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Life Cycle Assessment of Conventional and Sustainable Villas in the United Arab Emirates: A Comparative Case Study

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***Abstract* -** The construction industry significantly contributes to global greenhouse gas emissions and energy consumption. This study employs a life cycle assessment to evaluate and compare the environmental impacts of a conventional villa and a sustainable villa in the United Arab Emirates. Both villas were assessed from cradle-to-construction completion and during the operation and maintenance phases. The conventional villa utilized traditional materials, while the sustainable villa incorporated sustainable alternatives. Utilizing the ReCiPe midpoint impact method in SimaPro software, the study revealed that the sustainable villa demonstrated substantial reductions, more than 50%, in environmental impacts across multiple indicators. The results highlight the critical role of sustainable materials and consideration in reducing the environmental footprint of construction projects. This research illustrates the importance of integrating life cycle assessment and sustainable tools in the early design stages to promote sustainable development in the construction industry.

***Keywords*:** Life Cycle Assessment, Sustainability, Construction Industry, ReCipe Method, SimaPro

1. Introduction

The construction industry is responsible for one-third of global greenhouse gas (GHG) emissions and more than 40% of global energy use. Throughout the life cycle of a construction project, substantial quantities of raw materials and energy are consumed, land is occupied, and numerous negative impacts affect the environment, ecosystems, and human health. Therefore, it is crucial to find solutions to mitigate the environmental footprint of the construction industry. In the United Arab Emirates (UAE), the construction industry plays a pivotal role in the nation's development. Consequently, the UAE has experienced significant growth in sustainable frameworks, aligning with its 2050 vision and sustainability goals [1]. This shift has led to the implementation of more regulations and policies, such as the Green Building Code, the Abu Dhabi Pearl Rating System, and the Al Sa'fat Green Building Rating System. Sustainable development requires consideration of various factors, including building materials, design considerations, the availability of authentic data, skilled personnel, time, and cost. Developers, consultants, and contractors have increasingly emphasized the energy performance of buildings by performing energy benchmarking, establishing best practices, utilizing tools, and applying initiatives to enhance efficiency in the built environment [2]. Life Cycle Assessment (LCA) is a method used to evaluate the environmental impacts of a product or process by considering its entire life cycle, from cradle-to-grave. This study employs LCA to assess and compare the environmental impacts between a conventional villa and a sustainable villa in the UAE. By understanding these impacts, opportunities can be identified to reduce the environmental footprint of construction projects and promote more sustainable building practices.

2. Methodology

This research utilizes the life cycle assessment (LCA) methodology as outlined by the International Organization for Standardization (ISO), following the ISO 14040:2006 and ISO 14044:2006 standards [3]. There are four stages in this methodological framework: goal and scope definition, lifecycle inventory, lifecycle impact assessment, and interpretation of results.

2.1. Goal and Scope

The aim of this paper is to compare the environmental effects of two different villas' designs. Each villa covers an area of 165 square meters for both the first and second floor. The system boundary includes the cradle-to-construction completion phase as well as the use phase of the villas, as shown in Figure 1. Under these stages, the research evaluates the sustainability of the villas by looking at the materials and energy flows utilized. The first villa is a conventional villa (CV), which uses traditional materials, and the second incorporates green materials and sustainable alternatives, hence referred to as the sustainable villa (SV). To compare different systems, it is important to use uniform units measured with the same functional unit for both systems [4]. The study functional unit considered is 1 m^2, with a lifespan of 60 years for both villas.

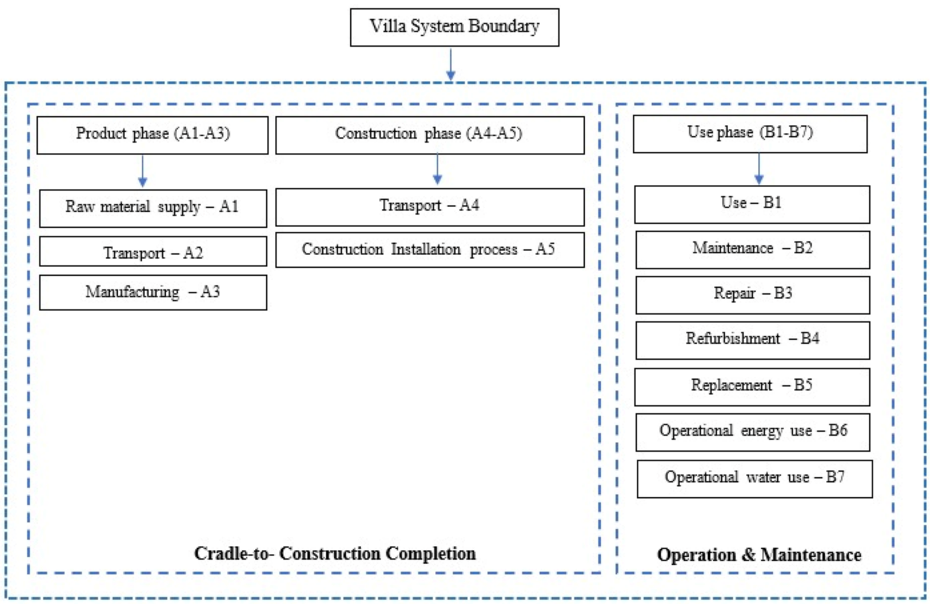

Fig. 1: Villa system boundary.

2.2. Life Cycle Inventory

The life cycle inventory (LCI) can be defined as the process where data on a product's resource utilization, energy consumption, and emissions is gathered to carry out an LCA. This assessment provides both quantitative and qualitative evaluations of the product's environmental impact [5]. The LCA was performed using SimaPro 9.5.0.2 software. The input data was obtained directly from multiple databases, such as ecoinvent, on SimaPro. Certain assumptions were made, including:

1. Several assumptions regarding the supply chain processes were made, such as transportation distance, vehicle types, and load.
2. The sitework and thermal/moisture insulation assemblies are the same for both villas.

2.2.1 Conventional and Sustainable Villa Considerations

The construction installation quantitative data of the CV was acquired from the bill of quantities (BOQ). The BOQ includes sitework, concrete, masonry, thermal/moisture insulation, doors and windows, finishes, landscape, and mechanical and electrical (MEP). To enter the data into SimaPro, the materials were separated into their primary components. For instance, concrete was segregated into cement, coarse aggregates, fine aggregates, and water. Furthermore, the paper considers the effects of on-site equipment use, for example, excavators etc. The operational energy and water use during the use phase were calculated based on UAE electricity and water consumption.

Moreover, various considerations were made for the CV and the SV to compare their environmental impacts. Firstly, the CV utilizes cement as the main constituent in concrete and imported aggregates. However, the SV contains fly ash as the main constituent, and it also includes recycled aggregates. Secondly, for masonry, solid and hollow concrete blocks were used in the CV, while aerated autoclaved bricks were used in the SV. Thirdly, the Heating, Ventilation, and Air conditioning (HVAC) system in the CV is a split system, but Variable Refrigerant Volume (VRV) system was used in the SV. Fourthly, the finishes differ significantly. For example, the SV features triple-glazed glass and more greenery for improved thermal insulation. Finally, sustainable practices in the SV include low-flushing toilets and flow fixtures, a home automation system, and the use of local materials to reduce transportation impacts.

2.3. Impact Assessment

The assessment was conducted using the ReCiPe midpoint impact method, known for its precision and extensive scientific data. This method includes 18 indicators, such as climate change, human toxicity, ozone depletion, acidification, and the depletion of abiotic resources, among others [4]. The impact categories included in this midpoint analysis are GWP (kg CO_2-Eq), ionizing radiation (kBq Co-60 eq), fossil resource scarcity (kg oil eq), ozone formation, human health (kg NO_x eq), ozone formation, terrestrial ecosystems (kg NO_x eq), human non-carcinogenic toxicity (kg 1,4-DB-Eq), human carcinogenic toxicity (kg 1,4-DB-Eq), stratospheric ozone depletion (kg CFC-11-Eq), mineral resource scarcity (kg Cu eq), land use (m^2a crop eq) and water consumption (m^3). The characterized impacts were retrieved as is and were not normalized nor weighted.

2.4. Interpretation

The last step of the LCA process, a life cycle interpretation, is performed, summarizing the findings from the first three stages and providing a foundation for drawing conclusions, offering recommendations, and supporting decisions (ISO 14044:2006).

3. Discussion and Results

The characterization impact assessments obtained by SimaPro software utilizing ReCipe method are discussed in the following sections.

3.1. Cradle-to-Construction Phase Impact Assessment

3.1.1 Conventional Villa Cradle-to-Construction Completion Phase Impact Assessment

Figure 2 illustrates the impact assessment for the CV from cradle-to-construction completion. The assemblies considered are categorized into different construction processes, including concrete, masonry, sitework, thermal and moisture protection, MEP, doors and windows, finishes, and landscape. The primary contributors to environmental impacts are the masonry assemblies and concrete structure, primarily due to the high cement content. Additionally, the transportation of concrete and masonry blocks from a supplier located outside the Emirate where the project is taking place has increased the environmental impact. Concrete and masonry also significantly affect the human carcinogenic toxicity impact indicator. A study conducted by [6] assessed the mortality and incidence of cancer among workers in the cement industry exposed to various operations involved in raw material extraction and the construction of concrete structures. The study revealed a higher incidence of stomach cancer and lung cancer among cement workers, attributed to inhalation of dust, smoking while working, and exposure to other minerals. Additionally, colon cancer rates were found to be higher in this occupational group. Finishes also have a significant influence on human health. A study found that the main cause of damage to human health during the construction phase of ceramic tiles is the presence of particulates larger than 2.5 μm in the air, contributing to 28.51% of the overall effect [7]. The primary factors contributing to the impact of finishes include the allocation of tiles to customers (23.01%), the manufacturing process (19.38%), the installation process (19.01%), and the supply of raw materials

(15.75%) [7]. These activities collectively contribute to the release of detrimental particulate matter, which has a substantial impact on human health [7]. Therefore, it is clear that the selection of materials and the logistics involved in their transportation play a critical role in determining the environmental and health impacts during the construction phase.

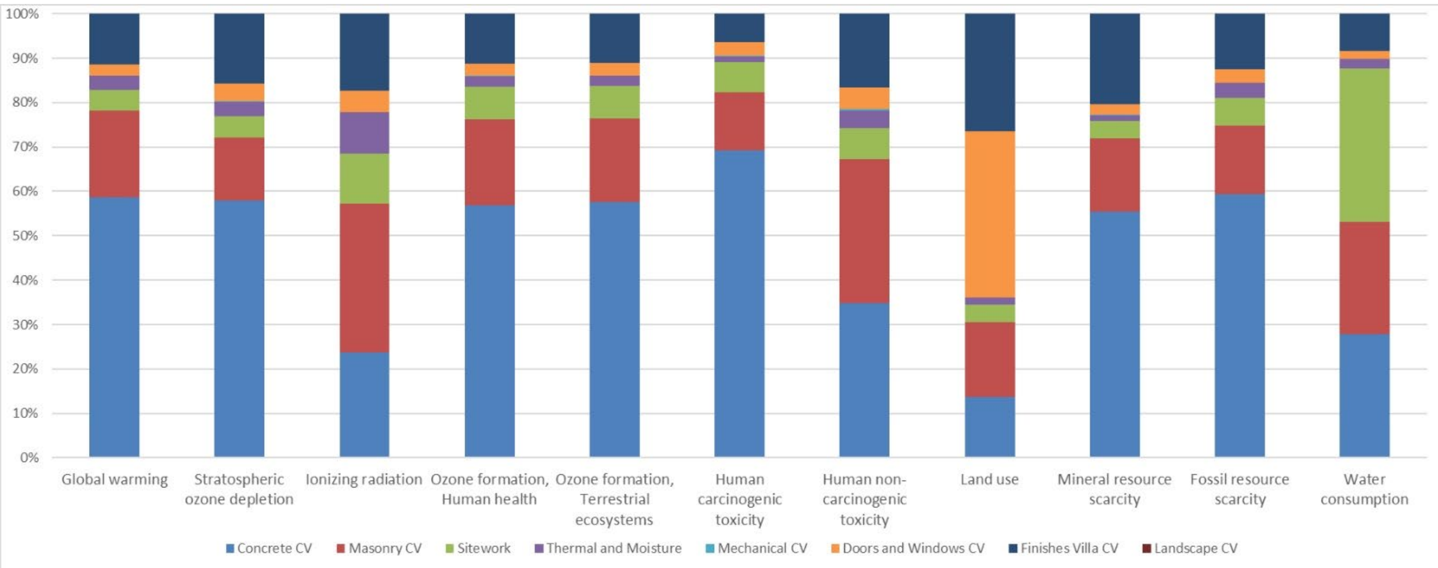

Fig. 2: Conventional Villa Cradle-to-Construction Completion Phase Impact Assessment.

3.1.2 Sustainable Villa Cradle-to-Construction Completion Phase Impact Assessment

Figure 3 illustrates the impact assessment due to the cradle-to-Construction completion of the sustainable villa with respect to the ReCipe midpoint indicators. The major contributor to emissions was concrete. However, there has been a significant drop in emission rates among most indicators after replacing regular concrete (40 MPA) with green concrete. This substitutes ordinary Portland cement with fly ash, an industrial waste material used as an alternative for cement in green concrete production. This offers higher performance than conventional concrete due to less energy consumption and less carbon dioxide emissions, leading to a reduction in global warming rates [8]. In the sustainable villa, advanced smart home technology was integrated using various assemblies modelled in SimaPro. Key components include displays, electronic parts, and materials such as copper, polyvinylchloride, and aluminum alloy. These components enabled efficient energy management, appliance control, and indoor air quality monitoring, aligning with sustainable living principles and enhancing the overall health and comfort of the home [9]. However, it was the main contributor in the human non-carcinogenic toxicity category. According to [9] there are concerns about the long-term health effects of the increasing number of wireless connections due to more signals being added. Additionally, the water consumption category shows that the site work had the highest impact. This is due to the human use requirements on site and the different construction processes involved.

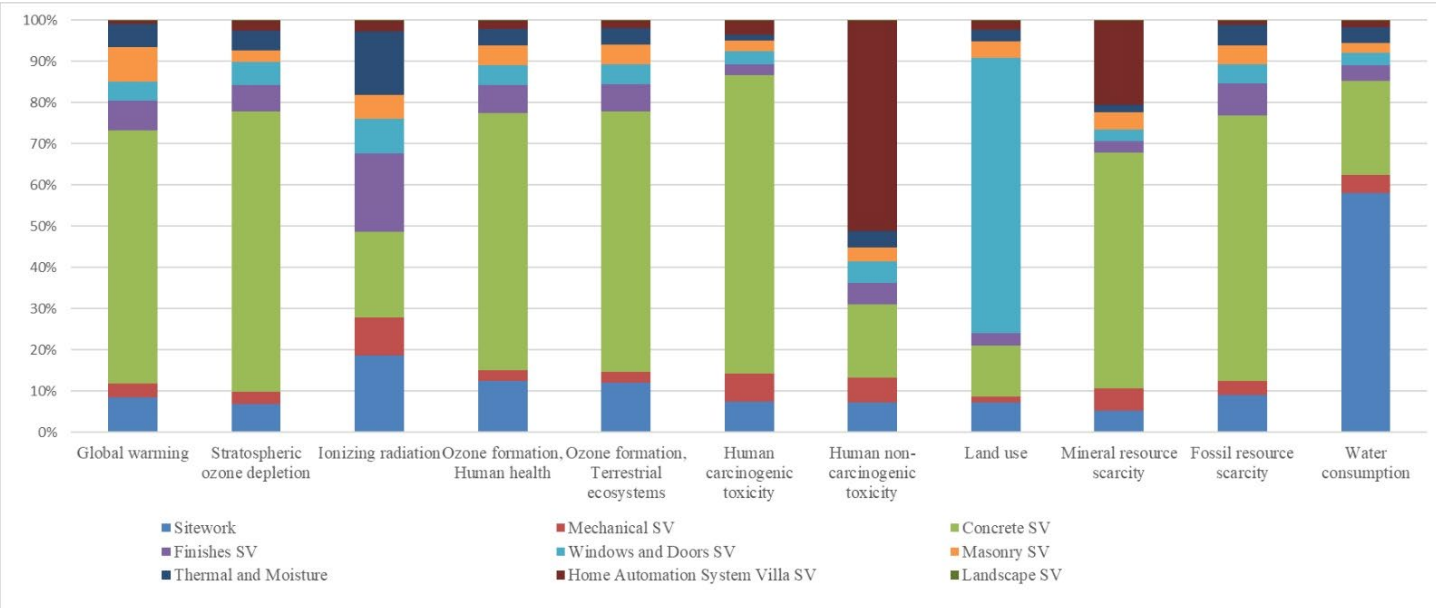

Fig. 3: Sustainable Villa Cradle-to-Construction Completion Phase Impact Assessment.

3.2. Operation and Maintenance Phase Impact Assessment Comparison

In the UAE, electricity consumption by residential buildings accounts for 30% of the total consumption [10] and around 94% of electricity comes from fossil fuels [11]. When fossil fuels such as coal, oil, and natural gas are combusted for electricity generation, they release carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) into the atmosphere. These gases trap heat by allowing sunlight to enter the Earth's atmosphere but preventing some of the outgoing heat from escaping, thus contributing to global warming and ozone depletion. Also, these emissions can lead to respiratory and cardiovascular diseases, as well as other health issues. The climate in the UAE is generally hot, with high temperatures and humidity in coastal regions. Therefore, the building sector needs HVAC systems to keep indoor conditions comfortable. Typically, the HVAC system accounts for 45-50% of total electricity consumption, followed by the water heater 12-14% and lighting 9-12% [12]. The UAE ranks among the top countries in the world for per capita water consumption. This is because the average usage of water in the UAE per capita per day is about 500 L [13]. According to the Environmental Protection Agency (EPA), around 70% of the water used daily is used indoors [14]. Therefore, it is important to include sustainable practices that can help in reducing electricity consumption for better environment and health.

Figure 4 illustrates the comparison impact assessment between the two villas during the operation and maintenance phase. The impact in all categories was reduced by more than 60% due to sustainable practices. Firstly, the implementation of the VRV HVAC system can reduce energy consumption by about 40%, which reduces harmful emissions [15]. Secondly, the home automation system reduces electricity consumption by more than 20% [16]. Moreover, the home automation system is connected to the irrigation system, which results in efficient water management and further reduces energy consumption. Thirdly, triple-glazed windows provide excellent thermal insulation, reducing heat transfer between the inside and outside of the home. This minimizes the need for cooling in the summer, leading to energy savings. Fourthly, the addition of low-flushing toilets and fixtures contributes to energy savings by reducing the 70% indoor water usage by at least 20% [17]. Finally, greener surroundings, such as trees and shrubs, can also contribute to energy efficiency by providing natural shading and cooling [18]. Overall, the SV demonstrates an improvement in reducing environmental impacts. This highlights the importance of using sustainable materials, and innovative building technologies for a healthier and more sustainable living environment.

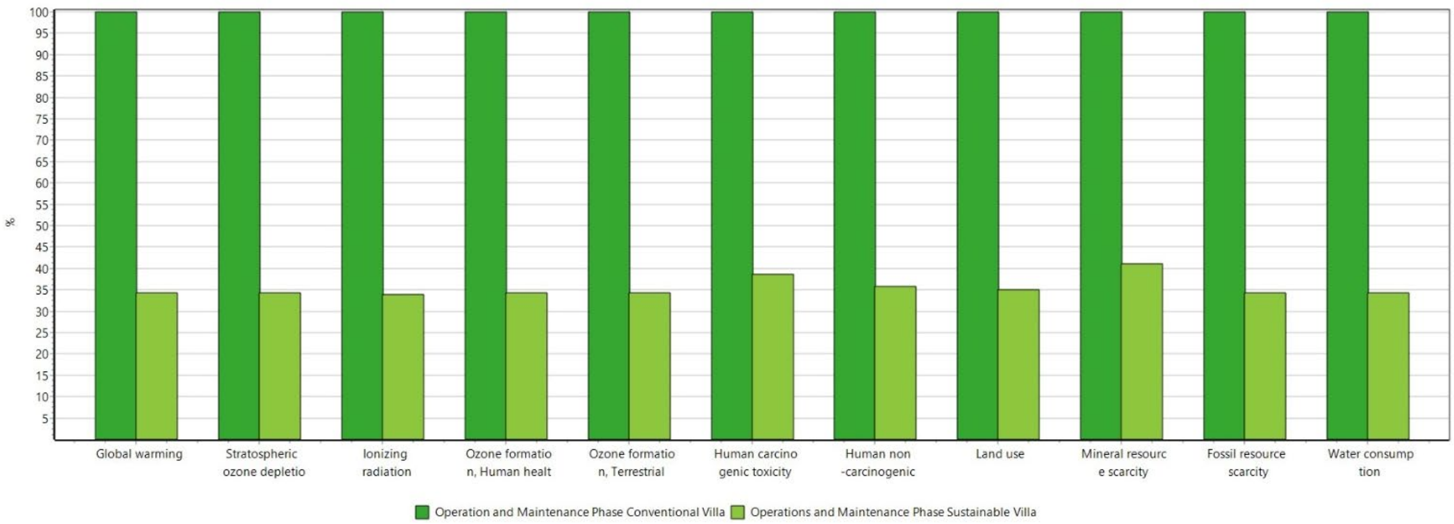

Fig. 4: Operation and Maintenance Phase Impact Assessment Comparison.

3.3. Life Cycle Impact Assessment Comparison

Figure 5 compares the life cycle impact assessments of the CV and the SV. It is evident that the CV has a greater negative impact across all indicators. The SV, on the other hand, exhibits substantially reduced impacts, less than 50%, in categories such as global warming, ionizing radiation, ozone formation human health, water consumption, and land use. This is due to the changes in design, choice of materials, and the strategies that reduced emissions during both the construction and use stages. Hence, this demonstrates that the sustainable villa is more environmentally friendly and has a lower environmental footprint compared to the CV.

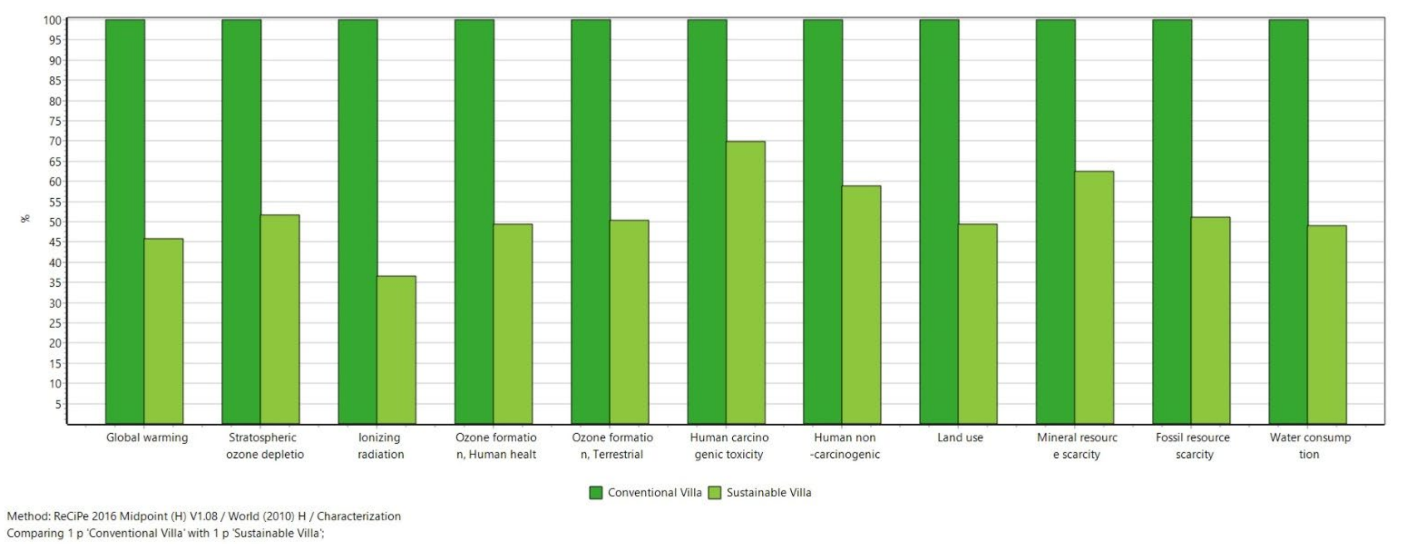

Fig. 5: Life Cycle Impact Assessment Comparison.

4. Conclusion

A life cycle assessment was conducted to analyse the environmental impacts of constructing villas in the United Arab Emirates using SimaPro software. The study compared two different villa designs: a conventional villa and a sustainable villa. Various materials, strategies, and systems were considered for each design. The study boundaries encompassed all phases from cradle-to-construction completion, as well as the operations and maintenance phase. The results demonstrated a significant reduction in emissions across all indicators at every life cycle stage for the sustainable villa, whereas the conventional villa exhibited higher emissions and environmental impact. Therefore, the study highlights the necessity of integrating LCA during the preliminary design stage to mitigate environmental impacts. Additionally, it illustrates the importance of adopting sustainable practices and strategies within the construction industry to reduce the environmental footprint of construction projects.

References

[1] "Sustainability UAE Built Environment Blueprint," EmiratesGBC, Abu Dhabi, 2023.
[2] K. A. Alobaidi , A. . B. Abdul Rahim, A. Mohammed and S. Baqutayan, "Sustainability Achievement and Estidama Green Building Regulations in Abu Dhabi Vision 2030," Mediterranean Journal of Social Sciences, vol. 4, no. 2, pp. 509-518, 2015.
[3] "Technical Committee ISO/TC 207," 2006.
[4] P. Hernandez, X. Oregi, S. Longo and M. Cellura, "Life-Cycle Assessment of Buildings," in Handbook of Energy Efficiency in Buildings, BH, 2019, pp. 207-261.
[5] Z. Wang and F. Liu, "Environmental assessment tools," in Industrial Ventilation Design Guidebook, Academic Press, 2021, pp. 435-448.
[6] D.-H. Koh, T.-W. Kim, S. H. Jang and H. W. Ryu, "Cancer Mortality and Incidence in Cement Industry Workers in Korea," Safety and health at work, vol. 2, no. 3, pp. 243-249, 2011.
[7] A. Ferrari, L. Volpi, M. Pini, C. Siligardi, F. García-Muiña and D. Settembre-Blundo, "Building a sustainability benchmarking framework of ceramic tiles based on Life Cycle Sustainability Assessment (LCSA)," Building a Sustainability Benchmarking Framework of Ceramic Tiles Based on Life Cycle Sustainability Assessment (LCSA), vol. 8, no. 1, p. 11, 2019.
[8] F. Hashmi, M. S. Khan, M. Bilal, M. Shariq and A. Baqi, "Green Concrete: An Eco-Friendly Alternative to the OPC Concrete," Construction, vol. 2, no. 2, pp. 93-103, 2022.
[9] B. Sovacool and D. Furszyfer Del Rio, "Smart Home Technologies in Europe: A critical review of concepts, benefits, risks and policies," Renewable and Sustainable Energy Reviews, vol. 120, p. 109663, 2020.
[10] "Annual Statistics Booklet 2023," DEWA, 2023.
[11] A. Hummieda, . A. Bouabid, K. Moawad and A. Mayyas, "The UAE's energy system and GHG emissions: pathways to achieving national goals by 2050," Clean Energy, vol. 7, no. 5, p. 962–980, 2023.
[12] "The Top 5 Biggest Users Of Electricity In Your Home," greenlogic, 2024. [Online]. Available: https://greenlogic.com/blog/the-top-5-biggest-users-of-electricity-in-your-home.
[13] N. Hilal, "World Water Day: A chance for the UAE to re-think our use of resources," The National, 2022. [Online]. Available: https://www.thenationalnews.com/opinion/comment/2022/03/22/world-water-day-a-chance-for-the-uae-to-re-think-our-use-of-resources/.
[14] "How We Use Water," EPA, 2024. [Online]. Available: https://www.epa.gov/watersense/how-we-use-water#:~:text=The%20average%20American%20family%20uses,in%20more%20water%2Dintensive%20landscapes..
[15] W. Altalaa , "Energy Optimization of an Existing Residential Villa in UAE Towards Net Zero Energy Building (NZEB) Concept," The British University in Dubai, Dubai, 2017.
[16] "Home automation and energy efficiency domestically," climertechnology, 2024. [Online]. Available: https://www.climertechnology.com/home-automation-and-energy-efficiency-domestically/.
[17] "Residential Toilets," EPA, 2024. [Online]. Available: https://www.epa.gov/watersense/residential-toilets.