Building Green in Rwanda

Green Architecture is a philosophy of building design, material selection, construction technique, and mechanical systems that can reduce immediate and long-term environmental impact and improve the aesthetic and utilitarian quality of the habitation. Green architecture can also be cheaper if one considers the cost of energy over the life of the building, as well as potentially improved health and productivity in the structure. Industrial material costs are very high in Rwanda, which suffers from excessive transportation costs and import duties on imported materials, very high energy costs, and a lack of water, wastewater, and electrical infrastructure in many areas. By balancing natural, local materials with careful selection of imported materials and equipment, the Rwandan building designer can achieve a good balance between durability and low environmental impact with more obvious financial and environmental advantage than in many other countries.

In terms of environmental impact and energy costs for construction, traditional architecture in Rwanda is 'green', due to lack of financial resources for value added products that are common in industrial country architecture. In terms of energy use, Rwandan homes are intensive users of scarce wood resources for cooking, though other energy requirements, such as electrical appliances or heating, are absent. Institutional and commercial architecture is not environmentally sound, with excessive use of cement and other fired brick materials, lack of on site wastewater treatment, and little concern for energy consumption. Schools in Rwanda are somewhere in between, with rainwater collection and biogas toilets common, but these buildings often use large quantities of cement and fired brick.

Because Rwanda is a small, land locked country with few financial or natural resources, the principles of green architecture are more important than in other locations. Rwanda must import almost all industrial products, as well as fuel for electricity and cement for construction. Currently, approximately 20% of Rwandan electrical production comes from domestic hydropower; the remainder is imported power or is generated from imported petroleum products. As the country continues to urbanize and civic leaders push for more modern architecture, sustainable principles will return substantial economic savings.

This document will detail numerous attributes of green architecture and describe materials, concepts, and resources in Rwanda and neighboring countries for achieving the goals described. The format will loosely follow the Green Building Council "LEED" (Leadership in Energy and Environmental Design) rating system, though this document does not necessarily endorse that system or any other. Prices quoted in the text may not be accurate due to rapidly fluctuating material costs and regional variation. Most facts and statistics are derived from the Kigali Conceptual Master Plan of 2006. This document is not intended to be an exhaustive description of all the topics or materials relevant to green architecture.

Traditional Architecture
Traditional Rwandan houses are of two types: adobe or wattle and daub. Adobe houses are made of earth blocks from soil found on site. This soil is combined with straw and water and formed in hand moulds. Wattle and daub is a method which uses a wooden frame for the walls, to which a mud plaster is applied. Both house types are common in Kigali, and regional variation exists: adobe is less common in northern Rwanda where the black volcanic soil is not suitable for block making due to its expansive character when wet. Although these house types exceed on sustainability
measures by material and construction measures, excessive wood is used for fuel in cooking, which has devastated Rwandan forests over the last century.

Rwandan traditional construction methods are not applicable to institutional architecture due to unprofessional quality and lack of durability, although adobe is commonly used for these applications in many places in the world. However, these materials exhibit qualities that should be maintained as standards through the building process: local materials should be prioritized, earth as a building material is preeminent, and construction should blend with the environment. By adding solar mechanical systems and waste treatment, an indigenous Green Architecture for Rwanda can emerge from the traditional forms.

**Site Selection and Landscaping**

Rwanda is the most densely populated country in Africa, and it is mountainous. In urban areas most construction is now on hillsides, requiring extensive excavation and subsequent slope stabilization, although this is rarely considered. Erosion is a major concern due to deforestation, depletion of top soil, and water quality downstream. Buildings should be located where excavation can be minimized, for example by orienting long buildings along slope and not down slope, or by using staggered floor levels. Vegetation should be protected if possible or replaced. Many hiking paths, particularly around schools, are severely eroded due to absence of erosion control techniques such as retaining walls, stairs, or switchbacks.

*Storm water* collection systems should collect runoff and reduce velocity before discharge into natural waterways or wetlands; total runoff can also be reduced by using permeable walkways and parking such as gravel or pavers instead of concrete. Clustering buildings will reduce total road area. Additional vegetation can serve to capture water and reduce erosion affects through drainage swales or constructed wetlands. Infiltration basins can capture water and return it to the water table.

**Water Efficiency**

Clean drinking water is a major concern in Rwanda, as many people do not have easy access. *Water collection* is a priority of the Rwandan government, and many schools now have rooftop water collection systems. Systems common to Rwanda use steel or plastic gutters and plastic, steel, masonry, or concrete cisterns. Stabilized soil block tank construction is another low-cost option found in Uganda and Kenya, but it has not yet been introduced to Rwanda.

For *large cisterns* (above 40m$^3$), above or below ground reinforced concrete units are common. Below ground cisterns can be located below floor slabs for better use of space but necessary pumps will require power and maintenance. Typically these tanks are over designed in Rwanda and consequently much more expensive than they should be. Schools in Rwanda now typically use 10m$^3$ plastic 'Afritanks' with gravity feed, although many steel, stone masonry, and brick systems are found.

*First flush' systems, which discharge the initial rainfall away from the cistern to reduce sedimentation, are not common in Rwanda, although some foreign groups are experimenting with these devices. Some have rock cages to collect large debris at the inlet to the tank.

Onsite water runoff storage with small *earthen dams* is also not common in Rwanda, although this should be encouraged to promote agriculture during the dry season. Meteorological data is available for much of Rwanda, but tremendous regional
variation exists, and recent weather patterns are unusual, so sizing systems or dams cannot be done with complete accuracy. Annual rainfall averages 80 cm, but is generally heavier in the mountains than in the eastern savannas.

Efficient plumbing components such as low flush toilets and efficient shower heads are not available in Rwanda, but indoor plumbing is not common in Rwandan homes and water users are efficient by default of having to carry the resource from tap stands to the home. In institutional applications efficient water fixtures can be imported to reduce total water requirements, but this is expensive. Traditional squat toilets do not use significant water and are a viable option also, although modern facilities favor western style toilets.

**Energy Efficiency**

Although located only two degrees south of the Equator, Rwanda's high elevation makes the climate temperate. Buildings in mountainous areas should emphasize solar heating and insulation, but this is less important in mid-elevation areas. In the eastern savannas where temperatures are higher passive cooling is more important.

Most houses and one-story buildings in Rwanda have vents over doors and windows. Due to the small cross sectional area and placement at mid-height on the wall (but below interior ceilings), these vents are merely aesthetic and do not promote convective cooling. Placing larger vents higher on the wall with intake vents in a cool area of the building low on the wall will promote convective currents in these buildings.

*Windows and doors* are of low quality by Western standards, and low emissivity glass and insulated units are not available. Because heat retention is not a major factor in most areas of Rwanda, the absence of these units is not important for building occupancy.

Traditional adobe or compressed earth block construction is useful for reducing indoor temperature variations due to its high thermal mass. Instead of insulating the interior space from outdoor high and low temperatures, walls with high mass will slowly gain heat during the day and slowly release this heat during the night. This buffer effect is not so significant with concrete or cement block walls.

*Solar hot water heating* is not common in Rwanda, although some companies are beginning to import systems. These systems are expensive but will reduce wood fuel use or electricity consumption for water heating. Available electric hot water heaters are not efficient and pipe insulating is not practiced in Rwandan construction, so the payback time on solar units could be short despite high initial costs.

Currently, 50% of electricity generated in Kigali is with diesel, which is vary expensive and must be imported through Mombasa, Kenya. Hydropower comprises the remainder of electricity generation, although this has decreased in recent years due to drought conditions. *Photovoltaic systems* (PV) are becoming more common on buildings. The current return on investment is approximately 25 years, but this comes down dramatically if one considers the costs of installing new power lines to remote sites or the cost of supplementary fuel and generators for the power outages common in Rwanda. Electrogaz charges approximately $50,000/km for power line service. Power can be out for days in some area, and even Kigali endures daily blackouts.
Electrical efficiency should be a major design concern in new construction. Daylighting is not common in Rwanda, although it can easily be incorporated into most designs through skylights, clerestory windows, or translucent glass. Daylighting can reduce electricity consumption by half during the day, but it must be done in a manner to diffuse light and minimize thermal gain and glare. Compact florescent bulbs are common in Rwanda and should be used exclusively. Additionally, low power consumption computers and refrigeration are available, at competitive costs with normal units. These items save money if the building is on the grid, or they allow a smaller system if energy is to be generated with local power systems.

Biogas systems anaerobically to break down human wastes and produce cooking gas are promoted by KIST and SNV, and several private companies are now installing systems. These are found at some prisons and schools, and are now being promoted for village houses as well. A system for a single house is approximately $1000 (5m^3), and a system for a larger facility can cost around $300/m^3, with some systems comprised of 5-10 units in the 12m^3 range. The methane generated by these systems can be used directly in a petrol generator or combined with diesel, although hydrogen sulfide in the gas can corrode equipment if it is not filtered.

Wastewater
Currently there are fewer than ten wastewater plants in Kigali, and most buildings use septic tank or direct discharge to wetlands. Although the country has addressed this problem in legislation, there are few wastewater firms operating in Rwanda and few cities or developments have the funding to install wastewater treatment plants, which can cost approximately $2-300,000 for a 300-unit subdivision. Furthermore, there is no trained staff or engineering in Rwanda for maintaining these systems.

As noted above, biogas is promoted by KIST and has a proven track record in Rwanda. Because these systems are inexpensive and require less sophisticated maintenance than traditional water treatment, they are recommended for houses and facilities where wastewater can be segregated from grey water (sink and shower water where soaps are used). This requires the use of dual wastewater lines. The production of methane and reuse of effluent for fertilizer are additional benefits of biogas systems.

Constructed wetlands are another water treatment option that is not currently practiced in Rwanda. Natural wetlands have inherent water treatment capability, but many areas of wetland have been converted to agricultural use. Constructed wetlands can be used to further purify wastewater, or to treat grey water if dual systems are installed. These areas will also trap silt from erosion and release clearer water to streams and rivers.

Materials
Materials for Green Architecture must balance durability with sustainability and energy costs, which includes production and transportation. This is especially important in Rwanda, where relatively few natural resources exist and the transportation sector is minimal.

The most common construction materials in Rwanda are soil, concrete, cement block, and brick, although stone is also common in foundations and sometimes used for walls. Soil is common in traditional housing as previously described. Concrete and cement blocks are made with cement produced in Rwanda or in neighboring countries. Cement is currently very expensive ($60/kg), and it is expected to remain
so or increase further if the new airport is constructed in Bugesera. Lime, which can be used as a substitute for cement in some applications, is currently more expensive than cement in Rwanda. It is more sustainable at a national level due to availability of the constituents and less energy required for production, and it was approximately 1/4 the cost of cement in 2006.

Commercial harvesting of wood for construction is also prohibited in Rwanda without a license, although local wood is still available in the market. Wood is used in house construction as noted above, but this is typically eucalyptus and is not high quality. Pine is available in Rwanda, but much wood used for doors and windows is reportedly imported from the Democratic Republic of Congo.

No steel products are manufactured in Rwanda, although some sheet metal operations are performed on imported materials. Steel roof framing is commonly used for expensive houses and commercial projects. Steel products are predictably expensive, and galvanized roofing material is often the most expensive component of housing for the poor.

The most sustainable building materials for wall construction in Rwanda are soil block, brick, and stone masonry, as these are made of materials found on site or locally. Brick quality from local sources varies tremendously in quality, and variations in dimension can require substantial amounts of cement mortar for wall building. Masonry skills are not very sophisticated in Rwanda and construction quality is low.

Soil blocks can be adobe or compressed earth blocks (CEB's), and CEB's can be made with manual or powered machines. Adobe is recommended for low cost houses, and if higher quality blocks can be produced these could be introduced to the commercial market. Manually produced CEB's (Makiga) are recommended for low-cost housing, and machine made blocks (Hydraform) are more appropriate for institutional or commercial construction due to higher production and better quality. CEB's should be stabilized with cement or lime to provide higher strength and better durability.

Fired bricks are made locally or at the BRR factory near Kigali using the ubiquitous red 'marram' soil. Brick costs have increased due to the ban on using wood for firing; coffee husk fuel is now used, as this is a more quickly renewable resource, although it does not have the same energy value as wood. Such sustainably produced bricks are suitable for green construction.

Stone availability varies by region. Generally, masons are available near stone deposits, but construction skill can vary. Transportation costs for stone can be very high if the material is not local.

Available roof materials are thatch, galvanized or painted metal sheets, and locally or factory produced tiles. Thatch is generally found only on round houses used for storage or habitation for the very poor; it has not found use in tourist facilities as it has in Kenya and Tanzania. Metal sheets are common on most houses and are favored for the ability to collect rainwater over traditional thatch roofs. Tiles are popular on custom homes. Roof panels are available in pressed shapes similar in appearance to roof tiles. Papyrus roof sheets were once produced in Rwanda, but it is unknown whether these are still manufactured.
Paints in Rwanda are very expensive. Although paint is manufactured locally, other alternatives include cement plasters, which are very common. Lime washing would be a viable alternative if the price retreats to previous levels.
Summary

Due to the high cost of imported materials, current construction practices in Rwanda are more sustainable, using locally available materials and minimizing cement, steel, and other manufactured products. This is changing as more materials are imported and as wealthier homeowners desire concrete construction for homebuilding. Currently, the following practices are recommended to meet Green Architecture criteria:

- Avoid steep slopes where excavation quantities are high and erosion control will be difficult.
- Use site slope to take advantage of gravity flow for water and wastewater systems.
- Avoid the use of powered mechanical systems for water and ventilation; use gravity fed water and natural convection whenever possible.
- Collect rainwater for domestic use, either in plastic tanks or above/below ground concrete cisterns. Soil block tanks should be promoted.
- Design for natural daylighting to reduce electrical consumption.
- Use low energy computers, light bulbs, and refrigeration.
- Choose local materials (earth blocks, stone, fired brick) for wall building when possible instead of steel, concrete, and concrete blocks.
- Minimize use of cement and other imported materials including paints, metals, and plastics.
- Install solar water heating and photovoltaic systems.
- Use biogas digesters for treating human waste and generating methane for cooking.
- Construct wetlands downslope of all wastewater systems to purify water before discharge.
- Use natural wall finishes such as lime and cement plaster.
Typical Adobe house.

Wattle and Daub roundhouse with thatch roof.

Typical building site in Kigali requiring extensive excavation and slope stabilization.

Erosion control structures near Kigali. Note color of water, indicating high sediments from erosion.

Erosion downslope of high-end development in Kigali with no storm water control measures.

5m$^3$ biogas digester under construction.

Cluster of 4 x 10m$^3$ plastic tanks at health clinic near Ruhengeri.

60m$^3$ masonry + concrete tank at school near Kigali.
18m³ steel tank at office in Gitarama.

Steel tanks (3 x ~12m³) at school in Kamonyi.

Very large (~100m³) underground cistern at CITT in Kigali.

PV array at school in Kamonyi.

Solar hot water heater from Australia at Virunga Lodge near Ruhengeri.

Typical ineffective vents above windows.

Larger vents above windows.

Custom concrete block making machine from Uganda.
Low quality locally produced brick.

Typical local brick kiln.

High quality cement blocks.

Adobe blocks.

Locally produced fired bricks.

Factory produced fired roof tile.

Manually produced, cement stabilized earth blocks.

Manually produced compressed earth block, detail.
Brick construction with tile roof. Note stone foundation.

Buildings at Virunga lodge made of stone masonry and tiled roof.

Earth block house at Shiyra hospital made of cement + lime stabilized blocks with lime plaster.

Virunga Lodge main building.

Rented diesel powered generators in Gikondo. Similar units around the country provide half of Rwanda's electricity needs with fuel from Mombasa.

New construction on Nyamata road using metal roofing with textured appearance similar to clay tile.

Runoff water channel in Kigali.

Adobe house returning to earth at end of life cycle.

Chris Rollins, PE  cebengineering@gmail.com  +250 08 58 21 46