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# Development of a new type of building in tropical regions based on the energetic performance and recovery of recycled wood

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**ABSTRACT**: The Congo Basin is the second world largest tropical forest. This world heritage plays a decisive role in the global warming and the services for the world populations. Its management and preservation is one of the success keys in the future. Despite a strong development of the wood industry in the region observed in recent years, almost no waste of products is sustainably recovered for a possible re use. Very few scientific works address the question of the valuation of related products from the wood transformation in Africa. In this present work, several ways of recovering this waste are studied. Based on a wooden made building case study, with local material in Gabon, we measure, simulate and optimize the hygrothermal comfort of the house from its components. The thermo-physical and mechanical characterization of some first materials consisting of Padouk sawdust plus a lime-based mortar are presented. The instrumentation work of the building made of these new materials completes the study in order to know the components best suited for a sustainable construction in tropical regions. Multi-physical measurements and modeling on the prototype building make it possible to propose new constructive solutions integrating the requirements and objectives of sustainable development.

**KEYWORDS**: re-use of wood waste, circular design for sustainability, building system, timber engineering, hygrothermal comfort, sustainable development, the Congo basin, tropical regions

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## 1 INTRODUCTION

The Congo Basin (CB), the second largest tropical forest massif in the world, just behind the Amazon, extends over 6 Central African countries including the DRC[3], Gabon, Congo, Cameroon, Equatorial Guinea and CAR[4] (fig. 1). Thanks to its area of approximately 6 million km² and its immense wealth of biodiversity (fauna and flora), this world heritage plays a crucial and determining role in climate regulation.


***Figure 1**: Cartography of rainforests of Congo Basin. (Source: G.A. Kombila & al., 2019).*

The importance of these Central African forests on the ecological, economic, social and cultural levels has placed them at the heart of international discussions aimed at preserving these unique ecosystems essential to the proper functioning of the planet (FRM, 2018). The timber industry in most of these CB countries is based mainly on the export of logs abroad. In Gabon, between 2004 and 2009, the annual volume of log exports averaged 1.7 million m3. And it is since 2010 that the export of logs is prohibited. This decision by the public authorities aims to encourage the private sector to carry out local wood processing, potentially generating more added value and better management of the resource (A.G. Kombila, 2019).

This obligation to process the wood locally has a direct impact on the production of logs on Gabonese soil. Indeed, the production of processed wood increased from a collection of 281,331 m3 in 2009 to 824,072 m3 in 2017, an increase of 192.9%. (A.G. Kombila, 2019). The local transformation of wood by total or partial cessation of log exports has become one of the major objectives of forestry development in most countries of the Congo Basin. These wood processing operations generate large quantities of waste (ranging from sawdust, shavings, to pieces of plank).

In Gabon, as in the other CB countries, waste from wood processing is very insufficiently valued. Almost all of it is used by local populations as a source of energy, as a sanitation component in the poultry sector, or else abandoned in wild dumps, thus contributing to environmental pollution. This waste is therefore not recovered under economically and ecologically satisfactory conditions, with a view to reuse by the wood industry or in another sector of crucial importance such as construction. The technologies for processing related products of the tropical timber industry within the reach of the populations of developing countries constitute a field that is very little addressed in the international scientific literature. At the same time, this BC sub-region, like most African countries where the majority of the population is rural, has a great deficit in decent housing. A study led by researchers from the London School of Hygiene & Tropical Medicine on the African continent between 2000 and 2015, estimates that 53 million urban Africans (in the countries analyzed) still lived in slum conditions in 2015 (UN-Habitat, 2016). A situation which should worsen with the strong demographic growth in forecast and which will have to be accompanied by a net increase in basic needs, including food and housing. According to the UN-Habitat report (2016), the African population will approach 2 billion by 2040. In addition, the concern to reduce energy consumption and the carbon footprint of the construction sector around the world and the preservation of exhaustible resources today make the use of bio-based on materials unavoidable. The aim is to integrate the tropical timber processing industry as best as possible into the process of sustainable development in the sub-region, so as not to suffer from waste, but to make it a lever for the development of the circular economy, guarantee of sustainable development.

In this work, we present a successful construction with only made of defects from the sawmill plus a raw red clay. The paper presents the material made and the first results

3 DRC: Democratic Republic of Congo

4 CAR: Central African Republic



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on the building performance for which two types of wall are instrumented and the energy performance is analyzed.

## 2 MATERIALS AND METHODS

### 2.1 PRESENTATION OF THE STUDIED BUILDING

The building project is located in the special economic zone of Gabon, in Nkok, located 27 km from Libreville the capital (0° 23′ 24″ North, 9° 27′ 15″ East).

***Figure 2**: Prototype wood-frame building*

This wooden frame house, built from wood waste from the wood processing industry in Gabon. This building (R + 1) of approximately 85 m² of total living space, it is one of the first prototypes of an eco-responsible construction with a high rate of valorization of local resources in the special economic zone of Gabon (GSEZ). The species used mainly is Padouk, renowned for its good mechanical performance and its attractive natural durability, which make it the wood of choice for exterior landscaping. It is the wood used at more than 80%, mainly for load-bearing structures; This gives the building good durability in the face of Gabon's harsh climate. The building has two levels: ground floor and first floor. On the ground floor, the building serves as a staff house, consisting of a bedroom, a bathroom, a small living room, an external, independent kitchen, and a courtyard serving as a space of conviviality. Upstairs, there is a large room of around 50 m², which serves as a showroom and meeting room, and a small WC area of around 1 m².

### 2.2 MATERIAL PROCESSING TECHNOLOGY AND CHARACTERISATION

Large quantities of shavings and sawdust are produced in the sawmill but they are not still used in industry in Gabon. The question is highly critical when short solid woods are considered as a defect and burned in the best situation. Concerning solid wood, the technology used consist by the utilize of the French technology of green finger jointing i.e. wood undried in an undetermined moisture content (high to 15%) (R. Pommier & al) with a Polyurethane specially developed for hardwood from tropical region (R. Lissouck & al.). These solid woods are used in the building as the structural part and the cladding.

The other part of the by-products of the sawmill are used for filling and insulation. With a view to enhancing them effectively, a composite material made up of a mixture of sawdust and wood. An experimental design is made and followed in the next tables. Two categories of composite materials are designed. The first category consists of composite materials made by valuing shavings from Padouk and a hydraulic solution based on slaked lime from the local paint industry, used as a hydraulic binder (Table 1).

***Table 1**: Sample compositions of composite materials - category 1 and processing methods.*

| | Wood chips [%.vol] | Sawdust [%.vol] | Aqueous solution of lime [%.vol] | How to implement |
|---|---|---|---|---|
| M1 | 50 | 25 | 25 | Moulding without compaction |
| M2 | 50 | 25 | 25 | Moulding with compaction |

The second category (Table 2) includes composite materials made mainly from Padouk wood chips, local raw earth and slaked lime marketed in Gabon.

***Table 2**: Sample formulations of composite materials-category2*

| C / F | Wood chips (%.mass) | Sawdust (%.mass) | Earth (%.mass) | Slaked lime (%.mass) |
|---|---|---|---|---|
| F1 | 30 | 0 | 40 | 30 |
| F2 | 30 | 0 | 40 | 30 |
| F3 | 40 | 0 | 40 | 20 |
| F4 | 40 | 0 | 5 | 10 |
| F5 | 0 | 50 | 20 | 30 |
| F6 | 0 | 25 | 50 | 25 |
| F7 | 25 | 0 | 60 | 15 |
| F8 | 20 | 0 | 60 | 20 |

The goal is to find the right material, that is to say the best suited to the construction method of the chosen building and to the external climatic conditions that the building

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must face. Thus, the material should represent a good compromise between thermal inertia and thermal insulation.

### 2.3 CONSTRUCTIVE MODE AND QUALITY OF THE BUILDING

#### 2.3.1 Constructive mode

In order to reduce construction time and deal with logistical difficulties (for an average wood processing plant), the 1100 mm long panels are manufactured in the workshop and installed on site, thus requiring skilled labor. reduced work. About 12 m3 of wood is estimated for the entire construction, 100 % of which comes from offcuts and wood that cannot be marketed on the market. The wall consists only of an exterior facing (exterior cladding in Padouk), a polyethylene membrane and an interior facing (plywood of 15 mm), between which there is a void, representing an air gap of 80 mm (figure 3).


1: Plywood (15 mm); 2: Air (80 mm) ; 3: Polyethylene membrane (0.5 mm); 4: Exterior cladding in Padouk (10 mm)

***Figure 3****: Initial building wall composition*

#### 2.3.2 Analysis of climate conditions and building quality

According to the Köppen classification, the Libreville region has a tropical savannah climate. Its average annual temperature is 26.3°C and its rainfall averages 1970.6 mm per year (DGMN, 2018). July is the driest month with 14 mm of precipitation, while October is the wettest month with 307 mm of rain. The building must then deal with these waves of heat and humidity, and guarantee to the occupants a good level of comfort. The building being light, the temperatures recorded inside the building are, for the most part, 30 – 33°C, temperatures above the recommended comfort limits (B. Givoni, 1978).

Wood material being a light and relatively rigid material, its acoustic insulation properties are not beyond reproach. In addition, the state of its surface which is compact and relatively smooth does not allow the wood to dampen noise, but it would tend to amplify it. The large hollow (void) in the walls also contributes to the propagation of noise. The integration of a material in the wooden frame structure is one of the possible solutions to optimize the performance of the building (hygrothermal and acoustic). In terms of energy, this material will have to provide, on the one hand, inertia and thermal insulation to limit heat exchange between the building and the outside environment through the walls, and on the other hand, sound insulation and thus improve the comfort of the occupants [17-18] and [21 - 25].

## 3 THERMAL ANALYSIS

### 3.1 THEMAL CHARACTERIZATION OF THE COMPOSITE MATERIAL

The guarded hot plate method (ISO 8302 standard) is used to determine the main thermal properties under steady state conditions. The principle of the experimental setup consists in maintaining a temperature difference ΔT between two flat parallel plates brought to constant temperatures T1 and T2. The sample of thickness e is positioned between the two plates (Ting-Ting Wu, 2011).

Several researchers worked on the thermal characterization of tropical wood. R. Mvondo & al. assessed the Influence of moisture content on the thermo-physical properties of tropical wood species; in (P.S. Ngohe-Ekam & al.) and (S.A. Smith & al.), thermal properties of some main tropical hardwood specie are studied and determined. In this current work, we then focus on the characterization of the designed composite material.

Using the thermal characterization bench of the I2M Bordeaux laboratory which is based on the "guarded hot plate" method, we determined the thermal conductivity (λ) and the specific heat capacity (Cp). Bulk density was also determined. Table 3 shows the main values of this characterization.

### 3.2 INSTRUMENTATION OF WALLS

The objective of the instrumentation is to ensure the measurement of the temperature and relative humidity gradients within the different walls and in the atmosphere, in order to evaluate the damping and the phase shifts in the different transient states studied (figures 5a, 5b and 5c). The selected temperature and humidity sensors are Sensirion SHT 85. These sensors have a standard tolerance announced by the manufacturer of 0.1°C between 20 and 60°C and 1.5% RH in humidity. They have the advantage of having a limited size (7 mm wide) but are sensitive in humid and alkaline environments [F. Collet & al, 2019]. We also use a mini Davis brand weather station which provides us with data on the site's microclimate. These data are temperature and relative humidity of the outside air, sunshine, precipitation, and wind speed and direction. The observation time is 3 days, from January 23 to 25, 2023.


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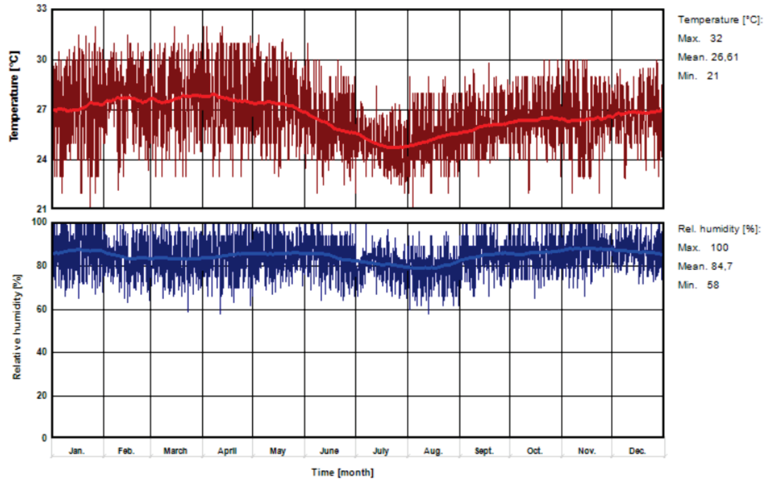


***Figure 4****: Climate conditions of Libreville: (a) Annual temperature; (b) annual relative humidity [ASHRAE].*

### 3.3.1 Integration of innovative composite material in the wall

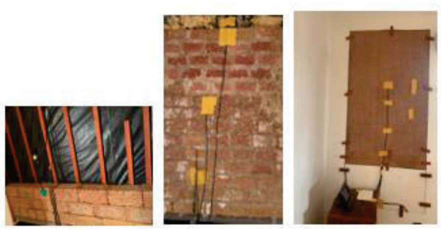

***Figure 6****: Installation of materials based on wood chips in the wall and settle of temperature and humidity sensors.*

Blocks of dimensions 14 cm × 7 cm × 7 cm are used to fill one type of wall (wall 2).

For a first test, the installation of these insulating materials is done in a portion of the wall of the prototype building. The choice of the facade is meticulously analyzed by using SunEarthTools which is an open source tool specially designed for the sizing of solar plants. Libreville being at the level of the Equator, the sun passes through its highest trajectory. Consequently, the East and West facades will be the most exposed to sunshine for this geographical location, and therefore the most vulnerable to overheating in a construction in Libreville, while the North and South facades will be the least exposed to the sun. This analysis allows us to choose the west facade as an experimental wall for an analysis of the hygrothermal behavior of the building envelope because of its strong interactions with the outside, resulting from the activity of the sun on it.

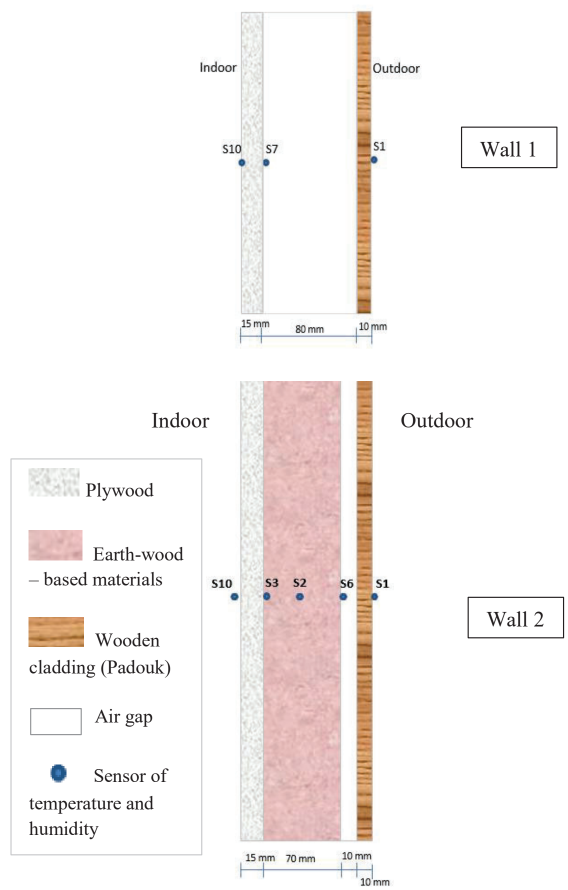


***Figure 5****: Two types of instrumented walls (Wall 1 and Wall 2)*

## 4 RESULTS AND DISCUSSIONS

### 4.1 RESULTS

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The first results of the thermo-physical characterization of the samples are listed in Table 3.

At this stage, only samples of the first formulation (M1) are tested to determined thermal conductivity and thermal capacity. The analysis of the results from the thermal characterization of this composite material reminds us of chipboard wood panels,–due to the similarity of their thermo-physical properties (ρ, λ and Cp) [13-14].

The composite materials of category 2 (from F1 to F8) presented in the table 3, even without thermal test in the lab, are more cohesive and rigid.

***Tableau 3**: Characteristics of the samples of composite material*

| | Apparent Density ρ [kg/m3] | Thermal conductivity λ [W/(m.K)] | Thermal capacity Cp [J/(kg.K)] | Drying time [days] |
|---|---|---|---|---|
| M1 | 735 | 0,1372 – 0.1530 | 1 500 - 1600 | 32 |
| M2 | 850 | - | - | 32 |
| F1 | 605 | - | - | 9 |
| F2 | 630 | - | - | 10 |
| F3 | 515 | - | - | 10 |
| F4 | 450 | - | - | 12 |
| F5 | 505 | - | - | 9 |
| F6 | 520 | - | - | 9 |
| F7 | 760 | - | - | 10 |
| F8 | 850 | - | - | 12 |

These first results allow us to orient the use of the material in the wooden frame structure as filling material. Its low thermal conductivity value of around 0.15 (about ten times less than that of solid concrete) and its good thermal capacity (Cp > 1500 J/(kgK)) give it essential properties of an insulating material.

The figure 7 shows us the evolution of temperatures in the different layers of the wall of the wood frame building. Two cases are presented.

In the first type of wall (Fig. 7.a), the temperature at the surface of the interior facing **S7** varies in the same way as the temperature at the level of the wooden claddings, which constitute the exterior facing. We observe a slight phase shift of the order of 1 to 2 hours between **S1** and **S7** (37th hour and 39th hour of observation). The very low inertia of this wall (wall without heavy materials) promotes a fairly rapid increase in temperature under the influence of external conditions.

The large layer of air (80 mm) inside hardly behaves as an insulator because the inside air is not trapped and therefore subject to heat transfer by convection. This **S7** temperature climbs to reach 36°C on the second day of the observation while the outside air temperature is around 33°C.

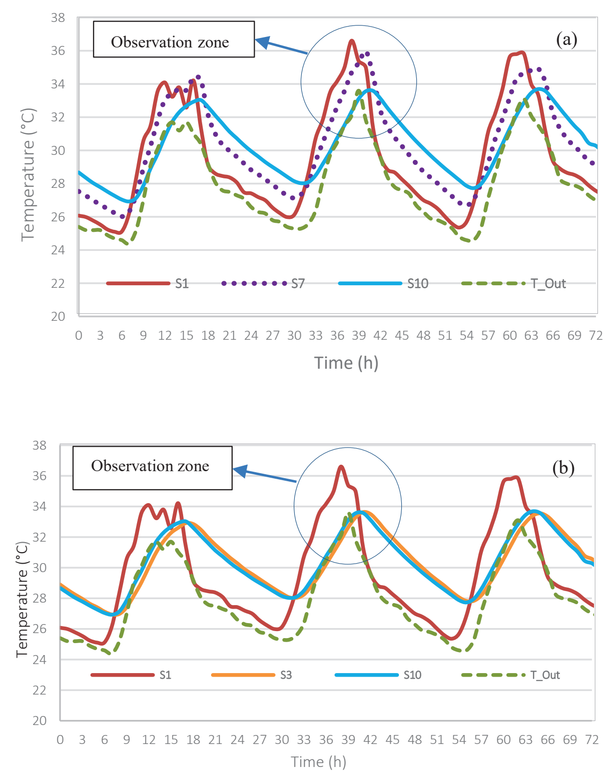


***Figure 7**: Temperatures in walls observed in 3 days: (a) wall 1 and (b) wall 2.*

In the second wall composition (figure 7.b), the integration of earth bricks and chips brings inertia to the wall. This results in a phase shift of 4h, observed between **S1** and **S3**.

## 5 CONCLUSION AND PERSPECTIVES

This work presented one of the ways of valorization of co-products of the wood processing industry in the construction sector. A prototype timber frame building made of reclaimed wood was presented and analyzed. Two types of vertical walls were considered in this study. The instrumentation of these walls made it possible to evaluate their thermal performance, according to the heat exchanges with the surrounding environment. From this analysis, the second type of wall show out interesting characteristics including thermal inertia, conferred on it by the integration of earth-wood chip bricks. This integration allows a significant phase shift and damping, compared to the first one (wall 1). In addition, these wood-


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based on materials, installed in an optimal way, could have a positive effect and then contribute to improving the acoustic comfort of the occupants.

In this study, only heat exchanges were analyzed. The consideration of mass transfers in the evaluation of the comfort of the building could be the subject of a future study. Next research will be made, such as establishing the link between the composition of the earth, its microstructure and the mechanical behavior of these composite earth-wood chip materials. We will aim to extend the study period (over the two main seasons) to get the most exhaustive data possible from physical measurements in situ in order to analyze the hygrothermal behavior of the wall and to assess the impact of these wood-based materials. We will also think about determining the thermal, hydric and mechanical properties in the lab and using them in modeling and numerical simulation at the scale of the building.

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