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DEVELOPMENT OF A SUSTAINABLE BUILDING MODEL IN CAMEROON

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ABSTRACT

The act of building involves several parameters and multiple stakeholders, making it a complex system. Therefore, modeling it requires consideration of all these factors. The construction context in Cameroon integrates the new requirements of sustainable development into projects. The need to develop a sustainable building model is based on specific cultural, environmental (climatic, resource scarcity), geographical, and economic constraints. This better frames the issue of sustainable buildings in terms of assessing the impacts of construction on the physical, cultural, political, and economic environment, using a methodological approach based on the possible choices that arise from analyzing future implications on surrounding ecosystems. This article aims to propose a developed model of sustainable construction, based particularly on available scientific assessment tools and decision-making support, aimed at adapting existing buildings within urban environments under various climatic contexts in Cameroon. The values obtained from our design model take into account pollution from construction, as well as energy and water consumption. The proposed tool is dynamic and highly beneficial for decentralized local authorities, particularly for implementing actions to *reduce greenhouse gas emissions and optimize the management of local resources. Our results suggest actions such as renovation, green roofing/vegetation, and the use of photovoltaic solar energy. The contribution of renewable energy equipment to existing buildings implies, for their implementation, a better analysis of the studied building. Cameroon can benefit from the development of tools for evaluating its buildings, thus gradually making existing constructions compliant with the requirements of sustainable urban development. This leads to interesting formulations in terms of strategies and policies for developing sustainable construction projects.*

Keywords: Sustainable building model, LCA (Life Cycle Assessment), bioclimatic architecture, environmental impacts.

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1. Introduction to the Issue of Construction

Global challenges such as climate change and the overexploitation of non-renewable resources demand resilience in the implementation of urban development and construction projects. Millions of urban buildings around the world struggle to access quality construction resources. They suffer from structural and planning issues. The need to develop a sustainable building model arises from alternative solutions aimed at improving buildings. Urban actions designed in relation to climate risks must be applied at the scale of urban systems, requiring effective control of site constraints, project setup, use, and deconstruction of existing buildings. A distinction is made between newly constructed buildings and existing ones that can be improved to meet new sustainability requirements. These involve the materials, equipment, and tools used in the construction sector. Although this sector is largely outward-looking and mainly supplied by imported industrial products, this can significantly hinder the promotion of locally available materials. Construction problems are reflected in the quality of products, their service life, building collapses, and landslides. Many of these buildings are constructed in non-building zones, raising safety concerns for residents who increasingly build in urban areas while rural zones, with more secure land tenure, are overlooked. The development of sustainable construction projects is challenged by a low supply of quality buildings amid ever-growing demand. As a result, any shortage of sustainable buildings raises concerns about environmental protection and the efficient management of available resources. In Cameroon, the built environment faces severe energy shortages, making it difficult for energy-intensive constructions, such as heavy aluminum and metal processing industries, to operate due to limited electricity supply. Environmental regulations (RE2020) have highlighted the concept of environmental sustainability, which has gradually become a guiding principle for the construction sector in their design processes. The models developed by modern builders aim, through their strategies, to achieve resilience for the prevention of climate risks affecting built systems. For the specificity of buildings, Lasvaux (2010) pointed out significant environmental impacts stemming from the sector. These impacts are linked to the construction, operation, and deconstruction of buildings. In the first case, the environmental impacts of buildings result from the extraction of natural resources necessary for their construction (Lasvaux, 2010). These include pozzolana, aggregates, and sand. The environmental impacts generated by the exploitation of these natural resources are also emphasized. In addition to these basic materials, metals, plastics, wood, and its derivatives are also used in building construction. The exploitation of these secondary resources is also responsible for significant emissions of air pollutants, including carbon dioxide (Rossi et al., 2015; Hendriks, 2000), sulfur dioxide (Brussels Environment-LRE, 2009), and highly toxic dioxins (Dobrzynski et al., 2009; Horvath, 2004).

1.1 Urban Land Planning and Sustainable Development Challenges

To better understand the complexity of the study context, the presence of 250 ethnic groups could lead to diverse and varied forms and styles of construction, depending on the identified climatic zone (figure). More generally, Cameroon has significant potential in terms of building architecture, naturally available resources that can be transformed for the land planning sector, and a rich and diverse artistic culture. Designing with a focus on enhancing the country’s different climates helps better frame the challenge of developing sustainable building models. This is equally important as the integration of the cultural values of the country’s four main cultural regions (Sawa, Fang-Beti, Bamileke, and Sudano-Sahelian), whose traditional construction methods promote respect for the natural environment and low pressure on forest ecosystems. Cameroon is part of the world’s second-largest forest basin, the Congo Basin, which plays a critical global role in regulating massive amounts of carbon dioxide produced by human activities. Like the Amazon, Cameroon must also contribute through its strategies to help maintain the planet’s ecological balance by preserving forest reserves that are keys to fighting climate change and reducing construction resource waste. These stakes and challenges call for contextually adapted models of sustainable development and industrialization. The building sector is particularly significant, especially when it comes to investing in mass housing and service infrastructure. Housing demand is growing rapidly, which strongly encourages self-construction practices often aligned with the informal sector. Territorial planning must integrate resilience strategies into its infrastructure and seek alternatives for urban resource production. Sustainable buildings represent an alternative solution for today's urban development, which is experiencing rapid urbanization—over 50%—with an annual growth rate of 6%.

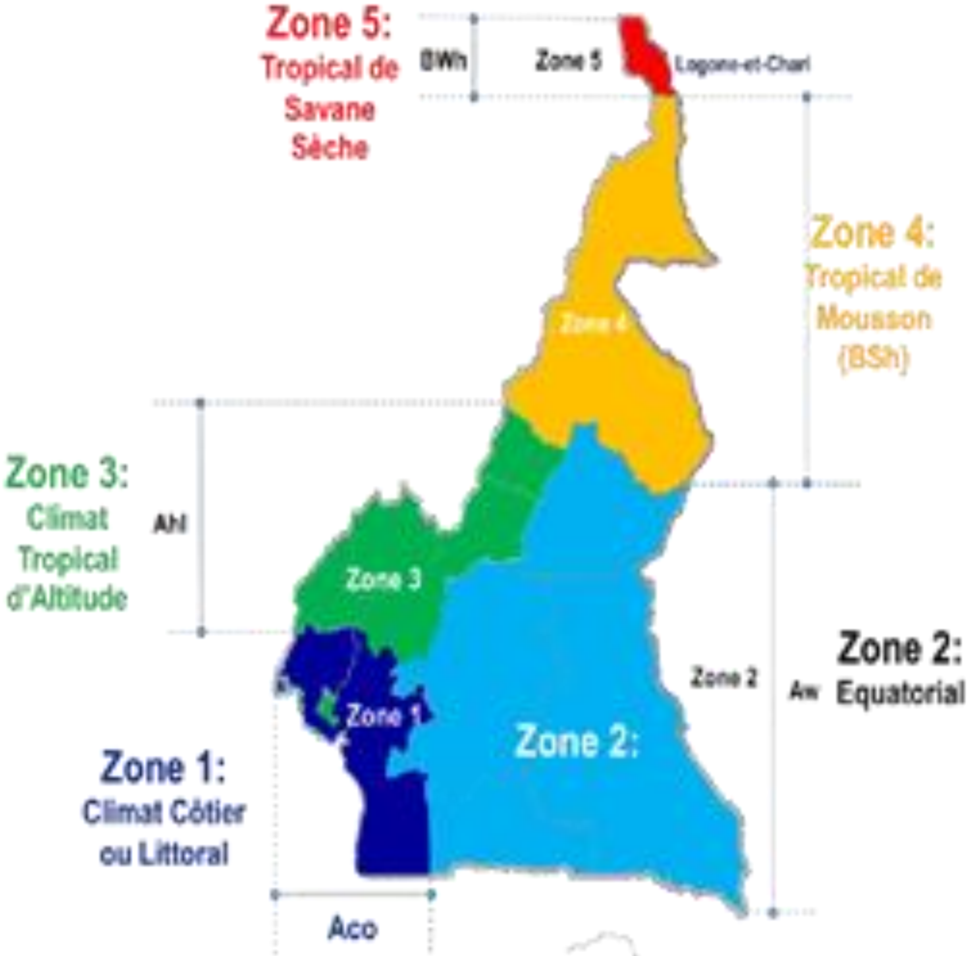
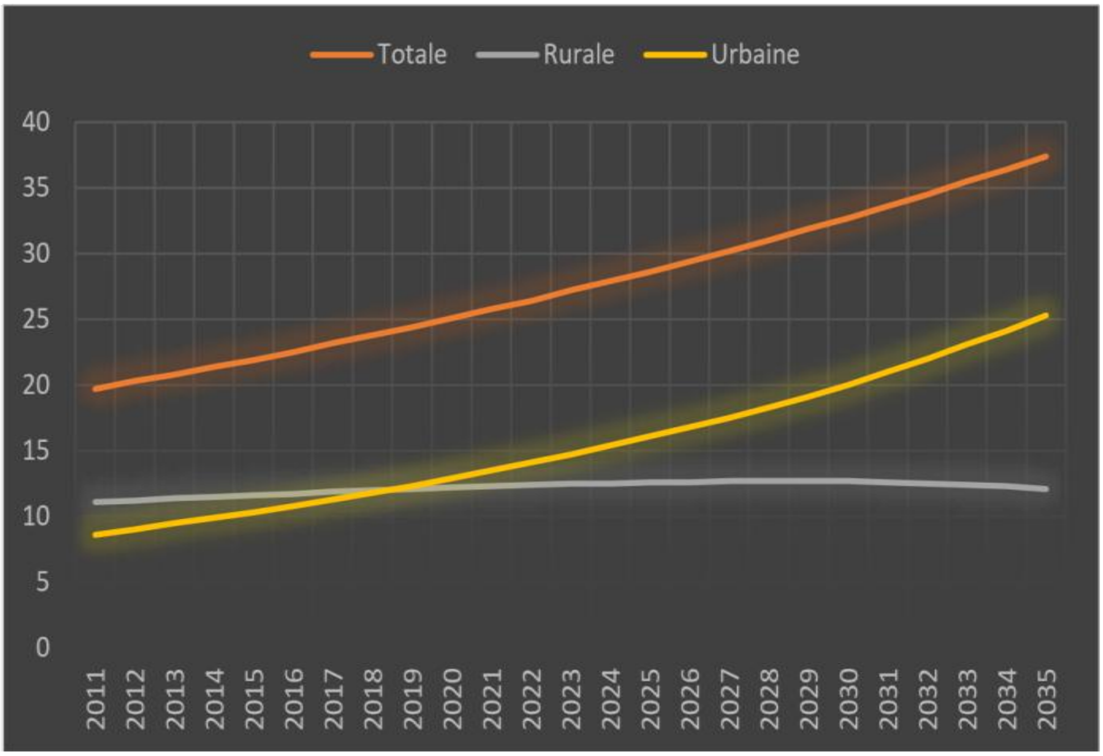


Figure 1: Climatic map of Cameroon

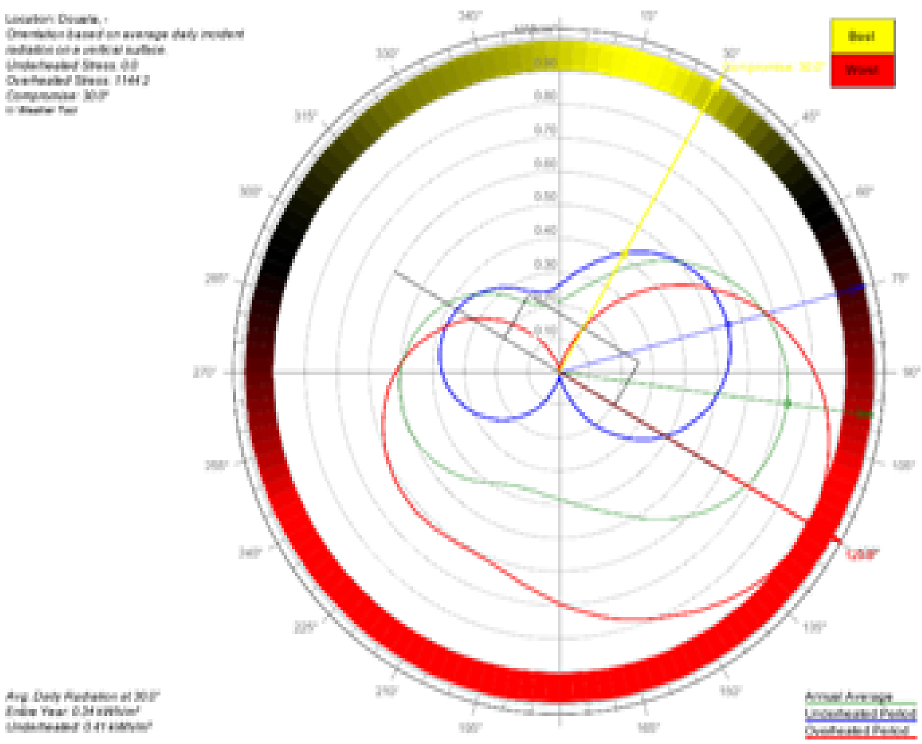


Graph 1: The disaggregated evolution of Cameroon's population by region between 2016 and 2035 as outlined in the National Housing Policy (PNH 2021)

Graph 1 clearly shows that by the year 2035, construction needs for the population will increase, given the projected growth to over 35 million people, with a concentration in urban areas and cities across the country. This exponential growth will be accompanied by an increasing and additional need for housing and service buildings. As a result, there will be an unmet demand for social sustainability in terms of adequate housing for the majority—unless public authorities improve their building strategies and production policies. For a diversified and massive demand in construction, there is a fundamental underlying need: the need for housing in order to exist. According to the Cameroonian definition, the concept of housing is segmented, with a central focus on the home itself, and other elements (infrastructure, superstructures, environment, cultural setting), whose nature and importance determine the quality of the habitat. Furthermore, infrastructure demands and environmental needs can be prioritized conceptually into three types of needs: the need for housing, the need for mobility and access to basic services (water, electricity, waste management...), and the need for community life, job opportunities, recreation, and positive interaction with both the immediate and broader environment.

1.2 Bioclimatic Building Design

Cameroon’s territorial space is composed of 98% land and 2% water, with 5,900 km² of coastline along the Atlantic Ocean. The main climate is humid tropical in the south and dry tropical in the north of the country. Average temperatures range from 25°C in the south to 32°C in the north (PNH, 2021). According to our study, Cameroon’s 374 localities are divided into five climate zones Zi: Z1, Z2, Z3, Z4, and Z5 (Figure 1), which are favorable for building in Cameroon based on thermal, cultural, and environmental specifics. Only Z1, Z2, and Z3 were used in our model; however, the model can be applied to zones Z4 and Z5 with some adjustments. Critical and useful recommendations for improving indoor comfort and reducing artificial air conditioning needs—favoring natural airflow and ventilation—have been highlighted. This includes the importance of endogenous or vernacular construction engineering adapted to the local climate. Although it is declining, its presence reflects its crucial role in the lives of communities as domestic, liturgical, commercial, funerary, industrial, and strategic spaces.



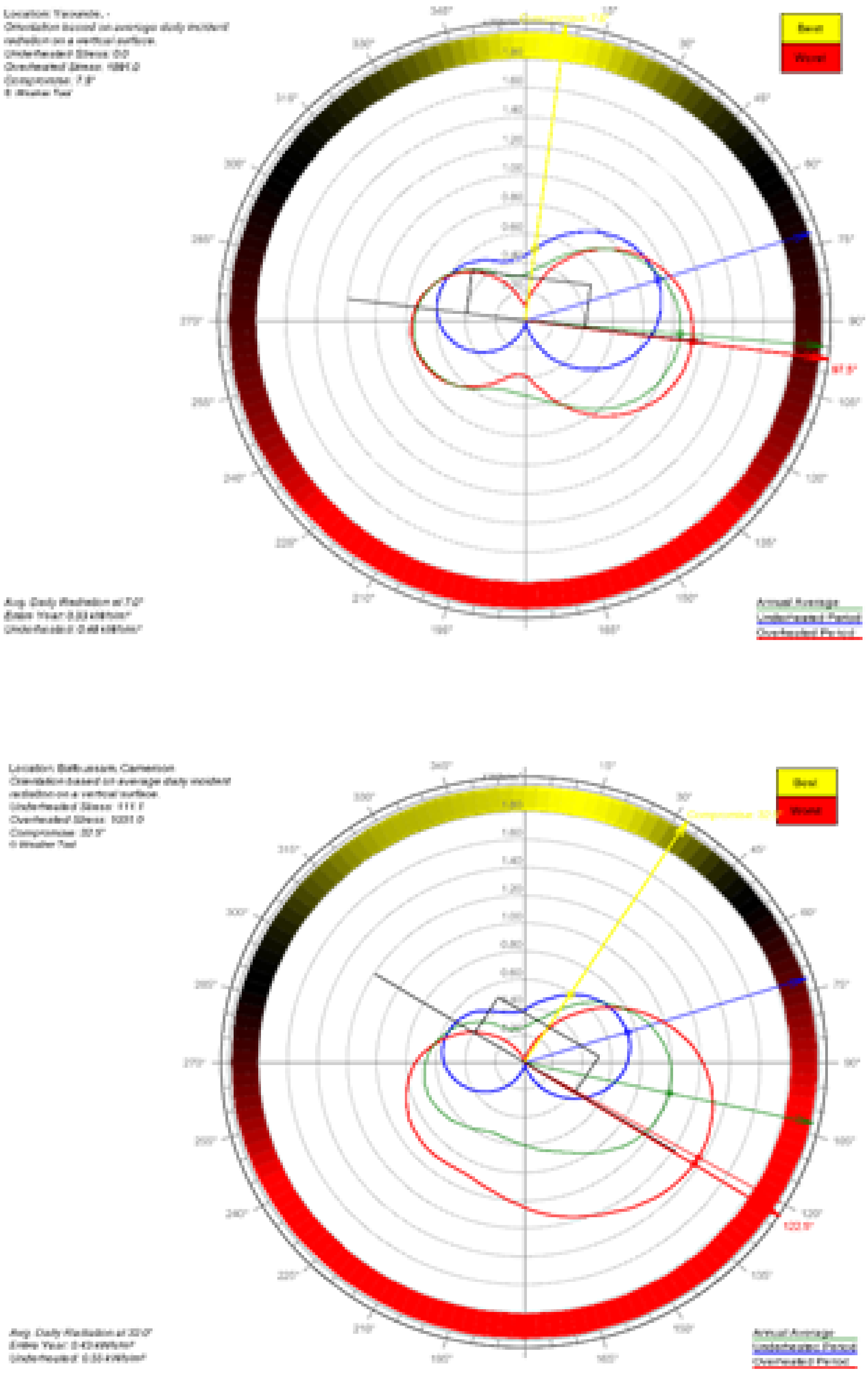


Figure 2: Optimal Orientation of Buildings (B1, B2, and B3) in the Climatic Zones of Cameroon

The figures were created using the Meteonorm software. They show the optimal orientation of buildings in different climatic zones and the climatic orientation of each building in its respective zone. The focus on the hottest months aimed to forecast the indoor environmental quality of the building during heatwaves. Heatwaves, or periods of extreme heat, were studied to help prevent loss of life during the building design phase. A construction zone located on the coast (5 m altitude, Douala) receives a global daily solar radiation on a horizontal surface ranging from 5.0 to 5.4 kWh/m²/day, except on cloudy days, and it gradually decreases to 4.5 kWh/m²/day further inland. The optimal compromise for orienting a prototype residential building (building B1) is estimated at 30.0° (NE) relative to the geographic north along the building's main axis. The worst-case scenario would be orienting this building at 120° (NE), which would make heatwaves extremely hard to manage. Climatic zone Z2 corresponds to the location of building B2. Following the geographic north axis and the sun's path clockwise, the optimal orientation along the building's central axis is 7.0° towards the northeast for an average annual solar radiation of 0.33 kWh/m². Starting from true geographic north, an optimal orientation is reached at an angle of 32.5° northeast along the building's central axis—opposite the trigonometric direction. The radiation compromise is 0.55 kWh/m².

1.3 Quantitative Needs for Quality Housing

Housing (B1) is among the basic needs of the population. It determines access to other fundamental rights, including the right to health, education, work, family life, and privacy. Cameroon has ratified several international instruments in favor of the right to adequate and decent housing, such as the Universal Declaration of Human Rights, the International Covenant on Economic, Social and Cultural Rights, and the Vancouver Declaration, to name a few. At the national level, the preamble of Cameroon's Constitution protects the right to property, which is a component of the right to housing. However, despite urban development and housing policies, the reality reveals a significant qualitative and quantitative housing deficit, estimated at one million five hundred thousand units according to the Ministry of Housing and Urban Development (MINHDU). In its urban planning measures, the Cameroonian government launched a program for the construction of ten thousand (10,000) social housing units and the development of fifty thousand (50,000) buildable plots, as outlined in the National Development Strategy 2020-2030 (SND20-30). This project was intended to be implemented in major metropolitan areas such as Yaoundé and Douala, as well as in regional and departmental capitals, including university towns, by the year 2020. However, as of 2024, it remains far from achieving its intended goals, as shown in Table 1.

Table 1: Current Status of Achieving the Objectives Set by Cameroon's National Development Strategy 2020–2030 (SND30)

SND20-30 Objectives	Current Status3 (MINHDU)
Housing: 10,000 units.	• In Yaoundé/Olembé, the first phase involves the construction of 500 housing units by 13 national SMEs: 80 sample units are completed; 40 others are 90% completed, and the remaining 380 units are about 70% completed. • In Douala/Mbanga Bakoko, 1,175 units are under construction by 23 national SMEs, with an overall completion rate of about 49% — 52% for the 560 units in the first phase and 42% for the 615 units in the second phase. • Under the Government Programme, another phase of social housing construction has started in Yaoundé/Olembé, carried out by a Chinese company, consisting of 33 buildings totaling 660 housing units (out of 1,800 planned across six cities: Yaoundé, Douala, Bafoussam, Bamenda, Limbe, and Sangmélima). Currently, two sample buildings are at the 4th slab level, while foundations are underway for 31 others.
Development of buildable plots: 50,000 plots.	The 50,000-plot component has begun in Yaoundé and Douala, with a few thousand plots produced. Implemented by MINDCAF, it lacks supervision and coordination from the program monitoring bodies created by a Prime Ministerial decree in 2010.

The construction of housing by public real estate development agencies, such as MAETUR, SIC, MIPROMALO, as well as private developers, does not always meet the demand. Cameroonian cities therefore suffer from a shortage of housing that can meet the expectations of urban dwellers. This situation is one of the consequences of the erratic evolution of the national macroeconomic framework, which affects the housing sector. Due to the disorganized nature of the housing sector in Cameroonian cities, most dwellings fail to meet the housing standards set by the Ministry of Housing and Urban Development (MINHDU). Among other issues, it is observed that in large urban centers in Cameroon, many dwellings are unsafe and unsanitary, with unreliable access to drinking water and electricity—indicating a persistently high number of poorly housed individuals living in non-sustainable constructions.

Yet, Decree No. 2008/0737/PM of April 23, 2008, establishes rules for safety, hygiene, and sanitation in construction. Regarding safety in residential buildings, the structure and materials must be selected to withstand, with a proper safety margin, the stresses and attacks they may face, and to offer sufficient fire resistance. They must also provide protection against humidity, temperature variations, and weather conditions, while ensuring sufficient sound insulation. In a context where the housing deficit is growing, the Cameroonian population is increasingly facing difficulties in accessing housing, even rental housing. Generally, finding quality housing that meets one's needs and budget is a real challenge for many urban families. Hence the relevance of sustainable building models.

1.3.1 National Review on Sustainable Construction

At the national level, the building sector is one of the largest consumers of energy worldwide, accounting for 41% of final annual energy consumption and 23% of CO_2 emissions. In a context of ongoing concern for energy savings and growing environmental awareness, the importance of developing strategies to minimize a building's energy consumption is undeniable. Whether these strategies involve recommending improvements to the building's structure, suggesting modifications in the management scenarios of heating/cooling and lighting systems, or promoting specific user behaviors, a multi-criteria optimization approach to building design becomes essential. Particular attention has been given to genetic algorithms due to the promising results they provide compared to other heuristics. In the same vein, another approach using artificial neural networks has also been explored. These mathematical methods were used to develop our optimization models. The models proposed in the thesis by Souffo M. (2021) focused on optimizing lighting consumption. The first optimization model highlighted the influence of the colors of the building's surfaces (walls, floor, ceiling) on the level of illumination. The color parameter, combined with a multi-criteria optimization (illumination level and uniformity) using the recently developed genetic algorithm NSGA III, was used to frame the optimization problem. The discussions showed the impact of primary colors, particularly the color "red," on the average illumination level. The reported energy savings were around 39%. Other models identified by this author (both mathematical and using artificial neural networks) also demonstrated the impact of user preferences on the energy savings achievable in a chosen test room. According to him, the lower the user's lighting needs, the greater the energy savings (up to 40%). To validate these results, a case study was conducted on a high-rise building in Yaoundé, where a model combining surrounding colors and NSGA III genetic algorithms was applied to show energy (and cost) savings ranging from 1% to 5% on the test building (pp. 113-114).

(Madjou T. L. A., 2022) presented a thesis on the adaptability in Central Africa of photovoltaic solar panels designed under different climatic conditions: the case of Cameroon. Through her studies, she concluded that the random selection of photovoltaic solar panels in various solar power plant projects in Cameroon has a significant impact on the efficiency of the panels and the plants themselves. Therefore, choosing the appropriate characteristics and technologies of photovoltaic solar panels is crucial to avoid excessive losses during operation. She also proposed that combining photovoltaic panels with interferential optical filters that limit the absorption of certain ultraviolet and infrared wavelengths would help adapt them better to the Cameroonian climate. For the continuation of her research, several prospects were identified. One key objective is to develop a mathematical model that considers the characteristics of different technologies, panel types, and climatic conditions, including temperature, wind speed, sunlight, duration of sunshine, humidity rate, and precipitation in the installation regions of photovoltaic projects. This model aims to facilitate the sizing of photovoltaic solar plants and to generate the most suitable panel specifications for the project's location (p.168). The three buildings studied were built using the common methods of medium-sized local construction companies, rather than high-efficiency industrial techniques (p.151). They also did not include new building technologies (such as home automation, energy-producing buildings, or modern finishing materials) (p.151). (Djeudjo Temene H., 2023) defended a thesis on the modeling and optimization of a hybrid hydro/PV/wind/diesel/storage power plant to address the energy deficit in tropical zones and in Cameroon. His research presented three case studies, emphasizing the use of certain optimization techniques to design a hybrid energy system for a building in Cameroon. He conducted an optimal sizing of an autonomous renewable energy system for a community multimedia center, considering technical, economic, and environmental aspects using optimization techniques such as PSO, PSOGWO, GWOCS, and SCA. His research explored seven energy configurations based on solar panel shading factors—specifically 0.6, 0.7, 0.8, and 0.9. The best results came from a panel shading factor of 0.9, leading to an optimal energy configuration (PV/DG/battery) with the best performance using the GWOCS optimization technique (p.155). (NSANGOU J.C., 2021) defended a thesis on energy efficiency in the residential electricity sector in Cameroon, contributing to the improvement of both supply and demand. According to him, energy efficiency relies on optimization through energy savings, rational energy use via behaviors and attitudes that reduce waste, and a comprehensive energy management approach. This approach is grounded in concrete actions to reduce the ecological, economic, and social footprints caused by energy production, transmission, and consumption. It also involves the adoption of more efficient equipment to improve energy security and reduce pollutant emissions. His study determined an average efficiency level of 32.4% across the households in his sample, indicating significant potential for electricity consumption reduction in the residential sector. Scientifically, few studies have addressed energy-saving strategies in the electricity sectors of developing countries. Most research has focused on Western nations. According to him, aside from works by (Tatietse et al., 2002) on urban electricity demand analysis in developing countries, (Nematchoua et al., 2014) on the relationship between thermal comfort and energy consumption in modern and traditional Cameroonian housing, and (Enongene et al., 2017) on the financial benefits of energy savings from switching to efficient lighting in households, very few studies have explored electricity end-uses in Cameroonian homes. His study fills that gap (p.107). As Recommendations (p.108), Nsangou J.C. (2021) suggests that policymakers and public authorities undertake several institutional efforts in implementing energy efficiency projects targeting households. This includes developing tools, resources, educational modules, and communication materials to highlight and reinforce the importance of energy efficiency, ensuring that projects are designed to maximize energy service benefits while minimizing costs. According to the author, consumer education is central to making information on energy efficiency and its benefits accessible. This can be achieved through brochures, training sessions, advertisements, radio broadcasts, and SMS messages. Reviewing subsidized energy tariffs can also make energy more accessible to a broader population. Nsangou acknowledges limitations in his work, particularly concerning the reliability of sources and the quality of data used in his study. He also notes uncertainties in the choice of methods and models, as well as potential errors in data coding. Future Perspectives (p.109), suggested the integration of additional data, especially regarding window usage, to enhance energy savings. Furthermore, testing the methodology within a specific panel data framework could help determine the levels of transient and persistent efficiency in electricity consumption. Diesse Youmbi A. (2021) defended a thesis on modeling building energy consumption for sustainable construction in Cameroon. His objective was to develop a method for designing and constructing sustainable buildings in the Cameroonian context by optimizing energy consumption and reducing atmospheric pollution generated by buildings. Considering six climatic zones in Cameroon and five construction materials (raw brick, fired brick, cement mortar block, wood, stone), he developed a tool to assess a building's sustainability by evaluating the amounts of energy and greenhouse gases emitted. This assessment involves varying the construction materials of the building's walls and its orientation. The stakes of his research lie in reducing the energy needs required for the construction and operation of buildings, and in capitalizing on the health and productivity benefits that a sustainable building could generate. The construction of his sustainable building model is based on the fundamentals of the concept—namely economy, environment, and society—to gradually establish the connection between global objectives, their related sub-objectives, and finally the targets and indicators useful for measuring the achievement of these goals. Two key areas emerge from his study. The first focuses on building physics and explores what incremental improvements can be made in building design methods to move toward a sustainable building. This area examines the building's constituent materials and its orientation. The second area uses the established preference orders and the conceptual framework of sustainable construction to develop a tool for designing sustainable buildings. His tool applies a multi-criteria method to analyze building alternatives differentiated by architectural determinants, particularly using the radar diagram method. Looking ahead, the author suggests avoiding oversimplifying the environmental system by considering the building as the sole evaluation entity. He recommends extending the research by introducing indicators that allow extrapolation from the building level to the territorial scale. Additionally, he proposes developing a building simulation library to be enriched progressively through specific research on various physical parameters. (Diesse Youmbi A., 2021) proposes construction and design methods for defining sustainable buildings in tropical and equatorial zones and developing a practical tool for implementing such sustainable designs. His sustainability tool allows, during the design phase, for the selection of the most environmentally viable project alternative, specifically based on energy and greenhouse gas emissions parameters. Through his study, he was able to rank different climate zones based on the performance of common wall materials in terms of energy efficiency in Cameroon. For residential buildings in equatorial and humid tropical zones, stone envelopes provide better energy savings for air conditioning (p.151). In the dry tropical and Sudano-Sahelian zones, fired clay brick was found to be the most energy-efficient material. According to the author, for equatorial zones of the Guinean and coastal Cameroonian types, minimal energy consumption is achieved when the longitudinal axis of the building is oriented North-South. For buildings in the Cameroonian high-altitude equatorial zone and the humid and dry tropical zones, the lowest energy consumption occurs when the building is oriented Southwest-Northeast (p.151). For buildings in the Sudano-Sahelian tropical zone, the lowest energy consumption is achieved when the building’s longitudinal axis is oriented in the preferred East-West direction. Additionally, using the radar diagram tool, the author evaluates three variants of an office building project—a 6-story building (R+6)—with different orientations (main axis facing north, northeast) and varying materials. His evaluation is conducted in a context where certain data and environmental factors are not specifically defined for Cameroon, particularly the embodied energy of materials like cement and aluminum.

1.3.2 Demand for New Housing and Commercial Buildings

The urbanization rate has experienced strong and steady growth, stabilizing at 59.3% in 2023, with an urban growth rate estimated at nearly 6% per year. Cameroonian cities have a national demographic growth rate of 2.4% per year. Over the years, significant urbanization has taken place across the country. The proportion of the urban population has doubled in 40 years, increasing from 28.5% in 1976, to 37.8% in 1987, 48.8% in 2005, and 52% in 2010 (3rd General Population and Housing Census of Cameroon, 2010). Taking into account the 2015 urbanization rate of 54.38%, the populations of Douala and Yaoundé were expected to be approximately 2,768,436 and 2,765,568 inhabitants, respectively. Between 1960 and 2015, there was a notable increase of 299% in the urban population. Based on the last five available values, it is estimated that the urbanization rate in 2020 was around 57.26%. Given this rapid growth, more than 75% of Cameroonians will live in cities within 25 to 30 years (MINEPAT, 2009). By 2030, the urban population will represent about 60% of the total population, with a large proportion living in slums. Studying the spatial distribution of the population reveals a significant impoverished rural population. Based on the average annual growth rate of Cameroonian cities, which is 5.5%, it is certain that by 2050, nearly 75% of the population will be urban dwellers. By then, the main cities will each have more than 100,000 inhabitants, with metropolises like Douala and Yaoundé accounting for 25-30% of the country's total population. Over 60 towns scattered across all regions will have populations between 10,000 and 100,000 inhabitants. This urban population growth is explained by the combined effect of demographic growth (natural increase) and rural exodus (migration) observed in these cities. This is naturally accompanied by an expansion of urban areas that encroach on cultivable lands at the city outskirts, reflecting a complex model that systematically combines a well-structured central core with a very large periphery. This urban expansion engulfs the central core and is, at its edges, disorganized and uniform without prior planning, consisting mainly of Spontaneous Habitat Neighborhoods (QHS), where density decreases progressively from the center to the periphery. Fixed forecasts for building demand for housing are estimated annually at more than one and a half million units between 2030 and 2035. When adding the demand for service buildings (commerce, hotels, hospitals, education, leisure, and sports), which are proportional to the population estimated at over 38 million inhabitants by 2035 (Graph 1), the concern for mass construction and the need to anticipate is clear for public authorities—both in terms of regulations and certifications to ensure better construction quality. Currently, construction is largely self-built and informal (PNH, 2021). From this perspective, financing models and mechanisms are necessary to meet the high demand, and there is a decisive need to shift paradigms toward sustainable urban development—hence the crucial importance of sustainable building in tropical and sub-Sahelian environments like Cameroon.

1.4 Issues of Sustainable Development in the Building Sector

The integration of sustainable development requirements aims to ensure access to quality infrastructure for all. In the context of Cameroon, sustainable buildings are therefore an approach that must be adopted now to leave behind a lasting legacy for future generations. The tertiary sector is closely linked to the activities of the primary and secondary sectors. It will experience increased dynamism due to renewed activity in construction (BTP) and the primary sector. This revitalization, driven by sustainable building measures, would stimulate growth in trade, food services, and hospitality. Improvement of road and port infrastructure would boost the transportation sector. Similarly, the commissioning of fiber optics would enhance telecommunications. As a result, the tertiary sector is projected to record an average annual growth rate of 8.5%, compared to 5.9% between 2020 and 2030 under Cameroon's macroeconomic and budgetary framework scenario (SND20-30, 2020). This performance will be mainly due to developments in trade, hospitality, food services, transport, warehousing, and communications. In the services sector, special attention will be given to the development of the country's vast tourism potential. Transport activities are expected to intensify with the implementation of a broad road network rehabilitation and expansion program. Additionally, the digital economy is expected to play a key role (SND20-30, 2020). To ensure sustainable buildings, the National Housing Policy (2021) makes several proposals, notably the development of urban planning documents: master plans, land use plans, and sector plans wherever possible. These would lead to green urban mobility plans—all to be implemented and monitored within multisectoral platforms that support the holistic development of a sustainable city. Environmental considerations must under no circumstances be separated from strategic urban planning or from the execution of major projects. Environmental management must become a central and essential concept.

1.5 Literature Review on the LCA Method Used for Our Evaluation

Life Cycle Assessment (LCA) is chosen in this article alongside numerous tools developed by building science for the evaluation of constructions.

Table 2: Summary of Building Evaluation Methods (Kaoula, 2017)

Method	**Uses et advantages**
Checklist method	- Examine the impacts of a construction project on a site. - Guide for developers and designers when multiple options are available.
Labeling Methods	- Award a certification or label to a building that meets a certain level of environmental quality.
Matrix Methods	- Analyze and assess the impacts of a project. - Show the links between project activities and their potential consequences.
Decision Support Methods	- Address various issues and challenges.
Life Cycle Analysis (LCA) Methods	- Assess environmental impacts. - Provide the ability to select the best alternative among many. - Identify the building life phase responsible for the impacts.

This section highlights the bibliography derived from our systemic analysis tool for evaluating the building sector. Buildings are typically constructed to remain in place for many years, requiring resources for maintenance and for the occupants' daily activities. They consume significant amounts of raw materials and continue to draw on resources for operations such as heating, lighting, air conditioning, and ventilation. At the end of their life cycle, buildings become sources of waste production, much of which may necessitate valorization. Although various waste management techniques exist (Abdoulaye, 2008; Adjagodo et al., 2016; Béguin, 2013), waste remains responsible for several environmental impacts. These impacts are increasing due to factors such as population growth (De-Souza et al., 2012 ; Cohen, 2006) and industrialization (Teng et al., 2010 ; Ebenstein, 2010 ; Carpenter et al., 2007 ; Davie, 2008). Therefore, accurately studying these impacts requires appropriate tools and a better approach to integrating sustainable development requirements into the building sector. Several environmental assessment methods have been developed in recent years (Lasvaux, 2010), all based on a set of knowledge related to industrial ecology. Among these, Life Cycle Assessment (LCA) is considered one of the most comprehensive and advanced analytical approaches (Ayres et al., 2009).

Nearly three decades have passed since the initial application of Life Cycle Assessment (LCA) in the building sector, notably through the pioneering work of Polster in 1995. Since then, LCA has remained a fundamental method for analyzing the environmental impacts of products, with significant advancements, including its application at the scale of neighborhoods, regions, and even specific materials. When applied to construction at the levels of buildings, neighborhoods, and cities, LCA serves as a method that prevents the shifting of environmental impacts across different locations and time periods. Since its early developments in the 1990s, the understanding and methodologies for evaluating impacts have continually evolved. Beyond the critical volume method, more sophisticated models, such as those proposed by Fantke et al. in 2017, facilitate the transition from emissions to concentrations in various ecological compartments, accounting for transport processes and (bio)degradation. These transfers lead to received doses and health effects, allowing for the assessment of damages to both human health and ecosystems, as discussed by Bulle et al. in 2019. However, such evaluations require sufficiently comprehensive inventory data, as emphasized by Frischknecht et al. in 2004. Overall, the application of LCA is contingent upon the specific objectives of the study. On this basis, it is recognized as a multi-objective approach. Compared to various other quantitative and single-criteria methods such as the Carbon Footprint (focused on greenhouse gas emissions), the Water Footprint (focused on water usage), and the Greenhouse Gas Protocol, as well as qualitative approaches like energy labels or eco-labels, LCA (Life Cycle Assessment) has the dual advantage of being both quantitative and multi-criteria (Léonard et al., 2019). This justifies our choice of this approach for modeling buildings. In this modeling, climate change potential is one of the indicators evaluated, along with others such as acidification, resource depletion, water use, eutrophication, and photochemical ozone formation, among others (Léonard et al., 2019). However, in Africa—and particularly in Cameroon—despite the availability of multiple evaluation tools, our literature review shows that few studies have focused on developing a sustainable building model based on life cycle analysis. Some partial studies have addressed LCA in specific building components (Elime, 2012; Ngouadjio, 2013; Jatta, 2018); others relate to roads, agroforestry (Karkour et al., 2021), and wooden poles (Nimpa, 2021). With the goal of developing a model to improve buildings and make them more sustainable in the African context, the literature review on Cameroon's energy potential and soil and subsoil resources shows these are underutilized. The methods used in building modeling are often purely energy-based and rarely account for renewable energy in construction. Few approaches explore sustainable building models aimed at achieving a low carbon footprint in the natural environment. To be clearer, Mushi et al. (2022), in their critical review on sustainable buildings in Africa, mention that between 1999 and 2021, out of about one hundred African publications on construction using Life Cycle Assessment (LCA) methods, only two were related to the context of Cameroon. We note that much of the work on building life cycle analysis has been done in Western countries, and this tool only became popular in Southern countries starting in the 2010s, with the first studies conducted in South Africa. This helps justify our motivation to carry out a study on developing a building model using LCA in the context of a country that is diversely rich in construction resources but still heavily dependent on foreign industries. Applying multi-criteria and multi-objective modeling for sustainable construction decisions upstream of construction or neighborhood renovation projects allows for integrating options to substitute or add equipment, but more importantly, it helps ensure compliance with existing construction standards, leading to a low carbon footprint and characteristics that respect the natural environment.

This article is focused on the following key objectives:

(i) Scientific, by exploring alternatives to better understand the sustainable building model in the context of informal settlements.

(ii) Normative, to promote the establishment of a thematic code for sustainable buildings aimed at architects, engineers, and technicians as a basis for public urban planning policies.

(iii) Informative, targeting stakeholders and actors in building construction regarding the need to control environmental impacts caused by different types of construction.

(iv) Inventory-related, with the aim of creating a scientific and technical database on building evaluation to strengthen the country's updated infrastructure data.

1.6 Modeling the Sustainable Building Problem

1.6.1 Formulation of the Sustainable Construction Problem

To formalize the decision-making process, the study relied on graph analysis to define the general problem of integrating sustainable criteria into construction project development. Here, the problem can be viewed as a system receiving multiple inputs (excitations) and producing a certain reaction or output response. Thus, consider P, Vd, f, and Y as factors characterizing the sustainable construction issue: P represents known parameters; Vd are decision variables linked to different scenarios or construction phases; f is the function governing the studied system; Y is the system's response. To formulate the sustainable construction problem or our sustainable building model in the context of Cameroon, the following graph is used:

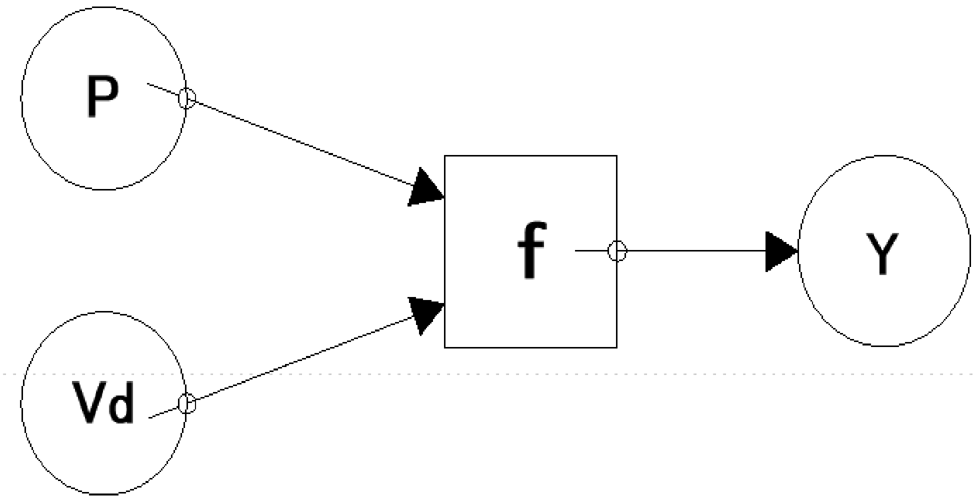


Figure 3: Graph illustrating the decision support model

Referring to Graph 2, three different models: the cognitive model, the predictive model, and the decision-making model. These models represent systemically modeled solutions to the problem posed. Our system is further detailed in Part II.

1.6.2 Solution Models as Decision-Making Tools

These solutions are summarized in the following table:

Table 3: Models Derived from Decision Solutions for Sustainable Construction

Model	**Model Characteristics**
Cognitive Model-1	In this model, f is unknown; the parameters, decision variables, and outcomes are perfectly known.
Predictive Model-2	In this scenario, the result Y is unknown; P, Vd, and f are known.
Decision Model-3	In this model, the decision variable Vd is unknown; P, f, and Y are known. We know what we want to achieve, we know how the situation evolves, and we want to find the best choices to make.

For our study, we chose Decision Model-3.

2. MATERIALS, TOOLS, AND METHODS

Through a specialized literature review conducted in I-5, appropriate approaches and key phases to consider in analyzing an urban project were identified, aiming to highlight added value in its sustainability. Besides LCA (Life Cycle Analysis), approaches such as probabilistic methods, metaheuristic methods, and engineering methods exist to translate and understand any urban problem. Numerous models also arise from these approaches, often targeting multiple objectives. Our methodological framework is based on LCA of buildings because it is one of the most advanced methods for analyzing products and evaluating the environmental impacts of products originating from urban environments and other industrial sectors. Although several types of LCA exist, we focus only on its objectives and the scope related to the construction, operation, and maintenance of buildings, with the aim of encouraging possible improvements toward more sustainable buildings.

2.1 Objectives of the Life Cycle Analysis of a Building

Our LCA analysis is initiated to integrate the various impacts of buildings in the context of Cameroon and to align the design process of current buildings with the requirements of sustainable building. This analysis is outlined following the model shown in the figure. The planned applications of this LCA allow for a better understanding of the environmental issues related to the operations carried out at each phase of the building project cycle. It is important to note that we work with a four-phase cycle: preparation, construction or project execution, operation and maintenance, and deconstruction. Thus, the target audience of the work developed in this article includes companies, architectural firms, engineering offices, and construction professionals, with the aim of establishing a digital experimental database to communicate the impact of constructions to stakeholders in the sector. For this study, we will focus on the following model inspired by (ILCD Handbook, 2010) and (Megange, 2022):

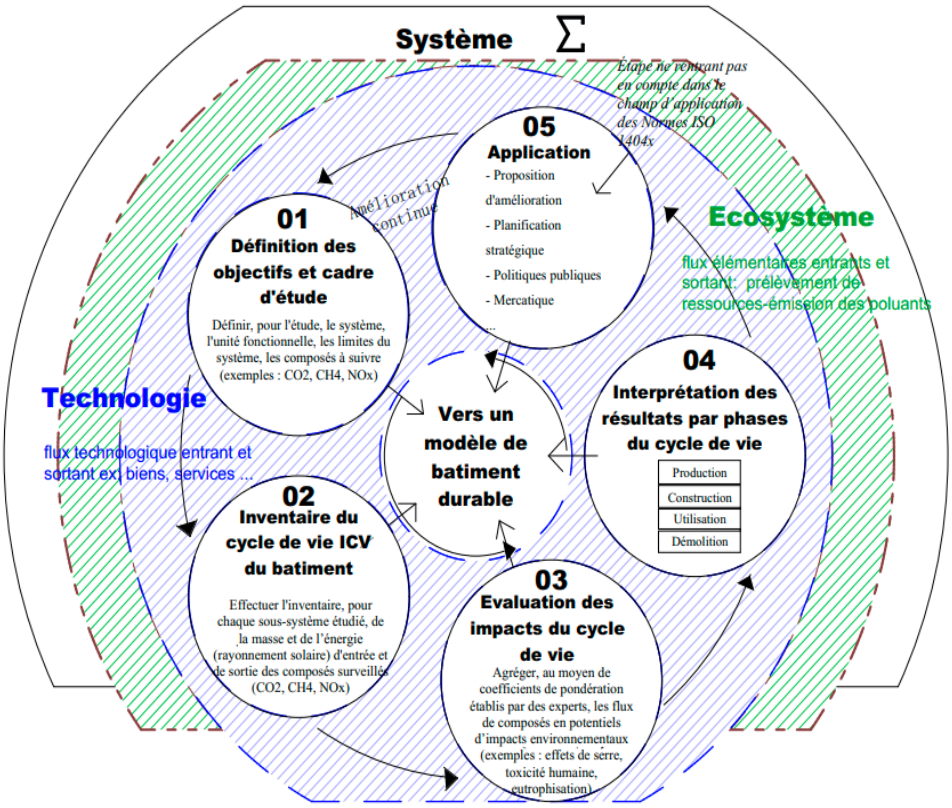


Figure 4: Systemic model of sustainable building, based on the life cycle analysis (LCA) of construction

2.2 Definition of Objectives and Study Framework

By objectives, we mean the justifying reasons for conducting an LCA and the intended use of the results. Their definition is therefore the preamble to highlight the importance of carrying out an environmental analysis.

These objectives may include:

1. Identifying the levers for environmental improvement of the studied product/system;
2. Making a technological solution choice during the design of a product while integrating certain environmental constraints;
3. Conducting an environmental comparison between two different products with identical functions.

During this first phase, significant environmental impacts are selected. This involves keeping the most relevant ones through a literature review. The objectives are only meaningful for the functions the product (building) must fulfill. Therefore, in this initial phase, it is necessary to define a primary function, which is a fundamental basis of the LCA. Its role is essential, especially in comparative studies, as it prevents discrepancies in evaluation criteria that would make the results unusable. This clearly defined and then quantified function leads to the identification of a Functional Unit (FU), which ensures an objective environmental comparison of two or more systems that have the same function and provide the same amount of service.

2.3 Data Collection or Life Cycle Inventory (LCI)

2.3.1 Data Collection Method

2.3.2 Presentation of the Software Used

Equer is an environmental quality tool for buildings that we selected from among many options (checklists, benchmarking, and other certifications and labels) to analyze the life cycle of public buildings and residential constructions. Its purpose is to help stakeholders involved in projects located in various places and different climate zones better assess the consequences of their choices. Such an analysis tool is usable by all building professionals. An architect, for example, can better justify their project to the client by presenting a rigorous environmental assessment of their project. Equer is a software tool that facilitates comparisons of variants and thus serves as a decision support system. Calculations are based on numerical simulations to represent reality more precisely. Integration with other tools, such as thermal simulation, creates a link between energy analysis and environmental analysis. Two types of data are necessary. The first type is measured during the LCA study (e.g., electricity consumption on a production line or pollutant emissions from exhaust). The second type comes from external sources like scientific publications or databases (e.g., CO2 emissions linked to the production of 1 kWh of electricity or the quantity of steel sheet required to stamp a part). A good understanding of the products, systems, or services studied is also sufficient to recover intrinsic activities (manufacturing and logistics processes) and the incoming and outgoing technological flows. Theoretically, data collection should cover the entire activity chain (from raw material extraction to the final disposal of waste or the recovery of building components at the end of their life). In practice, the main challenge is obtaining precise data, which requires consulting suppliers or referring to average bibliographic data whose relevance must be verified.

The final outcome of this phase 2 is the calculation of an inventory containing:

1. Technological flows (or product flows): These are the quantities of substances transformed and exchanged between elementary production processes within the technological sphere;
2. Emission flows of generated substances (emissions into air, water, soil), waste production, and raw material extraction. These are generally called elementary flows entering or leaving the ecosystem sphere.

2.4. Life Cycle Impact Assessment

Following the identification and quantification of physical flows of materials and energy associated with human activities, the Life Cycle Assessment (LCA) evaluates their potential impacts and interprets the results according to the initial objectives. This phase 3 translates the input-output balance of elementary flows into environmental impact potentials. For each studied impact, it combines multiple pollutants contributing to the same type of impact.

2.5. Interpretation of Results by Life Cycle Phases

At each phase of the LCA, the interpretation phase is fundamental. It allows analysis of both intermediate and final results, clarifies the limitations of the inventory, and may lead to redefining the study objectives. Linked to the previous phases, it is meant to provide objective conclusions and ensure a certain reliability of the results.

2.6. Applications

2.6.1. Impact Categories Selected for a Building

The life cycle analysis of various buildings was conducted in accordance with ISO standards 14040 and 14044, using the evaluation version of the Equer software. However, Equer uses eleven (11) indicators for the LCA of a building. The decision to evaluate these impact categories in this study was based on proposals from the review of sustainability assessment criteria for buildings developed by Kamaruzzman et al., 2016; Valazquez et al., 2011, and in line with ISO 14040 and 14044 standards (ISO, 2006a; ISO, 2006b) adopted by the version of Equer deployed. For this reason, all eleven (11) indicators were selected in this study. This phase consists of establishing, based on interpretations, proposals for improving existing conditions, strategic planning recommendations, public policies, and marketing mechanisms aligned with sustainable building. To quantify the environmental criteria for sustainable buildings, the five selected criteria can be detailed into a set of 11 measurable indicators involving flows of emissions of generated substances (emissions to air, water, soil), waste production, and extraction of raw materials in the ecosphere during the building's life cycle.

2.6.2. Life Cycle Inventory (LCI) of the Building

The LCI involved collecting and quantifying relevant data flows (inputs and outputs) of the product system as defined by ISO (14040, 2006). The use of LCI databases allowed the qualification of elementary flows for each system studied in comparable cases. Several databases were consulted, including data from:

1. The Civil Engineering and Mechanics Laboratory of the National Polytechnic School of Yaoundé,
2. Energy evaluation techniques based on civil engineering site tests,
3. Methods for quantifying the impacts of wood materials via LCA (Nimpa, 2019),
4. Building databases in Cameroon from institutions such as MINHDU (2019),
5. Data from Building Information Modelling (Pettang et al., 2014; Okpwe, 2021),
6. Energy savings data for high-rise buildings (Souffo, 2021),
7. Data on building orientation and energy consumption (Diesse, 2021),
8. Databases from the Totem software developed by Belgium (2018),
9. The Ecoinvent database provided by the Swiss Federal Institute of Technology Lausanne, widely used via the Equer software (2021),
10. Data from the building construction code in Cameroon (MINHDU, 2021).

In data collection, the study identified both primary and secondary data. Primary data relates directly to the system under study and was collected on the project site (such as characterization of the climatic zones where the buildings are located). Secondary data, of a general nature, mainly comes from published datasets, empirical and generic models from previous studies, and summary reports. While the LCI overall enabled the quantification of all exchange flows between the systems studied and their environment, its primary aim was to identify the type and quantity of substances and energy types received or generated by the object or system analyzed.

3. PRESENTATION OF RESULTS AND INTERPRETATIONS

Various representation models and approaches are provided in the literature. The design can be based either on the intended objectives or the level of representativeness the designer or researcher wishes to demonstrate. The environmental impact measurements carried out on the different building cases presented above allowed for the practical application of the developed methodology. The criteria Ci (where i ranges from 1 to 11) are derived from the interaction matrix between the pillars of sustainable development developed by Dsonwa et al. (2021).

3.1. Results

3.1.1. Environmental Impacts from the Life Cycle Assessment of Buildings*

Table 4: Environmental Impact Indicators of the Life Cycle

PE : Primary Energy **EAU : Water Consumption** **ADP : Abiotic Resource Depletion** **ADP Elts: Abiotic Depletion of Elemental Resources** **TMR : Non-Energetic Resource Consumption**	**ACI : Acidification of Soil and Water** **GWP : Global Warming Potential (Fossil) over 100 Years** **POCP : Photochemical Ozone Creation Potential** **PA : Air Pollution** **POE : Water Pollution** **Dech: Waste**

Table 5: Environmental impacts of the buildings in our sample obtained by multi-criteria modeling for sustainable building decisions expressed in indicator units per unit area

Impact Indicators		**Units**	**Sample variants**		
			B1 (Residential) in	B2 (office) in Z2	B3 (Hospital) in Z3
PE	C1	MJ/yr	1 110 999,94	1 326 109,36	463 431,132
EAU	C2	L-eq /yr	1 752 653,23	789 053,227	3 286 061,68
ADP	C3	kg eq-Sb/yr	0,15367327	0,15367327	0,27083532
ADP Elts	C4	kg eq- Sb/yr	8,9909E-07	8,9909E-07	1,4285E-06
TMR	C5	kg /yr	11 596,1293	11 596,1293	18 138,0355
ACI	C6	kg eq-SO_2/yr	317,19529	317,19529	413,359224
GWP 100	C7	kg eq- CO_2/yr	12 389 549,1	14 779 414,8	5 408 455,53
POCP	C8	kg eq- C_2H_4/yr	159,15985	159,15985	166,781276
PA	C9	m^3/yr	18 543,9292	18 543,9292	19 519,7121
POE	C10	m^3/yr	11 062,5889	4 991,61982	110 230,606
Dech	C11	kg /yr	17 546,0203	15 794,0203	32 893,3211

Table 6: Environmental impacts of the buildings in our sample obtained by multicriteria analysis expressed in indicator units per unit area per year.

Impact Indicators		Units	Sample variants		
			B1 (Residential)	B2 (Office) in Z2	B3 (Hospital) in Z3
PE	C1	MJ/m²/yr	2791,45713	3 331,93307	681,115715
EAU	C2	L-eq /m²/yr	4 403,65132	1 982,5458	4 829,6027
ADP	C3	kg eq-	0,00038611	0,00038611	0,00039805
ADP Elts	C4	kg eq-	2,259E-09	2,259E-09	2,0996E-09
TMR	C5	kg /m²/yr	29,1360032	29.1360032	26,6579005
ACI	C6	kg eq-	0,79697309	0,79697309	0,60752384
GWP100	C7	kg eq-	31 129,5204	37 134,2082	7 948,93523
POCP	C8	kg eq-	0,39989912	0,39989912	0,24512239
PA	C9	m³/m²/yr	46,592787	46,592787	28,6885833
POE	C10	m³/m²/yr	27,7954495	12,5417583	162,008533
Dech	C11	kg /m²/yr	44,0854781	39,6834681	48,3440934

3.1.2. Comparison of Indicators Distributed by Life Cycle Phase

The evaluation of environmental impacts generated by the sampled buildings in this study enabled a life cycle analysis. The comparative study of environmental impacts stems from this work. Figures 5 and 6 illustrate the project variant across the phases of production, construction, use, and demolition.

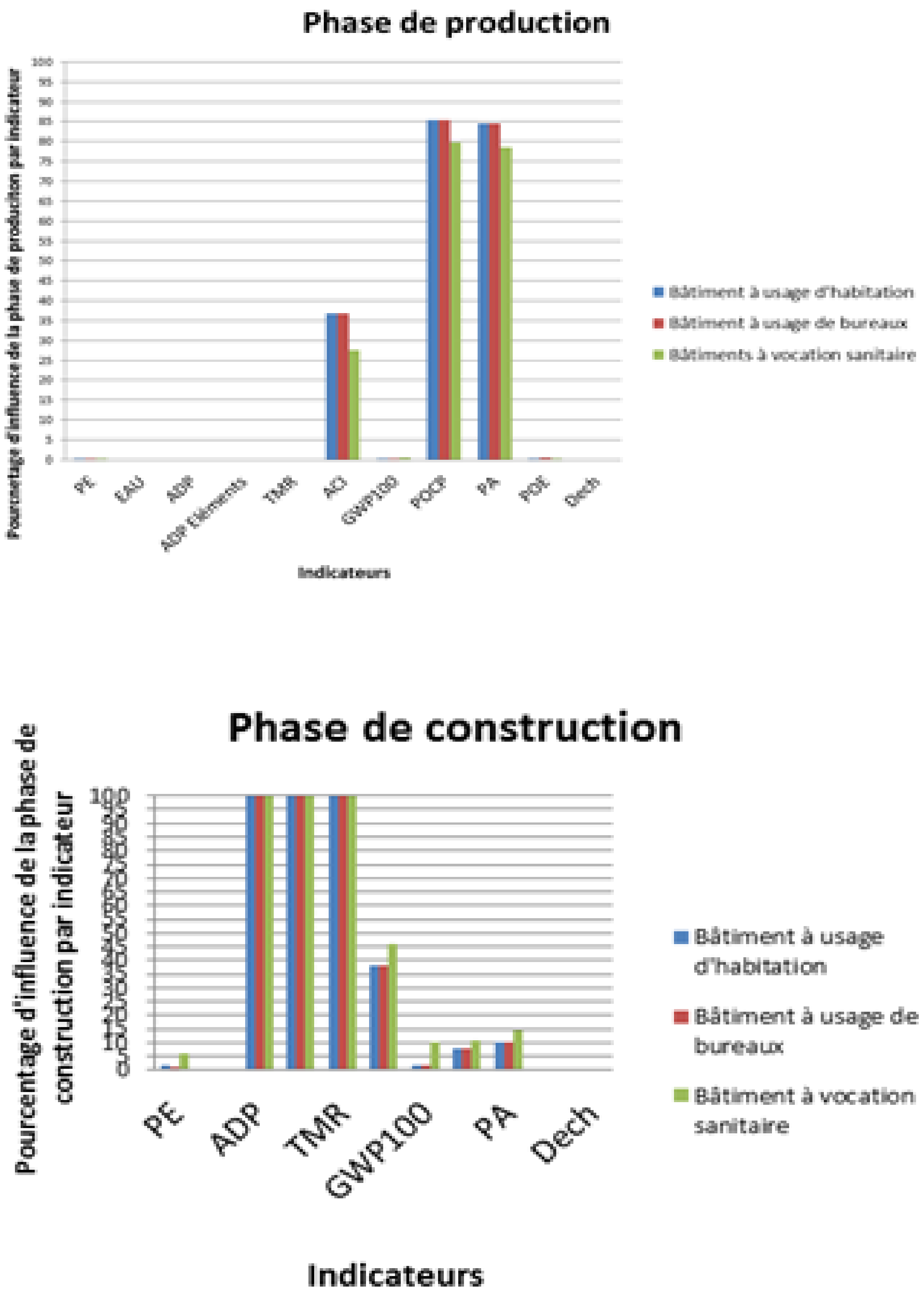
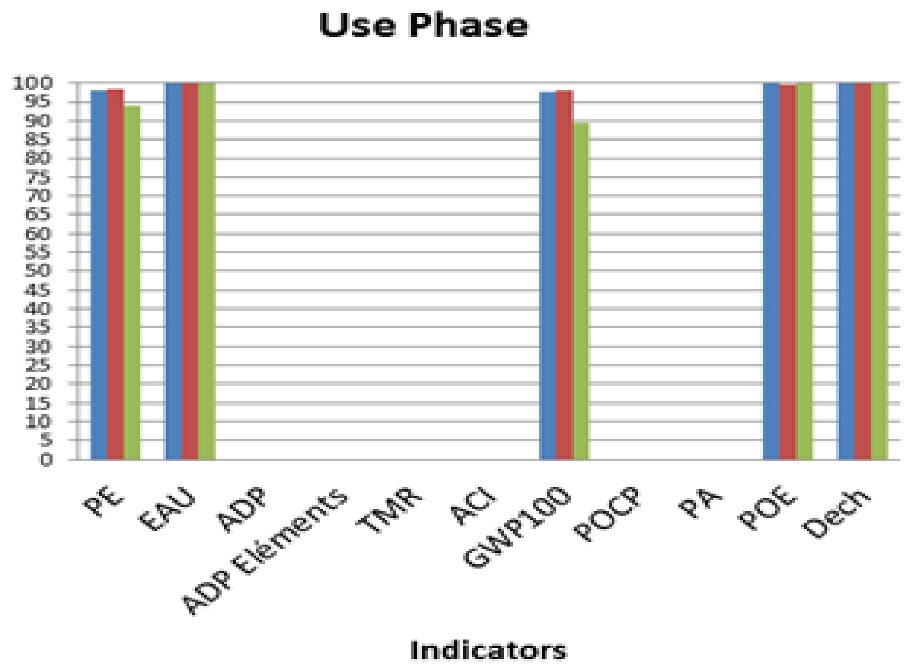


Figure 5: Indicator Categories by Project Variant During Production and Construction Phases



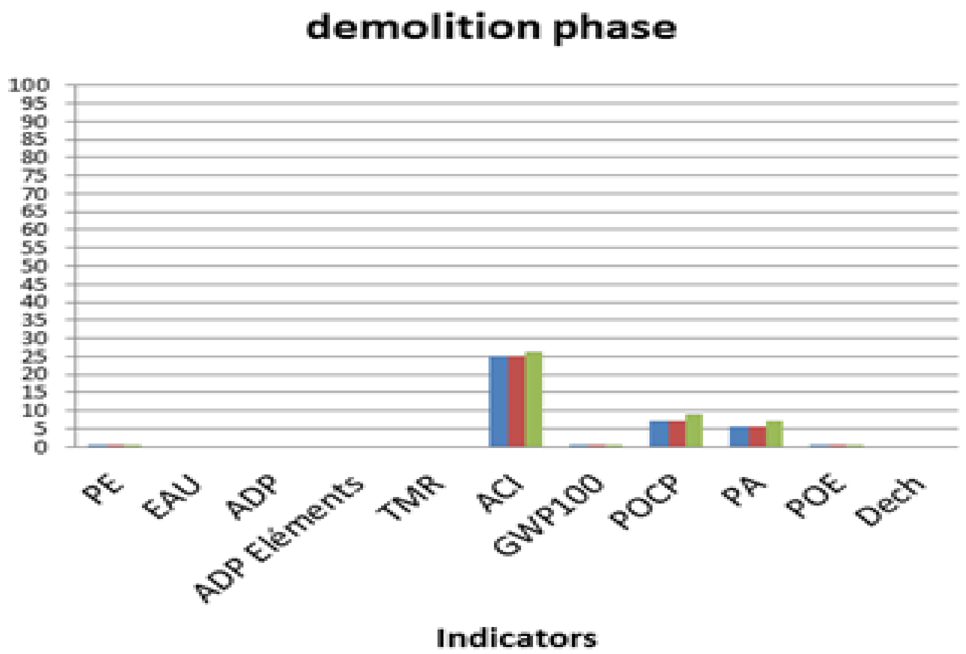


Figure 6: Indicator Categories by Project Variant During Usage and Demolition Phases

4. Discussions and Recommendations

4.1. Discussion

Tables 5 and 6 show that the most commonly observed environmental impact indicators are: primary energy, water consumption, fossil global warming potential over 100 years, air pollution, waste production, and water pollution. This energy is not always directly usable and often undergoes transformations that are, in most cases, sources of numerous environmental impacts such as photochemical ozone layer destruction, acid rain, soil and water pollution, and greenhouse gas emissions leading to climate change. Like processes with the highest material energy content, other products such as concrete blocks and concrete itself also contain significant proportions of material energy. The results broken down by life cycle phase for buildings Bi are presented in Figures 5 and 6. Figure 5 clearly shows that the production phase is responsible for most of the atmospheric acidification (27–37%), air pollution, and photochemical ozone formation. The construction phase (Figure 6) is characterized by a predominance of the depletion of energy and non-energy resources. This result is not surprising. In this phase of the buildings' life cycle within our sample, five environmental impact indicators are particularly concerning. These indicators relate to primary energy consumption, water use, climate warming, water pollution, and waste emissions. All these indicators are indeed linked to building use, potential renovation, and maintenance operations. In terms of climate warming, building B2 contributes more to environmental damage than building B1. However, overall, all the buildings in our sample significantly contribute to global warming through the greenhouse effect. In the same phase, studies show lower proportions when materials are varied, including biomass or earth combined with reinforced concrete-aggregate construction systems. The demolition phase has less environmental impact compared to the previous phases. Overall, compared to other phases, our studies show demolition accounts for barely one percent of the environmental impacts compared to construction (13%) and use phases. To reduce this percentage even further (to less than 1%), we recommend using design techniques that favor deconstruction rather than demolition, as deconstruction is less polluting due to the reuse of materials recovered at end-of-life. Examples include construction blocks that do not use binders and manual demolition, which can also provide employment in our context. Research on demolition methods is a promising avenue, especially to better manage demolition waste. The energy component suggests demolition energy expenditure is low for the three samples (B1, B2, B3). However, acidification risk ranges from about 25 to 27%, with sample B3 showing the highest. Air pollution and photochemical ozone formation are about 7–9% and 5–7%, respectively. Among all phases, demolition consumes little energy resources, indicating a need for upstream guidelines in building design to minimize energy use in this phase.

4.2. Recommendations and Perspectives

The multi-criteria modeling for sustainable construction decisions of buildings B1, B2, and B3, which made up our sample in the previous section, clearly showed that the construction sector is a major consumer of natural resources but also generates numerous environmental impacts. The evaluation of these environmental impacts was made possible through innovative approaches based on new resources such as renewable energy or waste valorization, requiring performance assessment tools to ensure that the replacement of conventional products or technologies leads to a reduction in environmental pressure.

Among these various innovative methods, multi-criteria modeling for sustainable construction decisions—defined as the compilation and evaluation of inputs, outputs, and potential environmental impacts of a product system throughout its life cycle (ISO, 2006a; ISO, 2006b)—remains the most widely used method.

5. Conclusion

In conclusion of this pilot study, it seems appropriate to recall what has been widely emphasized. The research approach adopted consisted of developing an analytical and systemic multi-criteria model for sustainable construction decisions based on data from three categories of buildings sampled in three cities in Cameroon according to their climates. Using multi-criteria modeling for sustainable construction decisions and the Equer software, the exact quantities of environmental impact indicators were obtained. The results showed that each phase of a building's life, depending on the activities carried out, generates environmental impacts, the most significant being primary energy and water consumption, climate change, air and water pollution, and waste production. Across the different phases (production, construction, use, demolition) of the building's life, the greenhouse effect is observable. For the same phase, studies have shown lower environmental destruction when materials are varied, including biomass or earth combined with reinforced concrete-aggregate construction systems or structural and energy renovation measures. Similarly, compared to other phases of the building life cycle, the demolition phase has little environmental impact. This offers new opportunities for decision-making by local authorities, who currently lack the means within communities to consider the environmental impacts of buildings—one of the sectors with high energy consumption and greenhouse gas emissions. This contributes to the goals of combating climate change. Today, it is important to note that a building or its built environment is a living element interacting with its surroundings. This work addresses issues of environmental quality and building sustainability. We established a model of the sustainable building challenge by associating it with a model for understanding its life cycle. For the cases studied, we envision improvements through the renovation of built systems and the integration of photovoltaic systems for energy production in one of the studied buildings—specifically residential housing, where energy demand is high and which is potentially an effective sector for energy production amid the shortages present in our context.

[3]https://www.minhdu.gov.cm/programmes/logements-sociaux-2/ consulted on 17/04/2024 at 9:53 pm.
[4]The decree n°2008/0737/PM of 23/04/2008, fixing rules of security, hygene and sanitation in the construction sector available on www.minhdu.gov.cm consulted on 05/04/24 at 9:53 pm.

References

[1] L. Ayagapin, Jean Phillipe Praene et al., 2021. Prospective life cycle assessment.

[2] Ayres, R.-U., Ayres, L.W., 2002. Handbook of Industrial Ecology. Cheltenham, UK: Edward Elgar Publishing Limited, 680p.

[3] Bartuska, T., & McClure, W., 2007. The Built Environment: A Collaborative Inquiry into Design and Planning (2nd ed.). Hoboken, New Jersey, U.S.A.

[4] Berardi, 2013. Sustainability assessment of urban communities through rating systems.

[5] Béguin, M., 2013. The history of garbage: from prehistory to the end of the nineteenth century. Vestigo 13 (3). DOI: 104000/vestigo.14419.

[6] Bruxelles-Environnement-LRE., 2009. Air quality in the Brussels-Capital Region: immission measurement 2006-2008, 4.7 Sulfur dioxide, Technical report, 10pp. Consulted March 10, 2022. URL: http://documentation.bruxellesenvironnement.be/documents/Qair_Rpt0608_Resume_fr.pdf?

[7] Brand, 2007, Ralf and Andrew Karvonen. The ecosystem of expertise: complementary knowledges for sustainable development.

[8] Bulle, C., Margni, M., Patouillard, L., Boulay, A.-M., Bourgault, G., De Bruille, V., Cao, V., Hauschild, M., Henderson, A., Humbert, S., Kashef-Haghighi, S., Kounina, A., Laurent, A., Levasseur, A., Liard, G., Rosenbaum, R. K., Roy, P.-O., Shaked, S., Fantke, P. and Jolliet, O., 2019. IMPACT World+: a globally regionalized life cycle impact assessment method. International Journal of Life Cycle Assessment 24, 1653–1674 (2019). https://doi.org/10.1007/s11367-019-01583-0.

[9] Carpenter, A.C., Gardner, K.H., Fopiano, J., Benson, C.H., Edil, T.B., 2007. Life cycle based risk assessment of recycled materials in roadway construction. Waste Management 27(10): 1458-1464.

[10] Cassady, Robert, 2003. White paper on sustainability

[11] Cohen, B., 2006. Urbanization in developing countries: current trends, future projections, and key challenges for sustainability. Technology in Society 28: 63-80.

[12] Davie, T., 2008. Fundamentals of Hydrology. Routledge Fundamentals of Physical Geography. London, UK: Taylor & Francis Library.

[13] De-Souza, R., Mutunga, C., Zulu, E., 2012. Population dynamics, climate change, and sustainable development in Africa. Washington, DC, USA: Population Action International.

[14] Dobrzynski, M., Calkosinski, I., Przywitowska, I., Kobierska-Brzoza, J., Czajczynska-Waszkiewicz, A., Soltan, E., Parulska, O., 2009. Effects of dioxins in environmental pollution on development of tooth disorders. Polish Journal of Environmental Studies 18(3): 319-323.

[15] Dsonwa Manfo Ervé Destin, Chrispin Pettang, Clautaire Mwebi Ekengoue, 2021. Management of Residential Building Construction in Cameroon: History, Current State, and Perspectives on Reappropriating Sustainable (Ancestral) Construction Techniques. International Journal of Innovation and Applied Studies ISSN 2028-9324 Vol. 32 No. 1 Feb. 2021, pp. 93-101.

[16] Djeudjo Temene H., 2023. Modeling and optimization of a hybrid hydro/PV/wind/diesel/storage power plant to solve the energy deficit in tropical zones and Cameroon. PhD thesis in Physics, University of Yaoundé I.

[17] Diesse Youmbi A., 2021. Modeling of energy consumption in constructions. PhD thesis in Civil Engineering. National Advanced School of Engineering of Yaoundé. University of Yaoundé I.

[18] Elime, B., 2012. Development of a life cycle analysis indicator: application to energy consumption. PhD thesis, National Advanced School of Engineering of Yaoundé. University of Yaoundé I.

[19] Endrit Hoxha, 2015. Improvement of the reliability of environmental assessments of buildings.

[20] Ebenstein, A., 2010. The consequences of industrialization: Evidence from water pollution and digestive cancers in China.

[21] Eco-city Builders, 2010. Ecocity Definition. Vancouver, Canada. Retrieved from www.ecocitybuilders.org

[22] Fantke, P., Buster, M., Hauschild, M. Z., Huijbregts, M., Jolliet, O., Kounina, A., Magaud, V., Margni, M., McKone, T. E., Rosenbaum, R. K., Van De Meent, D., and Van Zelm, R., 2017. USEtox® 2.0 Documentation (Version 1.00).

[23] Feraille Fresnet, 2016. From Material to Structure: Some Methodological Contributions Related to Life Cycle Analysis. HDR.

[24] Frischknecht, R., Jungbluth, N., Althaus, H.-J., Doka, G., Heck, T., Hellweg, S., Hischier, R., Nemecek, T., Rebitzer, G., Spielmann, M., 2004. Overview and Methodology, ecoinvent report No.1, Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland.

[25] Grimmer, A., Hensley, J., Petrella, L., & Tepper, A., 2011. The Secretary of the Interior's Standards for Rehabilitation and Illustrated Guidelines on Sustainability for Rehabilitating Historic Buildings. U.S. Department of the Interior, National Park Service, Technical Preservation Services, Washington D.C.

[26] Hueting, Roefie and Lucas Reijnders, 2004. Broad Sustainability versus Sustainability: The Proper Construction of Sustainability Indicators.

[27] Horvath, A., 2004. Construction Materials and the Environment. Annual Review of Environment and Resources 29: 181-204.

[28] Howard, J., 2012. Eco-Cities—Who, What, Where and Why? Lee Kuan Yew World City Prize. Retrieved from www.leekuanyewworldcityprize.com

[29] Kohler, N., & Moffatt, S., 2003. Life Cycle Analysis of the Built Environment. UNEP, Industry and Environment.

[30] Huijbregts, M. A. J., Steinmann, Z. J. N., Elshout, P. M. F., Stam, G., Verones, F., Vieira, M., Zup, M., Hollander, A., and Van Zelm, R., 2017. ReCiPe2016: A Harmonised Life Cycle Impact Assessment Method at Midpoint and Endpoint Level. International Journal of Life Cycle Assessment 22, 138–147 (2017). https://doi.org/10.1007/s11367-016-1246-y

[31] Kaoula, D., Bouchair, A., 2020. Identification of the best material-energy-climate compatibility for five ecological houses and the contribution of their impact sources to the overall balance. Sustainable Cities and Society, 52, 101781.

[32] ISO, 2006a. ISO 14040—Environmental Management—Life Cycle Assessment—Principles and Framework. Geneva: International Organization for Standardization (ISO), 20p.

[33] ISO, 2006b. ISO 14044—Environmental Management—Life Cycle Assessment—Requirements and Guidelines. Geneva: International Organization for Standardization (ISO), 46p.

[34] Jatta, I., 2018. Life Cycle Analysis of Compressed Earth Block. Final year project report for the civil engineering degree at the National Polytechnic School of Yaoundé, University of Yaoundé I.

[35] Kibert, Charles J., Sustainable Construction: Green Building Design and Delivery.

[36] Lasvaux, S., 2010. Study of a Simplified Model for Life Cycle Analysis of Buildings. Process Engineering, National School of Mines of Paris, HAL Archives, Id: Pastel-00712043, 435p.

[37] Lasvaux, S., Peuportier, B., Chevalier, J., 2010. Toward the Development of a Simplified LCA-Based Model for Buildings: Recycling Aspects. Proceedings of CISBAT 2009: From Nanoscale to Urban Scale, 12p.

[38] Lasvaux, S., 2012. Study of a Simplified Model for Life Cycle Analysis of Buildings.

[39] Léonard, A., Belboom, S., Gerbinet, S., Groslambert, S., Merchan, A., 2019. Life Cycle Analysis: A Multi-Criteria and Quantitative Tool for Environmental Impact Assessment. Bulletin of the Royal Society of Sciences of Liège 88, Conference Proceedings on Climate Change: 73-81. DOI: 10.25518/0037-9565.9220 [Online], Accessed March 22, 2022. URL: https://popus.uliege.be/0037-9565/index.php?id=9220

[40] Peuportier, B., Schalbart, P., 2022. Life Cycle Analysis Applied to Eco-Design of Buildings and Neighborhoods. JACV 40(2): 1-10.

[41] Polster, B., Contribution to the Study of the Environmental Impact of Buildings by Life Cycle Analysis, Doctoral Thesis, School of Mines of Paris, 1995.

[42] Rossi, M., André, J., & Vallauri, D., 2015. Forest Carbon in Motion. Reflections for a Policy Maximizing the Benefits of Wood. Lyon, REFORA Report, 40p.

[43] Stancheva, E., 2008. Urban Sustainability: Eco-cities. Retrieved from www.econhist.userweb.mwn

[44] Teng, Y., Yang, J., Zuo, R., Wang, J., 2010. Impact of Urbanization and Industrialization on Surface Water Quality: A Pilot Study of Panzhihua Mining Town. Journal of Earth Science 22(5): 658-668.

[45] Valance, S., Harvey C. Perkins, and Jebbifer E. Dixon, 2011. What is Social Sustainability? A Clarification of Concepts.

[46] Villot, J., Gondran, N., Laforest, V., 2011. Construction Labels: What Possible Contribution to Factor 4? Sustainable Development and Territories 1(2): 1-30. DOI:

10.4000/developpementdurable.8834. UN Statistics Division. Workshop on Environmental Statistics, Yaoundé, Cameroon, 47p.

[47] Madjou, T. L. A., 2022. Adaptability in Central Africa of Photovoltaic Solar Panels Designed for Other Climatic Conditions: Case of Cameroon. Doctoral Thesis in Electrical Engineering. ENSPY.

[48] McDonough, William, and Michael Braungart, 2002. Remaking the Way We Make Things: Cradle to Cradle.

[49] Ngouadjio, A. C., 2013. Life Cycle Analysis of Social Housing in Urban and Rural Areas. Final Year Project Report for Civil Engineering Degree. National Advanced School of Engineering of Yaoundé, University of Yaoundé I.

[50] Okpwe, M., 2021. Implementation of Generic Objects for the Optimal Use of BIM Platforms in Cameroon. PhD thesis, National Advanced School of Engineering of Yaoundé, University of Yaoundé I.

[51] PNH., 2021. National Housing Policy. 168 pages.

[52] Nimpa Desting, 2019. Environmental Profile of Wooden Poles. Doctoral thesis, National Advanced Polytechnic School of Yaoundé, University of Yaoundé I.

[53] Nsangou J.C., 2021. Energy Efficiency in the Residential Electrical Sector in Cameroon. Contribution to Improving Supply and Demand. Doctoral thesis in civil engineering, National Advanced School of Engineering of Yaoundé, University of Yaoundé I.

[54] Souffo Merimé, 2021. Modeling of Energy Efficiency in High-Rise Buildings. Doctoral thesis in electrical engineering, National Advanced School of Engineering of Yaoundé, University of Yaoundé I.

[55] Megange Patrice, 2022. Evaluation of Environmental Impacts by a Spatially Dynamic LCA.

[56] www.minhdu.gov.cm accessed on 04/05/2024 at 9:53 PM.

[57] https://www.minhdu.gov.cm/programmes/logements-sociaux-2/ accessed on 04/17/2024.

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