selim, 2007), (Beardsley, 2019).

Biophilic environment: Building design should include elements that support the natural affinity between people and the environment. One of the six recognized biophilic design components must be present on every 2000 square meters of the project. Those components are environmental considerations, organic forms and shapes, patterns and processes found in nature, plenty of space and light, geographically based connections and human-nature interactions have changed over time (Hamad, 2020). The building design plan should include natural components like topography, space, light, and organic shapes and forms. Also, include evolving human-nature connections as well as natural patterns and processes. Furthermore, create ties based on place that connect people to the environment, climate, and culture and lastly, have enough and frequent opportunities for people to interact with nature within and outside the building so that most residents feel a direct connection to it (Davenport, 2019), (Ibrahim, 2020).

Materials: According to the living building challenge, all construction materials should be renewable and have no detrimental effects on ecosystem or human health. The precautionary principle serves as the foundation for all material decisions. The reduction of embodied energy and other effects related to the extraction, processing, transportation, upkeep, and disposal of building materials is the focus of the materials petal in this context. A life-cycle approach to performance and resource efficiency is supported by the requirements (Davenport, 2019), (Ibrahim, 2020).

Red list: The project is not allowed to contain any of the red list substances such as asbestos, cadmium, chlorinated polyethylene and chloro-sulfonated polyethylene, chlorofluorocarbons, chloroprene (Neoprene), formaldehyde (added), halogenated flame retardants, hydrochlorofluorocarbons, lead (added), mercury, petrochemical fertilizers and pesticides, phthalates, polyvinyl chloride, and wood treatments containing creosote, arsenic, or pentachlorophenol (Salem, Bakr, & El Sayad, 2018).

Embodied carbon footprint: The building should account for the overall footprint of embodied carbon (tCO2e) from its construction through a one-time carbon offset related to the building boundaries (Salem, Bakr, & El Sayad, 2018).

Responsible industry: It is important to encourage the extraction of sustainable resources including stone, rock, metal, minerals, and timber using third-party approved standards (Salem, Bakr, & El Sayad, 2018). There must be at least one declared product for every 500 m2 of gross building area. For example, to clear a site for building or to maintain the continuous ecological function, all timber from salvaged sources must be certified to Forest Stewardship Council (FSC) 100% labelling criteria (Salem, Bakr, & El Sayad, 2018). Using resources from the living economy: The structure should include place-based solutions and support the expansion of the local economy by using sustainable procedures, goods, and services. In this situation, the restrictions that should be adhered to are (1) within

500 kilometers of the construction site, at least 20% of the construction expenditure should originate (2) an additional 30% of the budget for construction supplies must originate within 1000 kilometers or even closer to the construction site (3) within 5000 kilometers of the construction location, an additional 25% of the budget for building supplies must originate (4) about 25% of the materials can be sourced from any location (5) the project site must be within 2500 kilometers of the consultants' residences .

Net positive waste: To protect natural resources, net positive waste refers to the decrease or elimination of waste creation during design, building, operation, and end-of-life. In each of the subsequent phases, a Material Conservation Management Plan outlining how the structure maximizes materials should be put into practice at the design phase when parameters for the product should take appropriate durability into mind. At the building stage, which entails waste material collecting and product optimization. Additionally, at the operational phase, which consists of a strategy for gathering consumables and durables. Lastly, at the end-of-life phase, which entails a plan for deconstruction and reusability (Salem, Bakr, & El Sayad, 2018).

Equity: Communities should grant everyone equal access, regardless of their age, physical capabilities, sexual orientation, or socioeconomic background, according to the concept of equity. Human scale + humane places: Instead of being built to an automobile scale, the structure should be constructed to be human scale, fostering culture and social interaction (Hamad, 2020). For design features that contribute to livable spaces, such as paved areas, streets, block design, building scale, and signs, there are maximum and minimum requirements. Universal access to nature and place: All facilities, modes of transportation, roadways, and infrastructure ought to be open to all classes, irrespective of age, social status, economic standing, or even homelessness, to construct a living community (Beardsley, 2019). In this situation, reasonable precautions should be taken to guarantee that everyone benefits from the project and that those with physical disabilities have access to it in a reasonable manner. Additionally, the design should not impede or impair the society or surrounding areas' access to or quality of natural waterways, fresh air, or sunlight (Ibrahim, 2020). The initiative ought to address any noise that the public can hear. Equitable investment: The development must set aside and donate half a cent (or equivalent) or more to a charity of its choice, or contribute to ILFI's Living Equity Exchange Program, which directly funds renewable infrastructure for charitable enterprises. This requirement applies to all construction costs, including land, soft costs, hard costs, and even furniture. The charity needs to be situated in the nation where the project is being undertaken. Just organization: Through the open disclosure of the primary organizations involve business practices, the building should help to create a more JUST, equitable society. As part of ongoing advocacy, project teams are required to send JUST program information to at least ten project consultants, sub-consultants, or product suppliers. At least one project team member (architect, landscape architect, MEP engineer, interior architect, structural engineer, owner, or developer) must have a JUST label for their company (Hamad, 2020).

Beauty: This flower contends that every square meter of building construction ought to be use enhancing people's lives. In this regard, it is necessary to create and coordinate initiatives to inform the public about the advantages of their living building challenge projects in terms of the environment. the importance of beauty as a sign of preservation, conservation, and service to society. Beauty and spirit: The structure must contain elements that enhance human enjoyment as well as the infusion of place, culture, and spirit in accordance with its intended usage (Beardsley, 2019). Inspiration and education: The public should have access to educational materials about how buildings operate and perform to share successful solutions and incite others to make improvements that will result in more living buildings (Salem, Bakr, & El Sayad, 2018). In this situation, buildings should offer every year, a public open house to be held. Secondly, a website dedicated to education that provides details on the planning, building, and maintenance of the structure. Thirdly, a straightforward booklet outlining the project's architecture, the topographies of the surrounding environment, and tips for inhabitants on how to maximize building functionality. Fourthly, a duplicate of the maintenance and operations manual. Fifthly, a signage that provides information about the building to both visitors and tenants. Lastly the website of the institute will publish a case study on living building in addition to, non-sensitive portions of the building ought to be accessible to the public for at least one day a year so that people can interact with it in person.

4. Discussion

Hypothesis Analysis - H1: living buildings are different from green buildings

This section will provide comparative literature that attempts to prove the above-mentioned hypothesis by comparing the validity of this hypothesis from three main elements: (1) Pre-construction (2) Construction (3) Post-construction.

Pre- Construction: Studies that concentrate on life cycle stages other than the use phase have grown in number recently; more study is being done on material selection and end-of-life issues as the potential to reduce environmental impacts from embodied energy of materials is becoming apparent. Embodied energy contributes significantly to a building's life cycle effects and can be decreased in a variety of ways, such as by using eco-friendly materials or taking the goods' useful lives into account. The complicated technologies used in green buildings, such as solar panels and geothermal wells, can occasionally result in an increase in embodied energy. Thus, choosing materials carefully can result in several trade-offs that have been found to have negative building implications. Choosing materials with a reduced toxin level, a greater recycled content, or those that are locally sourced can all potentially have a positive impact on the life cycle of a product. In addition, recycling and reusing reduce the amount of material that is added to both manufacturing processes and waste streams, which reduces the overall life cycle impacts. Materials play a crucial role in the life cycle impacts of buildings, and the USGBC, ILFI, and other green building rating system organizations have recognized this. As a result, additional materials standards have been added to their certifications. There is potential for improvement even though the Living Building Challenge (LBC) is a comprehensive building assessment system. Quantifying material impacts, including material choice and embodied energy, is one topic. One imperative that calls for offsets for the embodied energy of just the construction phase is the only one in LBC 3.1 (2017) that deals with material embodied energy. As was previously mentioned, all other life cycle stages become more significant and warrant more assessment as the usage phase of high-performance buildings shortens, necessitating a more thorough evaluation of building materials to quantify the shifting effect distribution of those phases. The examination of construction material choices, which in this context refers to the steps of material extraction, production and processing, and transportation, should be considered in the planning and design stage of construction. Table 3 in the appendix clearly demonstrates the similarities in the pre-construction stage which can be summarized in the focus on landscape and access to nature, water, energy and carbon reduction whereby the main differences is more focus of living buildings on the ecology of the place of living buildings through numerous additional strategies imposed than in green buildings.

Construction: Living building structures are similar to the living organisms, getting older slowly but rapidly and simply changing on cell level. In construction phase of the living building, instead of the concentrating of extending the lifetime or renovating the whole building, they are focusing on components rather than complete buildings, buildings are considered as a collective of elements with different properties and lifetimes. In this case, a construction work of living building is determined as an intervention in the built environment. An intervention occurs at element, component and is understood by calculating the change in value and the change in costs for the entire system over the design lifetime of these particular components or elements. As per de Ridder and Vrijhoef, the changed value as result of the intervention is subdivided in (1) architectural value (form), (2) functional value (quantity, capacity), (3) technical value (quality) and (4) the extracted value from the world around the building (system). The changed costs consist of: (1) the investment associated with the intervention and, (2) the savings in maintenance and operation due to the intervention over the design lifetime of the changed component or sub- system, so living building are keeping in consideration the value, price and cost as variables which keeps the building up to date with state of art technology unlike the green building where value and price of the building are fixed. Table 4 in the appendix clearly demonstrates the similarities in the construction stage which can be summarized in the focus on healthy interior performance and all projects must connect people with nature in both interior and exterior of the building being constructed whereby the main differences is green building construction explicitly outlines the exact strategies that must be adhered to while the living building construction is more structured and flexible as it recommends strategizing the construction approach from a material, procurement, and environmental friendly project life cycle operation (Hwang, Zhu, Wang, & Cheong, 2017).

Post – Construction: Upon the collection of architect approved as-is built drawings, collection of warranty and maintenance manuals, vendor bill certification, rectification of snags and creation of defect contact list, preparation of completion certification and facilitation of handover to facility management; starts the two main phases to the post construction stage, first is the occupation while the second is the maintenance phase (Virginia's United Land Trusts, 2021). However, historically, considering the building’s long-term use and sustainability was not always a core concern during the preconstruction and construction stages. Nowadays the urge is to place a high premium on the building’s sustainability in order to control the post-construction costs (Davenport, 2019). Is the post construction phase in living buildings any different from that of green buildings? According to (PWC, 2022), sustainable construction has lower yearly cost for energy, water and maintenance than its non-green counterpart. That is more direct cost saving and financial benefits to the building owners and surrounding as they have 14% less impact on environment due to the reduced Greenhouse Gas Emissions (GHG) (Selim, 2007). However, there were limited studies on whether living buildings are different from sustainable green buildings. Table 5 in the appendix clearly demonstrates that in the post-construction stage the similarities is both type of buildings relying on digitalization and automated monitors to control energy, water, waste, temperature, moisture and ventilation of occupying and maintain both types of buildings however the differences can be summarized in the form of living buildings further demanding strategies on the facility management front.

5. Conclusions

The core finding of this research is that, in the pre-construction stage which can be summarized in the focus on landscape and access to nature, water, energy and carbon reduction whereby the main differences are more focus of living buildings on the ecology of the place of living buildings through numerous additional strategies imposed than in green buildings. The similarities in the construction stage which can be summarized in the focus on healthy interior performance and all projects must connect people with nature in both interior and exterior of the building being constructed whereby the main differences is green building construction explicitly outlines the exact strategies that must be adhered to while the living building construction is more structured and flexible as it recommends strategizing the construction approach from a material, procurement, and environmental friendly project life cycle operation. While in the post-construction stage the similarities are both type of buildings relying on digitalization and automated monitors to control energy, water, waste, temperature, moisture and ventilation of occupying and maintain both types of buildings however the differences can be summarized in the form of living buildings further demanding strategies on the facility management front.

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Appendix

Table 1. Living Building Criteria vs. Greenstar Criteria

Living Building Criteria	Greenstar Criteria
Limits to Growth	Sustainable Sites
Urban Agriculture	Ecological Value
Habitat Exchange	
Human-Powered Living	Sustainable Transport
Net Positive Water	Metering and Monitoring/Potable Water/Stormwater
Net Positive Energy	Metering and Monitoring/Greenhouse Gas Emissions/Peak Electricity
Civilized Environment	Provision of Outdoor Air/Visual Comfort
Healthy Interior Environment	Ventilation System Attributes/Exhaust or Elimination of Pollutants
Biophilic Environment	
Red List	Indoor Pollutants/Responsible Building Materials/Refrigerant Impacts
Embodied Carbon Footprint	Life Cycle Assessment
Responsible Industry	Responsible Building Materials: Timber Products/Sustainable Products
Living Economy Sourcing	
Net Positive Waste	End of Life Waste Performance/Environmental Management Plan
Human Scale + Human Places	
Universal Access to Nature & Place	Innovation Challenge Universal Design
Equitable Investment	Innovation Challenge: Social Enterprise
Just Organizations	
Beauty & Spirit	
Inspiration & Education	

Table 2. Living Building Challenge imperative vs. Innovation Claim in Green Star

Living Building Criteria	Greenstar Criteria
Urban Agriculture	Global Sustainability: Green Star - Communities 'Access to Fresh Food'
Habitat Exchange	Global Sustainability
Net Positive Water	Exceeding Green Star Benchmarks
Net Positive Energy	Exceeding Green Star Benchmarks
Red List	Global Sustainability
Living Economy Sourcing	Innovation Challenge: Local Procurement
Human Scale/Human Places	Global Sustainability
Universal Access to Nature and Place	Innovation Challenge: Universal Design
Equitable Investment	Innovation Challenge: Social Enterprise/Social Return on Investment
Beauty and Spirit	Global Sustainability
Inspiration and Education	Global Sustainability

Table 3. Green Building vs. Living Building Pre-construction Strategies.

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Pre-construction	Planning	Preliminary performance targets set by the integrated design team and building owner at the outset of the project; appropriate to the site and program	According to (International Living Future Institute , 2019): S1: Energy (Energy Use, Energy Source, Clean Energy Transport) S2: Water (Water Use, Water Filtration, Ground Water Recharge, Human Waste) S3: Landscape (Integrated Pest Management, Green Space, Native Plantings and Wildlife Habitat) S4: Materials (Recycled Materials, Efficient Materials, Salvaged Materials, Local Materials, Durable and Low Maintenance) S5: Waste (Recycling and Composting Facilities) S6: Construction Practices (Construction Waste, Reuse Topsoil, Vegetation and Watercourse Protection) S7: Indoor Environmental Quality (Air Pollutant Emissions, Ventilation Effectiveness and Air Filtration, System Commissioning and Cleaning, Daylighting) S8: Economic Performance (Life-Cycle Assessment, Capital Cost Accounting)	According to (WBDG, 2021): S1: Ecology of Place S2: Urban Agriculture S3: Habitat Exchange S4: Human-Scaled Living S5: Responsible Water Use S6: Net Positive Water S7: Energy and Carbon Reduction S8: Net Positive Carbon S9: Healthy Interior Environment S10: Healthy Interior Performance S11: Access to Nature S12: Responsible Materials S13: Red Line S14: Responsible Sourcing S15: Living Economy Sourcing S16: Net Positive Waste S17: Universal Access S18: Inclusion S19: Beauty and Biophilia S20: Inspiration and Education
Pre-construction	Planning	Research Funding Opportunities	S1: There are many financial and supporting resources to support green buildings which are to be applied at the initial stages of the project (International Living Future Institute , 2019)	S1: Set a per square foot of the living building project site [27] S2: Offset through land acquired through an accredited land trust, if applicable [27]

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Pre-construction	Planning	Start early to source salvaged materials	According to (International Living Future Institute , 2019): S1: Look for appropriate salvageable materials from demolition contractors, specialty suppliers, salvaged building material suppliers, or buildings that are being deconstructed S2: All consultants should be ready to specify salvaged materials, when a source has been specified, the availability, quality of material, timing and storage should be confirmed	According to (WBDG, 2021): S1: use responsible materials as a baseline for all projects which is known as 'responsible materials' S2: Follow 'responsible sourcing' when calculating material requirements S3: Divert within the project 80% of the construction waste material from the landfill and provide dedicated infrastructure for the collection of recyclables and compostable food scraps during occupancy S4: Third-party certified standards for sustainable resource extraction and fair labor practices for all construction material extractions S5: Third-party certified standards for sustainable resource extraction and fair labor practices for all construction material extractions S6: 20% of the materials construction budget come from within 500 kilometers of construction site S7: 30% of the materials construction budget come from within 1000 kilometers of construction site S8: 25% of the materials construction budget come from within 5000 kilometers of construction site while the remaining 25% from any other location

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Pre-construction	Planning	Select appropriate land	According to (International Living Future Institute , 2019): S1: The land selected should be of a short walking distance from public transit, pedestrian and bicycle routes, exists in an already-urbanized area, is within walking distance from amenities, is already serviced by the requisite urban infrastructure such as roads/utilities/etc., is a brownfields site to remediate, allows infill development and allows mixed-use development S2: Avoid selecting sites that are flood land, greenfield areas, wetlands, ecologically sensitive land which is a habitat for rare or endangered species, or used as wildlife corridor	S1: include a performance-based approach to the project location, local ecology, and community which is what is known as 'ecology of place' (WBDG, 2021)
Pre-construction	Planning	Selection of the Design Team	According to (International Living Future Institute , 2019): S1: Select a design team with experience or interest in green and integrated design S2: Green design knowledge, skills and experience are criteria for the selection of architects, landscape architects, engineers and other members of the design team S3: Request from all design applicants to provide proof of their knowledge and previous experience with green design principles and practices S4: Ensure that the selected design team members have skills in facilitation, energy simulation, green expertise, value/cost analysis	According to (WBDG, 2021): S1: Consider 'inclusion' and diversity in hiring and provide the team members access to training S2: Consider at least one Living Future Accredited (LFA) subject matter expert in the project team

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Pre-construction	Design	Protect or enhance site's ecological integrity and biodiversity	According to (International Living Future Institute , 2019): S1: Minimize the development footprint, cluster buildings together, re-establish damaged native ecosystems, preserve, establish, or re-establish wildlife habitat by providing shade, shelter, food and water to sustain the desired wildlife, pedestrians, cyclists and others S2: Make connections between the natural ecology of the site and natural systems both within and beyond the site S3: Build support for urban greenways that can be used by wildlife, pedestrians, cyclists, and others through working with the relevant local or regional government agencies to help establish, connect with or further develop a greenway	According to (WBDG, 2021): S1: Consider biophilic design for beauty S2: Protect land for other species by setting aside in each project land identical to the project area away from the site
Pre-construction	Design	Reduce or eliminate disturbance to water system	According to (International Living Future Institute , 2019): S1: Minimize storm water runoff by using organic stormwater management features S2: Make natural water management techniques into attractive landscape elements S3: Install oil/water separators to treat run-off from parking lots only and not from fields or roofs S4: Design roads and parking lots without curbs or with curb cuts or openings that drain to stormwater treatment & infiltration measures	S1: Net Positive Water (Lootah, 2011) S2: Divide the water requirements into core and living under what is known as 'the water patel' (WBDG, 2021) S3: Treat water like a precious resource (WBDG, 2021)

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Pre-construction	Design	Prevent or reduce the use of potable water for irrigation	According to (International Living Future Institute , 2019): S1: Harvest rainwater or use recycled storm water, or site-treated grey or waste water for irrigation ° Use water-efficient plants. These are often native species, or species that have adapted ° Use water-efficient irrigation, including: ⇒ micro irrigation ⇒ moisture sensors ⇒ weather data-based controllers	According to (WBDG, 2021): S1: Treat all stormwater on-site without chemical use and based on pre-development hydrology and current ecological conditions S2: Minimize waste and the use of potable water for irrigation • New Building 50% • Exiting Building 30%
Pre-construction	Design	Reduce urban heat islands	According to (International Living Future Institute , 2019): S1: Maximize green space through use of native gardens, trellises, roof gardens S2: Maximize previous surfaces for parking areas, paths, courtyards S3: Use light colored, high-albedo materials for all non-pervious surfaces S4: Drawings and specifications must record expected albedo requirements S5: Provide shade on impervious surfaces where high-albedo materials cannot be used	According to (Lootah, 2011): S1: Net Positive Carbon S2: The generation of renewable energy on the project site allowing for portions of the remaining energy consumption to be met with non-fossil fuel energy
Pre-construction	Design	Design infrastructure to support alternative transportation	According to (International Living Future Institute , 2019): S1: Locate building to have access to public transit, bike routes, and pedestrian routes S2: Encourage walking and bicycling by designing attractive, safe pedestrian and cycling infrastructure S3: Maximize bicycle-parking spaces and minimize car parking spaces S4: Build changing facilities and showers for cyclists and joggers S5: Give preferred parking to carpool cars	According to (WBDG, 2021): S1: Contribute toward the creation of walkable communities that minimizes the usage of fossil fuel vehicles S2: Provide electric vehicle charging stations S3: Provide bike lockers and shower facilities to encourage the use of bikes in the communities S4: Ensure parking larger than 20m x 30m separated with planted areas S5: Enhance pedestrian routes to encourage walking S6: Advocate the use human-powered or public transportation S7: Provide carpool coordination assistance by providing access alternative fuel vehicles

Table 4. Green Building vs. Living Building Pre-construction Strategies.

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Construction	Construction	Building Orientation and Configuration	According to (International Living Future Institute , 2019): S1: Use existing and proposed trees & plantings S2: Orient the building to optimize prevailing winds and solar opportunities S3: Use existing and proposed topography to create thermal mass around the building S4: Assess the feasibility of using on-site renewable or alternate energy S5: Narrow floor plates can be used to give greater access to daylight, views, and natural ventilation S6: Interior temperature fluctuations can be moderated by thermal mass S7: Computer simulations of thermal massing and natural ventilation strategies can help to assess which strategies save energy and work as designed S8: Reduce heating, cooling, lighting and ventilation loads through careful placing of internal uses S9: Locate internal spaces to optimize natural ventilation, daylighting, and site resources like trees or topography for shading S10: Uses that do not need windows can be located on the north side S11: Create zones S12: Use circulation areas as buffers S13: Be as space efficient as possible S14: The integrated design team should select the best concept design, including the orientation, configuration, massing and siting S15: Finalize all non-energy performance targets	According to (WBDG, 2021): S1: Improve the accessibility to fresh food through the introduction of a secondary path and ensure food storage requirements are considered and design modified accordingly as part of the 'urban agriculture' to accommodate at least two-week supply of food S2: Implement a resilience strategy for all projects to provide 75% of emergency supply for occupants up to three days

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Construction	Construction	Building Systems Design – Structure Design	According to (International Living Future Institute , 2019): S1: Conduct an energy simulation S2: Design with salvaged, recycled and efficient materials as much as possible S3: Use locally harvested or manufactured materials S4: Use materials with low environmental impact over their life S5: Use low-VOC materials S6: Design for flexibility, disassembly and reuse S7: Design building for solar heat and light S8: Control solar heat gain and glare S9: Design building to incorporate the site’s wind and air resources S10: Assess the feasibility of incorporating renewable energy into the envelope, using: ⇒ passive solar technologies like solarwall ⇒ active solar technologies like photovoltaic panels S11: Optimize daylighting and views S12: Design the envelope to provide adequate fresh air S13: Set ventilation targets S14: Select an efficient mechanical or natural ventilation system S15: Assess the potential for heat recovery systems S16: Consider using zones to group areas with similar occupancies and ventilation needs S17: Weigh the benefits of VAV (variable air volume) air distribution systems S18: Provide individual controls for ventilation S19: Separate air intakes from pollution S20: Use carbon dioxide sensors to monitor ventilation rates and to provide ongoing information concerning air quality S21: With the help of building users and owner, reduce pollution sources S22: Ensure that indoor air is free of pollution	According to (WBDG, 2021): S1: Ensure a healthy interior performance through civilized environment and healthy interior environment inclusive of extended options for fresh air and controls S2: Use carbon-free renewable energy resources S3: All projects must supply 105% of project’s energy needs S4: Develop and incorporate a resilience strategy S5: Consider deconstruction and appropriate durability in product specifications
Construction	Construction	Building Systems Design – Envelope Design	According to (International Living Future Institute , 2019): S1: Design an energy-efficient envelope: appropriate insulation, tight construction and high-performance, low-e windows (when this reduces life cycle costs) S2: Avoid thermal bridges in walls (use continuous insulation, or eliminate metal studs in outside walls, or otherwise ensure thermal break) S3: Optimize solar heat gain and reduce glare S4: Locate and size fenestration to capture the wind and fresh air available on site	According to (WBDG, 2021): S1: All projects must connect people with nature in both interior and exterior of the project

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Construction	Construction	Building Systems Design – Ventilation Design	According to (International Living Future Institute , 2019): S1: Set ventilation targets S2: Select an efficient mechanical or natural ventilation system S3: Assess the potential for heat recovery systems S4: Consider using zones to group areas with similar occupancies and ventilation needs S5: Weigh the benefits of VAV (variable air volume) air distribution systems S6: Provide individual controls for ventilation S7: Separate air intakes from pollution S8: Use carbon dioxide sensors to monitor ventilation rates and to provide ongoing information concerning air quality S9: With the help of building users and owner, reduce pollution sources S10: Ensure that indoor air is free of pollution	According to (WBDG, 2021): S1: Select interior materials with lower than industry average carbon footprint S2: Prohibit smoking within any buildings or enclosed spaces including air supply vents S3: Develop a healthy indoor environment plan that tackle cleaning protocols and improves air quality S4: Provide direct exhaust for kitchens, bathrooms and janitorial areas S5: Provide sufficient functioning windows that provides natural ventilation for a minimum of six months per year S6: Occupants can change their airflow and temperature through direct inputs or controls
Construction	Construction	Building Systems Design – Water System Design	According to (International Living Future Institute , 2019): S1: Install water-efficient toilet fixtures S2: Install alternative wastewater technologies S3: Select and install water-efficient fixtures S4: Install water meters to allow measurement of potable water consumption S5: Minimize energy use in water systems	According to (WBDG, 2021): S1: Capture precipitation or closed loop water systems or infiltration S2: Recycle used project water and purify without chemical use S3: No potable water use for non-potable uses S4: Address grey and black water through on-site treatment and reuse
Construction	Construction	Building Systems Design – Lighting Design	According to (International Living Future Institute , 2019): S1: Install high-efficacy lamps & fixtures S2: Maximize daylight to reduce the need for electric lighting S3: Ensure occupied spaces have direct access to outdoor views S4: Ensure all occupied spaces have access to daylight S5: Reduce glare and unwanted heat gain by using sun shading, interior or exterior window treatments and or light shelves S6: Consider consulting professionals S7: Provide individual controls for lighting where feasible S8: Minimize glare and visual discomfort from electric lighting sources	According to (WBDG, 2021): S1: Provide outside and daylight for 75% of regularly occupied spaces S2: Projects must demonstrate shading of adjacent buildings will not have a negative impact on the occupants of those buildings

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Construction	Construction	Building Systems Design – Mechanical Design	According to (International Living Future Institute , 2019): S1: Optimize mechanic al system to meet reduced loads by avoiding over-sizing equipment S2: Install high-efficiency heating and cooling equipment S3: Maximize the use of passive heating and cooling, using such methods as solar heat gain and natural ventilation S4: Explore the life-cycle costs renewable and alternate energy sources S5: Do a computer-simulated energy modelling of the building, to minimize energy use by optimizing the site, envelope, ventilation, water, lighting, and mechanical systems design S6: Reduce ozone depletion by using HVAC systems, refrigerants and fire-suppressant equipment that do not contain CFCs, HCFCs or Halons S7: All major building system designs should be documented for commissioning S8: Monitor carbon dioxide to ensure indoor air quality S9: Perform ventilation effectiveness S10: Ensure adequate air filtration	S1: Install renewable energy systems (WBDG, 2021)
Construction	Construction	Building Systems Design – Finalize Building Systems Design	According to (International Living Future Institute , 2019): S1: Finalize energy and environmental performance targets S2: Reduce internal loads by installing high-efficiency appliances S3: Provide built-in recycling amenities that make it easier for occupants to recycle than throw away S4: Provide built-in composting amenities, including storage and use areas for composting S5: Select indoor finishes that are recycled or salvaged S6: Select indoor finish materials for minimal indoor air pollutant emissions S7: Surfaces exposed to inhabited spaces, supply or return air should not trap or release dust, mineral or glass fiber S8: Locate air intakes distant from sources of outdoor pollution	S1: Install renewable energy systems (WBDG, 2021)

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Construction	Construction	Specifications / Construction Drawings	According to (International Living Future Institute , 2019): S1: Specify the overall environmental intent of the project S2: Provide detailed spec and drawing information for the preservation of site ecology S3: Provide detailed spec and drawing information for all site water features S4: Specify the package of energy conservations measures and other systems that were selected through the use of energy computer simulation software S5: Specify energy efficient equipment S6: Specify that all mechanical systems and all ventilation systems meet current best standards S7: Specify space around ventilation equipment S8: Specify products and systems that use water efficiently S9: Specify salvaged, recycled and efficient materials as much as possible S10: Specify local materials, rapidly renewable materials, minimally processed products, low-emissions products, alternatives to ozone-depleting substances, alternatives to PVC, polycarbonates, and other hazardous components, and durable and low maintenance materials and products S11: Minimize the disposal of construction waste S12: Commission all major systems S13: Conduct the final energy simulation to verify performance	According to (WBDG, 2021): S1: All projects must safeguard access for occupants with physical disabilities S2: Projects may not restrict access to the edge of any natural waterway except to those that are public safety
Construction	Construction	Construction and Commissioning	According to (International Living Future Institute , 2019): S1: Prevent erosion during construction by minimizing site disturbance S2: Ensure protection of site ecosystem by protecting rare vegetation, large trees, and watercourses are protected during construction S3: Use a formal Site Sediment and Erosion Control Plan to ensure that stormwater does not erode site soil and contaminate local water bodies S4: Construction and demolition waste is reused, recycled or salvaged for later reuse S5: Ensure that the contractor follows a formal Waste Management Plan S6: All topsoil removed during construction is saved and reused S7: Develop and implement an Indoor Air Quality Construction Plan S8: Plan and implement construction sequencing that requires absorptive materials (like insulation, carpeting, ceiling tiles, gypsum, textile materials) to be installed after drying or curing of materials that may emit chemicals S9: Ensure absorptive materials are safe from moisture damage [26] S10: Ensure supply and return air duct systems are clean and verified before occupancy S11: Conduct a complete building flush out using new filters and 100% outdoor air for a minimum of one week before occupancy S12: All major building systems are commissioned	According to (WBDG, 2021): S1: All projects must conclude a post-occupancy evaluation to address health benefits identified from it S2: All projects must avoid the use of red list chemicals

Table 5. Green Building vs. Living Building Pre-construction Strategies.

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Post-Construction	Operational and Maintenance	Facility Management	According to (Ibrahim, 2020): S1: Use design tools such as energy modeling and computational fluid dynamics to avoid oversized building systems that lead to both money and energy waste S2: Rely on smart building systems and devices to enable facility managers gather, analyze and act on building performance information reducing costs and energy consumptions	According to (Dittrich, 2001): S1: Train building occupants, facilities managers, and maintenance staff in sustainable design principles and methods that will minimize system failures S2: Purchase cleaning products and supplies that are resource-efficient, bio-degradable and as safe as possible for both janitorial staff and building occupants, and thereby ensure good indoor air quality S3: Test sensor control points on a regular basis to ensure energy efficiency is not compromised S4: Use automated monitors and controls for energy, water, waste, temperature, moisture, and ventilation S5: Reduce waste through source reduction, reuse, recycling and/or composting to eliminate disposal of reusable materials at landfills and incinerators S6: Minimize travel by supporting telecommuting programs and enabling a mobile work environment S7: Perform scheduled energy audits and re-commissioning of systems; and When updating a facility or its systems, choose higher efficiency equipment and durable materials that will withstand storms and other natural events, and improve the tightness of the building envelope if feasible