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Sustainable Architecture in Developing Countries: Harvest Map of the Lusaka Territory, Zambia

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Abstract: In Zambia, Western materials, techniques, and technologies, a symbol of emancipation, are replacing the local building culture, which is relegated to the poor sections of society, with a negative impact from an environmental, social, and economic point of view. Designing and building sustainable architecture in developing countries is a particularly complex task mainly because of the absence of scientifically codified information about vernacular architecture and available resources. The starting point for designing and building sustainable architecture is to know the territory and its resources. The research outlines the harvest map of sustainable resources in Lusaka's geographic surroundings, created through site surveys and analysis of international databases. The method for creating a harvest map follows well-defined steps involving knowledge of climate, intangible resources, and material resources as described below. Knowledge of the climate is intended to enable a critical reading of the area's resources; it is functional to understand the logic of traditional architecture and consequently to identify fields of innovation in it. Intangible resources are related to the building culture and techniques and technologies of vernacular architecture of the territory; material resources, on the other hand, are related to traditionally used materials, raw materials not yet exploited, but potentially usable and waste materials. The vernacular architecture of the Lusaka territory is based on low-tech systems and natural materials (mainly raw earth, plant fibers, wood, and bamboo). There are also tree species in the territory that, for their quantity and performance, could be used in the construction field, as well as waste materials from common use or from the agricultural supply chain. Starting from this harvest map, every designer has the knowledge of the area from which to use already known building systems related to the resources of the area or innovate them while respecting local culture and resources.

Keywords: harvest map; tangible and intangible resources; reuse; sustainable architecture; vernacular architecture

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1. Introduction

The history of colonialism in Africa is related to the search for new markets and the exploitation of its mainly mineral resources. Nowadays, Africa is in a moment of strong change in which colonization no longer has a formal connotation, in which there is the imposition of European culture on the colonized by the colonists [1,2], but moves in a latent form in the economy of the continent. A formal independence that hides an economic dependence. Foreign states enter African markets, not only by taking and exporting local resources, as has historically happened, but also by materially occupying the land, especially in areas with a greater tourist vocation [3–5]. The lifestyle of developed countries is a *status symbol* to be achieved, that is implemented by importing Western cultural models at the expense of local culture. The construction sector, as the driving sector of the economy, is also involved in this radical change. On the African continent, as well as in Zambia which is the subject of this research, Western materials, techniques, and technologies, a symbol of emancipation, are replacing the local building culture, which has been relegated to the poor sections of society. In addition, a secondary motivation for Africans to use Western materials is the durability of the materials (concrete and steel), which allows them to avoid frequent maintenance. This is unsustainable: from an environmental point of view, it results in the import of Western materials such as concrete and steel, resulting in pollution both related to transportation and to the materials themselves, whose production and disposal process has a high environmental impact and which are linked to construction systems that irreversibly alter the environment; from a social point of view, because it leads to the gradual loss of the local construction culture, among other things not scientifically codified but handed down orally among craftsmen in the sector or, in rural villages, by the oldest members of the tribes; from an economic point of view in that it produces the development of foreign markets and operators and not of local companies, which are unable to handle Western construction processes. With the aim of avoiding the loss of Zambian culture, research aimed at the mostly typological classification of traditional Zambian architecture has been carried out [6–8]. Such research, together with the mapping of intangible local resources (building types, techniques, and technologies) and material resources (traditional, current, and waste materials), the subject of this research, should contribute to providing a knowledge base for the design and implementation of sustainable architecture, that is, capable of being a driver of sustainable development of the area from an environmental, social, and economic point of view. In fact, knowledge and enhancement of local culture and resources makes it possible to identify its weaknesses and strengths, on which to act to produce innovation that starts from the territory and returns to the territory in a cyclical process that becomes a guarantor of the sustainability of the process. Zambian vernacular architecture is linked to low-tech systems and natural materials. The limitations of these building systems, however, can be overcome through technical, technological, and material expedients that can enhance the local building culture without distorting it, and, at the same time, produce both a specialization of local practitioners in the sector and the development of local economies linked to the realization of materials/components using local resources. This process contributes to the achievement of all the goals set forth in Agenda 2030 [9], as it produces a cultural advancement of society that bases its future on tradition, incentivizes the circular economy by founding it on local intangible and material resources, and reduces the environmental impact of the construction sector.

2. Research Objective: Case Study in the Lusaka Territory

The objective of the research is to create a harvest map of available resources (tangible and intangible) that can be used for sustainable architecture in the geographical surroundings of Lusaka (Figure 1), the capital of Zambia, located in the southcentral part of the country and situated 1186 m above sea level. Starting from this harvest map, each designer has the knowledge of the area from which to use the already known building systems related to the resources of the area or innovate them while respecting local culture and resources. For the creation of the harvest map, a maximum supply radius of 200 kilometers is proposed, considering the difficulty in sourcing resources due to poor infrastructure in the Zambian state, although Lusaka is the main hub of the present road infrastructure [10]. The research outlines the harvest map of intangible and tangible resources in Lusaka's geographic surroundings. Intangible resources are related to the building culture and techniques and technologies of vernacular architecture or more generally to the Zambian tradition; material resources, on the other hand, are related to traditionally used materials, untapped but potentially usable raw materials, and waste materials.

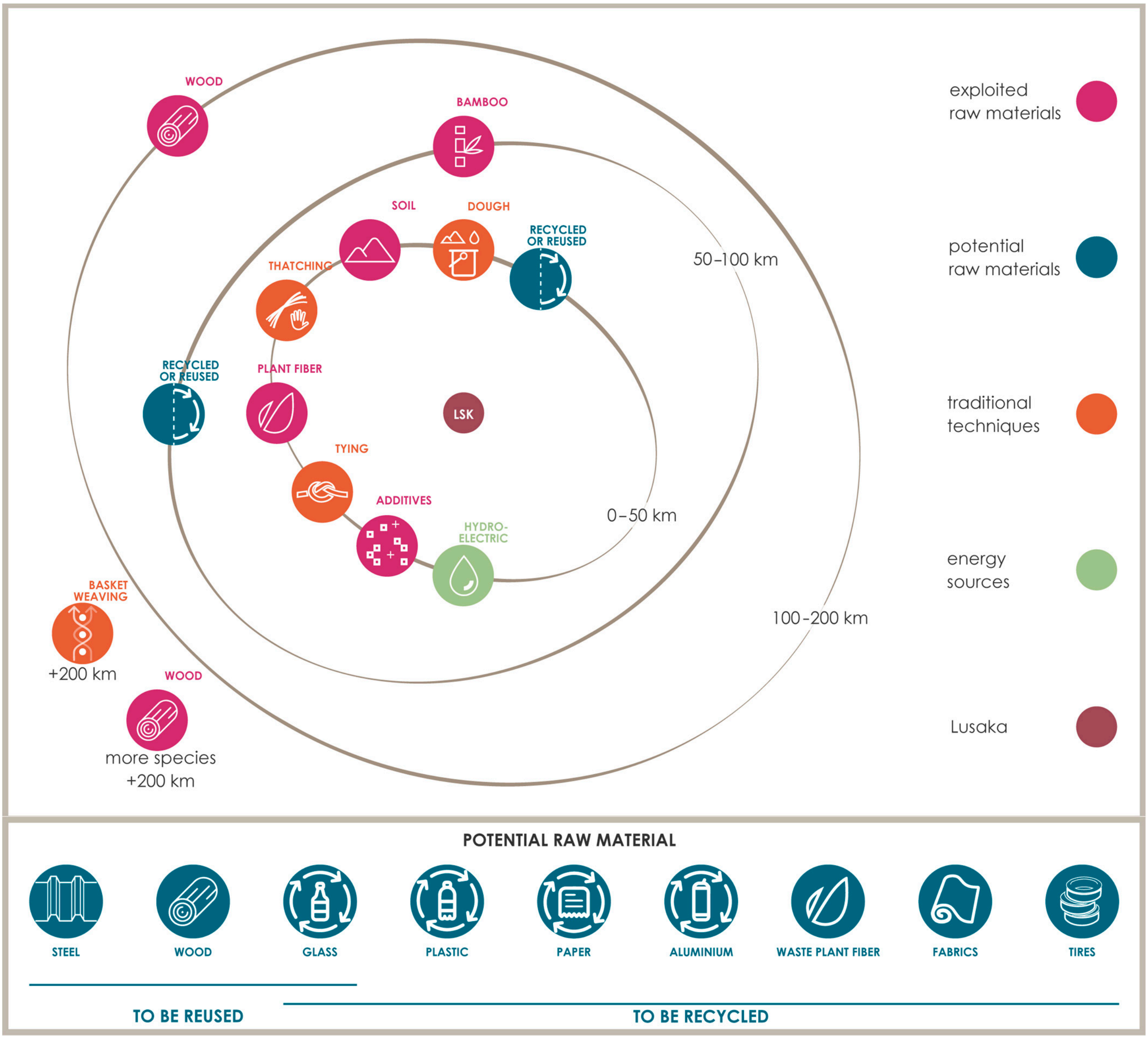

Figure 1. Schematic harvest map of the Lusaka territory, Zambia.

3. Methods

Designing and building sustainable architecture in developing countries is a particularly complex task, mainly due to the absence of scientifically codified information regarding vernacular architecture (techniques, technologies, and materials) and available resources. As a result, research focused on ways to innovate traditional building systems is rare, pushing architecture deemed to be of quality toward Western models. The starting point for the design and implementation of sustainable architecture is therefore to know the land and its resources.

Internationally, there are databases aimed at mapping and geolocalizing the waste materials present in a given territory, the reuse of which transforms them into 0 km materials, with benefits for environmental, social, and economic sustainability. These are online platforms in which companies operating in a given territory voluntarily enter the waste they have available, indicating its type, quantity, and location [11–16]. These are harvest maps of materials, but they only partially define the resources in the territory. In fact, the mapping of a territory should consider not only waste materials, but also the materials traditionally present in the territory, based on whose characteristics, before globalization and the possibility of easy exchange of goods and people, traditional building systems were designed. The latter, moreover, represent an intangible heritage to be preserved and innovated as they are strongly linked to the territory in terms of technique, technology, and materials. Vernacular architecture also strikes a balance with the local climate through typological, distributive, and constructive solutions designed to ensure sufficient comfort for humans to live, without the use of thermal systems. By analyzing and identifying the relationship between climate, building systems, and local materials, it is possible to understand the dynamics of the area and direct the building industry toward innovating the values of the place that defines its identity. For this reason, the method for realizing a harvest map follows well-defined steps involving knowledge of climate, intangible resources, and material resources as described below (Figure 2).

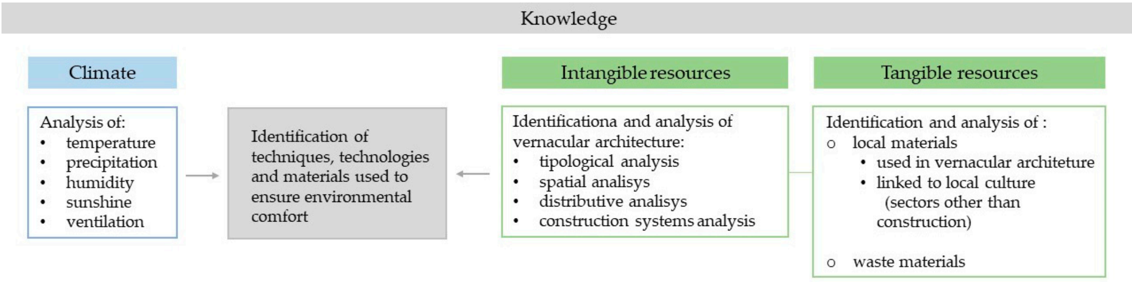

Figure 2. Scheme of the steps of the method for the creation of the harvest map.

3.1. Climate Knowledge

The purpose of climate knowledge is to enable a critical reading of land resources; it is functional to understand the logic of traditional architecture and consequently to identify fields of innovation of the same. Climate knowledge can be achieved through a direct survey campaign with the placement of weather stations. However, such a survey campaign requires the processing of data for a minimum period of one year in order to be reliable. In the absence of such a possibility, which is often difficult to achieve in developing countries, it is necessary to use databases reporting information on temperature, precipitation, humidity, sunshine, and ventilation in order to identify what requirements and performance the building envelope must have in order to ensure thermal comfort. Considering that the temperature from 1880 to 2023 has increased by 1.1 °C [17] with a consequent influence on relative humidity and ventilation as well, the climate analysis using databases must involve a period of at least 10 years to have as reliable a simulation as possible. The data must be analyzed and schematized to identify, by means of histograms, the critical periods due to the combination of unfavorable conditions inherent in temperature, relative humidity, and ventilation.

In addition, knowledge of climate makes it possible to understand the ways in which vernacular architecture has evolved, how it has evolved with respect to the need for climate protection, to ascertain what the limitations and strengths of traditional architecture are, to verify whether the latter is able to respond to today's varying environmental comfort needs even with respect to the climatic extremes dictated by environmental changes, and to understand what construction expedients can be used in order to overcome the performance limitations of the building system.

3.2. Knowledge of Intangible Resources

Intangible resources consist also of the traditional local building culture, which is based on the availability of local raw materials [18–20]. Typological analysis and analysis of the spatial geometries of vernacular architecture allows us to learn about the customs and traditions of the local population (think, for example, of the proportions between the living and sleeping areas of a house). The analysis of building systems, on the other hand, allows us to understand what the local material resources are and what the strengths and performance limitations of these materials/components are. Just think of the conditioning of structural spans with respect to the stem height of local trees. In addition, correlations between climate and the technical and technological arrangements of the building system must be identified. Think, for example, of the roof overhang to protect walls exposed to wind-driven rainfall, or roof slopes functional for water disposal. Traditional architecture is, therefore, a compass capable of both indicating what resources are available and how they can be used, and defining the construction priorities to be considered according to climatic aspects [21]. Knowing the building systems also makes it possible to identify their limitations with respect to available materials, and to define maintenance methods with respect to climatic conditions.

3.3. Knowledge of Material Resources

The stage of knowledge of material resources is based on the qualitative and quantitative identification of resources historically present in the territory that have already been used, resources available in the territory that have not yet been exploited, resources related to the current economic-political situation, and local waste [22].

The identification of resources historically present in the territory for which a use is already culturally rooted is performed by analyzing vernacular architecture. The latter allows us to identify the existing correlations between materials used, prevalent mode of use (load-bearing structure, floors, walls), and the performance they achieve in traditional use, while also defining constructive and performance limitations and strengths of these materials. These are materials that local workers are able to handle and control [23]. It is also necessary to verify that, at the time of harvest map implementation, such resources are still available in sufficient quantities to ensure their effective use. Consider, for example, a reduction in the availability of a particular tree species that has changed its characteristics in response to climate change.

The identification of resources available in the territory, but not yet exploited, is performed mainly through the analysis of sectors other than construction, to identify whether there are materials that by quantity and characteristics can also be used for construction-related purposes. These are resources that, although present, have been used in other sectors because there was inadequate understanding in the area to allow their use in construction. Consider, for example, hemp traditionally used in food or textiles, but which can also be used to make building components based on current scientific knowledge.

Analysis of the developing industrial sector gives us an indication of the main materials in the area. The identification of waste resources is achieved through the analysis of the primary sectors (such as agriculture and livestock) and the local industrial system and land management policy choices. Indeed, the primary sectors and the industrial system inherently produce large amounts of waste that can instead be used in new life cycles. In developing countries where the industrial system is not yet defined, primary sector waste is generally easier to come by and quantitatively significant. Political land management choices influence the type of waste materials, quantity, and economic value. Suffice it to say that most of the African population does not have access to any kind of waste collection, resulting in the burning or landfilling of waste materials [24]. This generates the free availability of waste materials that, being in everyday use, are easy to obtain (such as plastic or glass bottles). Traditional materials, being linked to an artisanal production system, are, by type of processes, easily remissible in nature at the end of their life cycle. Conversely, materials related to industrial production processes are difficult to dispose of, especially in view of the fact that the industrial system itself is developing and therefore often not capable of managing the process throughout its life cycle.

4. Result and Discussion

4.1. The Climate of Lusaka

Lusaka is located at 1186 m above sea level and is characterized by a climate that can be classified as humid subtropical, which features a wet season characterized by abundant thunderstorms (761 mm of water per year) and high temperatures alternate in December, January and February (average minimum temperature for the season 16.2 °C and season average maximum temperature 28.8 °C), and a rainfall-free dry season with lower temperatures resulting in cold nights in May, June and July (season average minimum temperature 10.5 °C and season average maximum temperature 29.5 °C).

The analysis of climatic features was carried out by processing data in international databases [25,26], and therefore covers a time span (2007–2016) conditioned by the information actually available. Air temperature and relative air humidity trends were analyzed considering the annual plot. In view of the presence in the survey area of a humid subtropical climate, a parallel analysis was carried out between the temperature and the corresponding relative humidity in the coldest months (May, June, and July) in order to identify critical situations in which low temperature and high humidity could generate condensation problems to be identified as critical issues to be solved in the design phase of a building body. Given that there are several periods when maximum humidity levels were reached, particularly during the night between May and July, in addition to the annual parameters, a biweekly assessment chosen around the wettest day of each month was carried out and the relationship between humidity and air temperature as a function of time of day was analyzed (Figure 3).

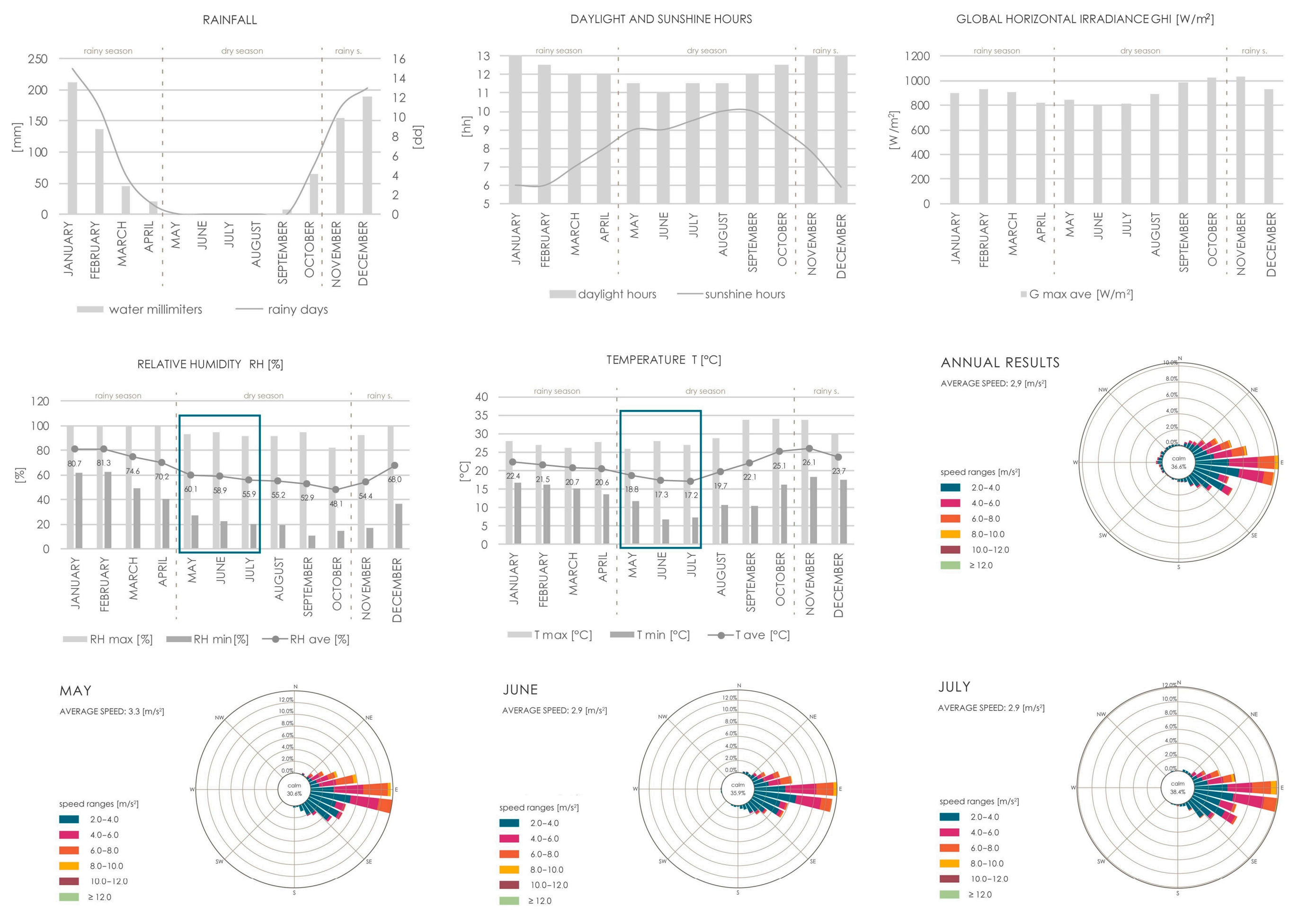

Figure 3. Diagrams inherent the analysis of climatic features: rainfall, daylight and sunshine hours, global horizontal irradiance (W/m^2), relative humidity (%), temperature (°C), prevailing wind directions (annual, May, June, and July).

The trend of prevailing winds was calculated with data for a four-year time span from 2013 to 2016 [27]. The analysis was performed on an annual basis, and insights were made for the months of May, June, and July. A more accurate analysis in the cold months was aimed at verifying the contribution of ventilation to the mitigation of condensation problems on external components of the building. This information is especially useful for the purpose of choosing from local resources materials for structural use or for the purpose of planning building maintenance (Figure 3).

Beaufort scale [28] was used, which showed:

- annual wind with easterly direction and a percentage between 8% and 10% (fresh-moderate breeze);
- wind in May with direction from the east and a percentage between 8% and 14% (fresh-moderate breeze);
- wind in June with direction from the east and a percentage between 10% and 14% (moderate-strong breeze);
- wind in July with direction from the east and a percentage between 8% and 12% (moderate-strong breeze).

It was observed that, in the wet season, the high temperature compensates for the moisture due to heavy rainfall, while, on the other hand, in the dry season, characterized by low temperatures, it is the wind that performs a moisture-mitigating function, limiting problems related to condensation on the constituent parts of the building exposed to the outside.

4.2. Zambian Vernacular Architecture

The knowledge phase of Zambian vernacular architecture was initially conducted through the study of the bibliography [6–8]. However, these research refer to Zambia in general, and there is no bibliography specifically referring to the geographical surroundings of Lusaka. Therefore, it was necessary to carry out site visits to rural villages in the Lusaka territorial context in order to identify the characteristics of vernacular architecture in that specific local surroundings, and to check for consistency, if any, with the patterns already described in the existing bibliography. The surveys covered ten rural villages, a representative number. In Zambia, much of the settled population lives gathered in villages scattered throughout the rural areas. The villages occupy large areas, and are fragmented into smaller agglomerations that have a more or less orderly and articulated development. Villages have similar typological and construction characteristics; differences are due to socio-cultural factors, climatic and geographical conditions, and the availability of materials that the local intonation offers (Figure 4).

Figure 4. Aerial view of 3 rural villages from Google Earth (**above**) and photo taken in a rural village located near Lusaka (**below**).

In the rural villages bordering Lusaka, the contamination of traditional architecture building systems with Western building systems (concrete and steel plates) is, moreover, evident, which is over time transforming traditional villages into high-density slum-like aggregates. The village is configured as a set of buildings in which each element performs a specific and well-defined function: there are the dwellings of community members, the estates of the wealthiest families (homesteads), and a series of accessory elements such as: the *insaka*, the granary, the latrines, the stable or the dovecote [7]. The *insaka* is a covered space with a circular plan development, dedicated to the meeting of the population, who live in a highly developed social dimension and spend a good part of the daytime hours outdoors, a fact that is also due to the climatic conditions and the simplicity of construction of the enclosed spaces that fails to provide large and environmentally comfortable spaces.

Buildings are made through the application of simple construction principles developed and established in tradition, and more complex realizations consist of variations of the basic elementary structures. From a typological, constructive, and performance point of view, the living space is the most complex and is the most widespread. Therefore, in order to identify the intangible resources of Zambian culture, the houses found in the rural villages were analyzed [7]. From this, six main typological-constructive patterns spread over the territory were identified (Figure 5) as described below:

- Pole and dagga house: oval or squared-plan construction consisting of conical-shaped horizontal roof closure made of plant fibers on a branch substructure, resting on a perimeter beam supported by the vertical load-bearing closure given by a perimeter of poles firmly pitched together. The structural wall is often internally plastered with dagga, and, in some cases, externally as well. Ground connection can be direct or indirect.
- Stilt house: is similar to the pole and dagga house but built on stilts, made of branches arranged according to a double horizontal frame, which serves to protect the construction by raising it off the ground. With this type, an additional outdoor space is created, interposed between the ground and the house's tax floor, which is often used for animal shelter.
- Basket house: circular-plan construction characterized by an interior space, bordered by a cylindrical woven bamboo membrane, and an exterior veranda, carved out between the perimeter of the membrane and that of the supporting structure made of wooden poles. Examples are also found where part of the veranda has been infilled with a second membrane to carve out additional interior spaces used as kitchen or sleeping quarters. The punctual structure carries the horizontal roof closure, made of a covering of plant fibers on a sub-structure of bamboo canes arranged in a halo pattern. The basket wall is covered with mud on both sides to bring stability to the system; portions of the wall are instead left uncovered to promote natural ventilation. Despite attempts, the application of the bamboo membrane principle to the rectangular form does not achieve the same structural performance.
- Grass house construction with a square plan (with now disappeared attempts at a circular plan) consisting of: a horizontal gabled enclosure with a plant fiber covering on a sub-structure of branches arranged orthogonally on the sloping planes of the roof; a load-bearing frame structure on which a double horizontal wooden frame is set to support the roof; and a vertical enclosure characterized by a "infill" of woven plant fiber mats. The frame elements were cut and previously treated with carbolite as a deterrent against termite attacks, while the walls were plastered internally, and only in some cases externally, with clay.
- Brick house: a square-plan construction with a more complex plan development than the previous ones, it is characterized by a gabled roof with a plant fiber covering on a sub-structure made of branches arranged in a radial pattern mounted on a double horizontal warp of logs resting on a load-bearing wall of earth bricks (unfired or fired). The vertical brick enclosure, externally plastered in the case of unfired bricks, is attached to the ground by means of a baked brick or stone foundation. In this type there is often a small entrance porch given by the setback of a portion of the perimeter walls from the outer edge.

- Fisherman shelter: an oval-shaped dwelling, this is a form-resisting overall shelter with a wooden frame covered with straw and plant fibers. Bindings are made using plant fibers.

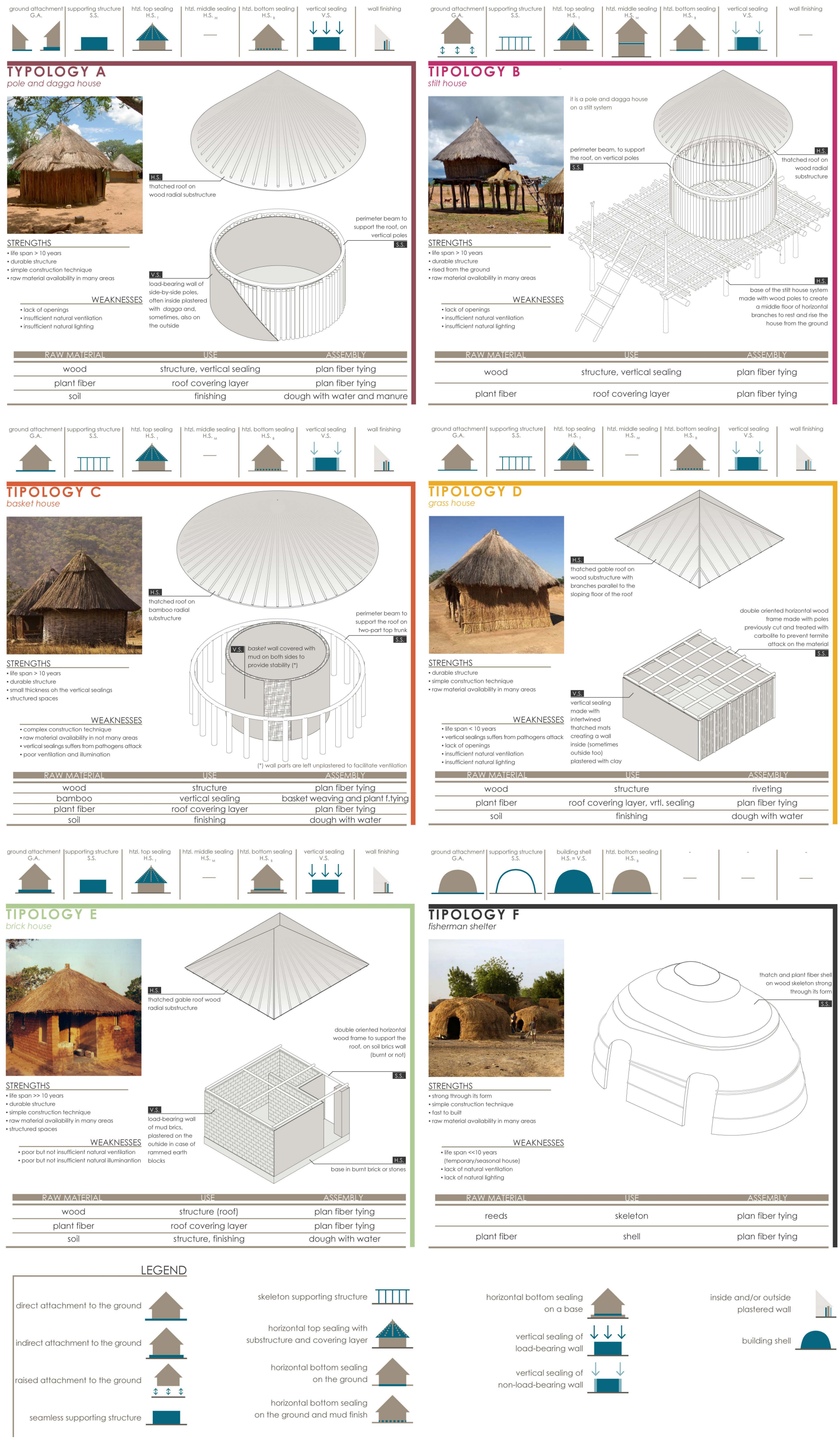

Figure 5. Typological-constructive patterns spread over the Lusaka territory.

A common feature is the presence of protruding and steeply sloping roofs made of plant fibers. The protrusion is intended to protect the walls made of unfired earth or thatch from water in order to prevent their runoff, while the slope is intended to promote the rapid runoff of rainwater before the plant fibers get wet and water infiltrates inside the inhabited space. The upper part of the wall is covered instead by the roof overhang.

To prevent the earth in contact with water from turning into mud, the outer walls of buildings in the part that is in contact with the ground and not covered by the eave overhang of the roof are covered with manure, which, as it dries in the sun, acts as a barrier to water. The construction systems used due to the inherent characteristics of the structural systems that constitute them only allow the construction of spaces with spans of a maximum size of 3 to 5 m depending on the type.

For each type, strengths and weaknesses have been highlighted (Figure 4). This information contributes to the completeness of the harvest map, as in this way it is possible to act in order to innovate the system by enhancing its strengths and overcoming its criticalities. Any designer who wants to implement sustainable architecture in the area will be able to start from such information to design innovative materials and technical and technological solutions.

Intangible resources also include construction techniques. The analysis of vernacular architecture shows the predominance of four construction techniques:

- Slurry: this consists of combining earth with water and any additives to create a more or less workable and homogeneous mixture depending on the use to be made of it. The mixture can be used "raw" or "fired".
- Basket weaving: this is a developed and well-established skill in bamboo-rich areas that makes it possible to produce membranes with a regular surface. Typically made from whole bamboo canes split lengthwise in half, this technique involves weaving half canes in a horizontal line to bundles of vertical canes planted in the ground.
- Thatching: this is a technique that uses dry plant fibers (of various types, depending on local availability) and is made by joining layers or bundles of straw to create weavings or actual coats suitable for covering or covering vertical, horizontal or sloping frames.
- Binding: generally made from plant fibers, this is a technique used to dry join various elements together.

4.3. Material Resources in the Territory of Lusaka

Raw materials related to the Zambian building tradition are earth, plant fibers, bamboo, carbolite, lime, manure, and wood. Earth is definitely the most widely used resource in terms of quantity and characteristics; it is classified into:

- common sand: used in mortar mixes in the construction industry;
- clay soil: rich in clay, yellow to reddish color, used for making vertical walls, floors, and plasters in the construction industry.

Clay soil can be used for making both unfired and fired earth walls. In the geographical surroundings of Lusaka, there are artisans who make bricks using simple production systems. Raw earth bricks are generally made by means of various forms that can be made from everyday objects (such as a metal bucket) or specially made (from iron or by assembling pieces of wood) within which the earth is pressed by hand; once formed, the bricks are left to dry in the sun until completely dry. Alongside this process commonly used in different parts of the world [29–32], site surveys have revealed an alternative system, whereby once the excavation area with the right type of soil (clay soil) has been identified and the topmost layer removed, water is poured directly into the soil and the mixture is left in contact with the soil for about three days; in this way the mixture reduces its level of hydration while remaining malleable and smooth. Next, the slurry is formed and placed in place. In this way, the hydration of the dough acts as a mortar between bricks. Therefore, the drying of the brick takes place in place. Construction walls are built by "layers" from bottom to top, waiting about a day between the paving of one layer and the next in order to make the bottom layer less hydrated than the top layer, a feature that facilitates the construction process.

Depending on the type of soil present, it is mixed with varying amounts of plant fibers. The quantitative ratios of soil, fiber and water are defined without scientific codification but empirically, according to the sensitivity of the operator and information passed down orally (Figure 6).

Figure 6. Some steps of the production process of unfired earth brick (**above**) and fired earth brick (**below**).

The making of terracotta bricks is conducted through the following stages: preparation of the dough, forming, drying in the sun, and firing. In the latter stage, the bricks are placed on top of each other, leaving an empty space at the base. The group of stacked bricks is covered with unfired earth of similar mixture to that used for the bricks themselves, and in the empty space at the base a fire is lit by means of wood. When the firing is completed, the bricks are allowed to cool by stacking and then they are cleaned and stored (Figure 6).

In the traditional architecture of the Lusaka territory, plant fibers are used both to make the bindings between the various components, such as in the union between vertical and horizontal elements, and in the mixtures with the earth in order to increase their strength and reduce their weight. In the geographic area analyzed, the sun-dried leaves/stalks of the following species that are widely spread in the area are used: elephant grass, mupani grass, and lusanbo grass, being strong, are mainly used for bindings, while mwange grass and matengenya grass, being thin, are mainly used for earth slurries.

Since this is an area where termites are common, wood or bamboo elements in contact with the soil and outside are treated with carbolite (carbolic acid or coal tar) [7] or lime. Specifically, the treatment consists of spreading 3 mm of carbolite/lime on the affected elements and letting it dry in the sun until dry.

Bamboo is a widespread plant in the area, both in its common hollow cylindrical stem variant (common bamboo, *Bambusa vulgaris*), and especially in its full cylindrical stem variant, found and widespread only in Africa (solid bamboo, African bamboo, *Oxytenanthera abyssinica*). It is a species characterized by fast growth and good mechanical properties useful for structural use. However, it has a high vulnerability to biological attack and a high resistance to impregnation by protective treatments. This limitation has conditioned its use for structural use. In fact, even in vernacular architecture, bamboo has a structural use in the basket house. Untreated bamboo in contact with soil is also prone to rot in a time frame of 1 to 3 years. However, if used without soil contact, and if protected by additional layers of the building system that prevent its attack by xylophagous insects, it has high durability and mechanical properties that allow it to be used structurally.

Site surveys and analysis identified which wood species are used in traditional architecture: *Brachystegia spiciformis* (Miombo), *Burkea africana* (Burkea), *Colophospermum mopane* (Butterfly tree), *Pericopsis angolensis* (Mubanga), *Pterocarpus angolensis* (Mukwa), *Terminalia Sericea*, and *Trichilia emetica*. These are species suitable for use in creating structures with spans generally of a maximum of 5 m. The "potential natural vegetation map" [27] was used to assess the quantitative availability of the species found and to evaluate the presence of additional species in the area suitable for structural use even with larger spans than the traditional ones.

The steps for identifying wood species that can be used in the construction sector are:

- perimeter on the PNV Map of Lusaka's local surroundings (100 km radius) and identification of the ecoregions present in the area of interest;
- for each ecoregion identification of species (Figure 7) [33]:
    a. dominant: if the regional documentation classified the species as dominant,
    b. characteristic: if the species was documented to be characteristic for at least half of all the national manifestations of the vegetation type and if the species was characteristic in at least two national manifestations of the vegetation type. Species were always classified as characteristic if the species was a regional indicator or regional characteristic species for the vegetation type,
    c. present: if the species was documented to be characteristic in at least one of the national manifestations of the vegetation type or if the species was documented to be present in at least half of all the national manifestations of the vegetation type. Species that were already listed as characteristic were excluded;
- exclusion of species in the category "present" because the amount of territorially available is not sufficient for the creation of a supply chain to serve the construction sector and species at risk because their use is not sustainable;
- analysis of the remaining species by assessing for each the size characteristics, physical properties, mechanical properties, resistance to biological attack, and environmental sustainability [34–36];
- identification of species with the minimum characteristics and properties that would allow their environmentally compatible structural use.

The analysis led to the identification of six wood species: *Afzelia quanzensis*, *Brachystegia spiciformis*, *Colophospermum mopane*, *Pericopsis angolensis*, *Pterocarpus angolensis*, and *Baikiaea plurijuga*. These species have dimensional characteristics and mechanical properties compatible with structural use, but, at the same time, are resistant by nature or by treatment to biological attack. It is highlighted that among the identified species, four are already present in vernacular architecture (Figure 8). Among the remainder, we highlight the possibility of covering large spans with the species *Afzelia quanzensis*, *Brachystegia spiciformis*, and *Pterocarpus angolensis*, thus overcoming the performance limitations of traditionally used species while remaining in the local supply chain. So far, there is no regulation in Zambia for the structural calculation of wooden structures. Therefore, this database can also direct the designer towards the choice of local wood that has characteristics useful for structural use, in which calculation, in the absence of Zambian legislation, can be carried out using international standards.

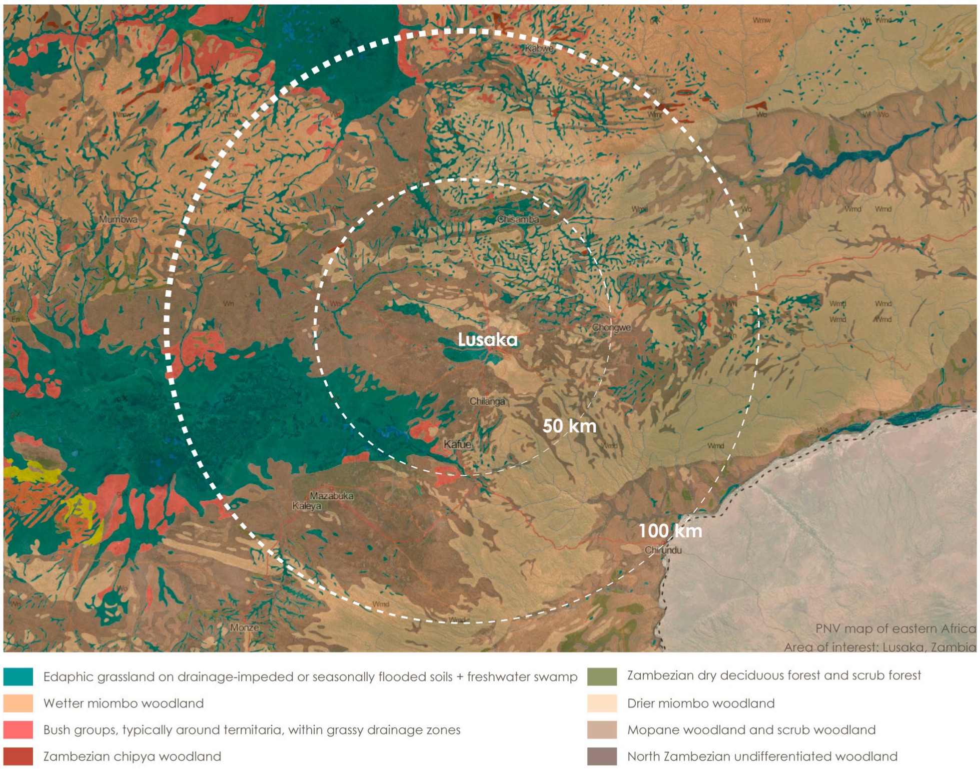

Figure 7. Identification on the PNV Map of Lusaka's local surroundings (100 km radius) and identification of the ecoregions present in the area of interest.

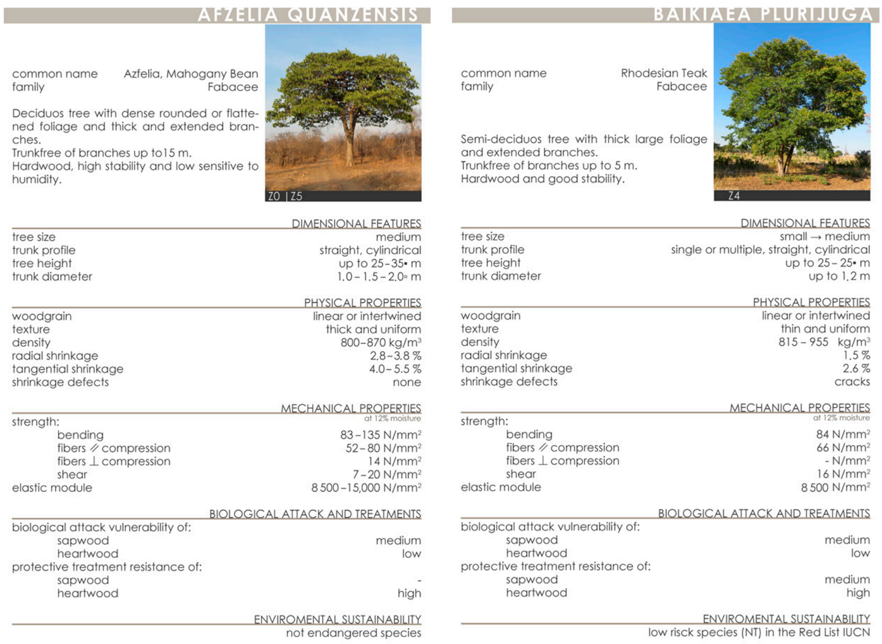

Figure 8. *Cont.*

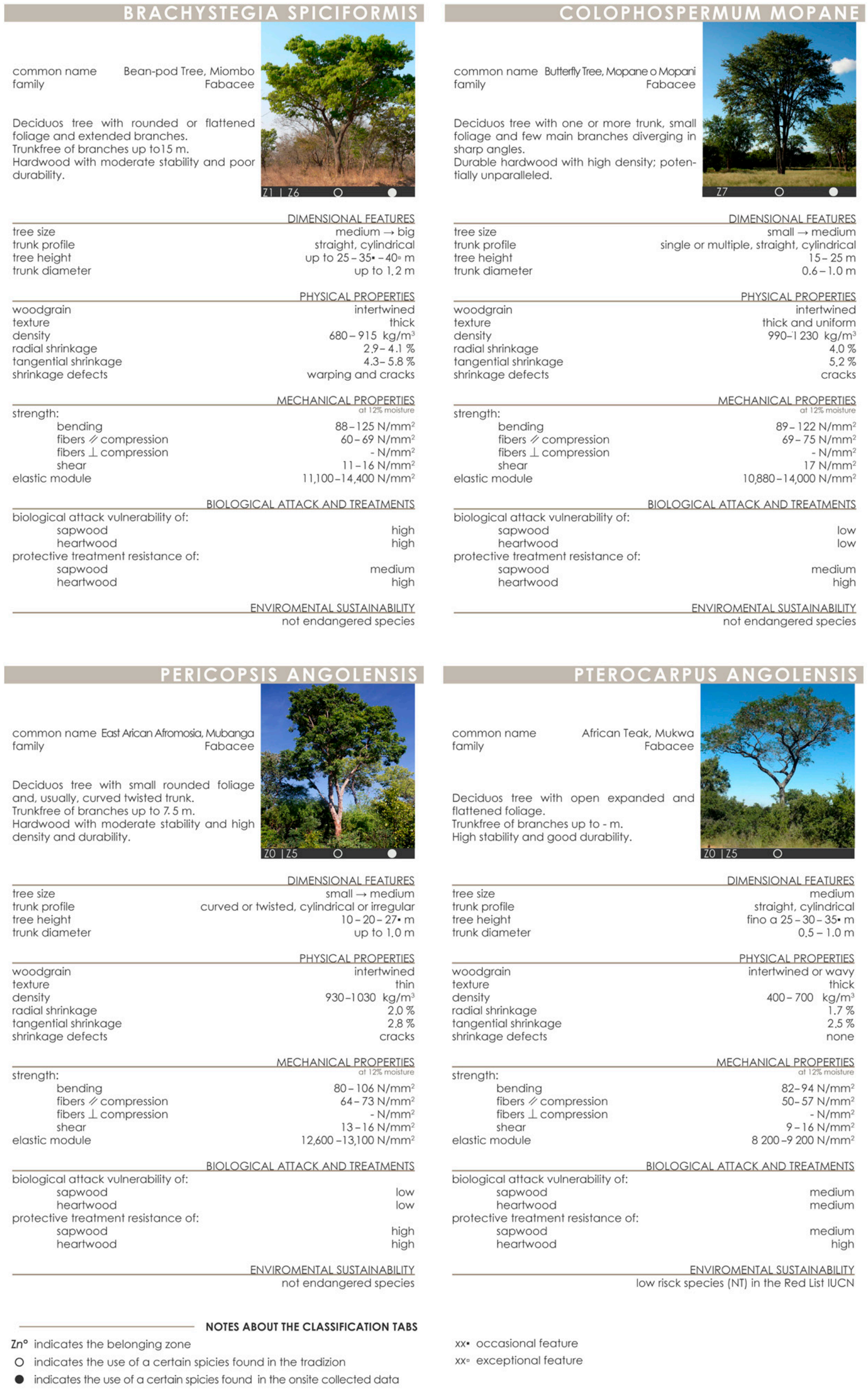

Figure 8. Local wood species compatible with a structural use: analysis of the size characteristics, physical properties, mechanical properties, resistance to biological attack, and environmental sustainability.

On-site surveys and analysis revealed the absence of functional end-of-life supply chains for materials. The result is a wide availability at zero cost of commonly used waste materials, such as plastic and glass bottles, cans, paper and cardboard, tires from decommissioned vehicles, and clothes no longer fit for use. The reuse of waste materials is a sustainable operation, capable of triggering new local supply chains [37,38].

In addition, the analysis of the area highlighted the preponderance in the local cuisine of the use of corn (the typical *nshima* dish is in fact made from cornmeal), the cultivation of which is widespread in the area [39]. Maize leaves, a waste element in the food chain, dried in the sun are plant fibers that can also potentially be used in the construction field.

Similarly, the plastic bags in which cornmeal is packed can be reused as waterproof containers/envelopes in construction. At the end of its life, it is important to maintain the integrity of the plastic bag so that it can be reused. Otherwise, unfortunately there is no possibility of recycling it due to the absence of specialized plants in the area. Raw earth, wood, bamboo, and maize leaves are natural materials that, at the end of their lives, can be returned to the environment without producing pollution. In fact, the production process is based on low technologies that do not involve the addition of chemicals that would not allow reintroduction into nature.

5. Conclusions

Architecture based on western construction techniques and materials is preferred by the Zambian population over traditional architecture above all because it is a status symbol of social welfare, as well as due to the high cost of imported materials compared to traditional ones; the vernacular architecture is therefore currently associated with the poorer classes. This conviction is also confirmed by the use of Western systems by foreign investors, who prefer materials and construction techniques known to them for the construction of infrastructures and services (think, for example, of hotels). Foreign construction operators could instead be encouraged to use local materials and construction techniques by virtue of obvious economic advantages (materials and labor at lower costs), thus re-qualifying the symbolic value of these construction systems. This would also produce a cascade of interest on the part of the local population in vernacular architecture, used "also by Europeans". Therefore, making operators and investors in the construction sector aware of the possible use of local resources and providing them with useful tools for their use, such as the harvest map that is the subject of this paper, are therefore fundamental tools for guaranteeing sustainable development of the territory, equipped with its own identity that becomes a value and freed from unsuccessful imitations of Western models. The harvest map also takes on value in view of the difficulty of finding information and data in developing countries.

The creation of a harvest map of tangible and intangible resources in the Lusaka area provides information regarding building materials, techniques, and technologies related to vernacular architecture and locally available materials related to current geographical, political, and economic conditions. The climate analysis allowed for an assessment of the strengths and weaknesses of the building systems while at the same time gaining information regarding usage patterns, so as to enhance the performance of locally available materials. Codifying and knowing what local building techniques are means being able, in the construction of a building body, to use local workers and to train them with innovative techniques that have traditional techniques as a starting point. Knowing what local materials and technologies are and using them makes it possible to promote existing supply chains and trigger new processes of economic enhancement related to the area. The harvest map, therefore, makes it possible to use information, gathered through surveys carried out on site, as the starting point for designing and implementing sustainable architecture, capable of safeguarding the environment, enhancing the traditional building culture by having local workers who can manage the construction process without having to resort to foreign operators, and generating positive economic repercussions for the territory through innovation.

In future research developments, the traditional building processes currently handed down orally may be scientifically codified, and analyses may be made to identify the technical characteristics of the materials, particularly regarding unfired earth (% clay, density, conductivity, etc.). This will provide additional information aimed at identifying how to innovate the traditional system to overcome its limitations and facilitate its dissemination in quality architecture. In addition, a quantitative analysis of local waste materials may also be made in order to identify their actual potential use.

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