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# Performance Analysis of Locally Available Materials in Rwanda Construction Industry

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**ABSTRACT**

Rwanda's population has been increasing and according to official sources, it is expected to double by 2050. With that increase, the population will need different facilities for living comfort, as that is one of the key priorities of the government. Among other aspects, there is a growing high need in comfortable and affordable housing as well as other basic infrastructure like schools, hospitals, roads, etc. In order to make those infrastructures not only available but also sustainable, the application of local construction materials has been considered as one of sustainable solutions. However, it is worth to note that not all local materials are adequate, and they need to be checked against materials selection criteria. The purpose of this study is to analyse the key sustainability potentials of identified materials in local construction industry. Musanze district was selected as a case study due to the abundant presence of local construction materials that could be used by different regions of the country. During this study the field exploration, discussions with local leaders and professionals as well as laboratory experiments, were performed. It was concluded that local construction materials had a good quality and therefore should play a great role in implementation of different infrastructure, if their selection is conducted considering construction materials quality requirements. Other studies related to performance improvement through manufacturing, recycling processes or other ways are encouraged, so that their application can be extended to more important structures.

**Keywords:** Aesthetics; Affordability; Clay Burnt Brick; Compression; Construction Materials; Durability; Housing; Local Materials Performance; Los Angeles Abrasion; Selection Factors; Strength; Sustainability; Volcanic Aggregates; Water Absorption.

## 1. Introduction

### 1.1. Background and status

Rwanda's population was 10.5 million in 2012 and currently, this population is around 13.2 million (NISR, 2022). According to the same source, the Rwandan population is projected to increase by more than 50% to 17.6 million by 2035 and to double to about 22.1 million people by 2050 (MINALOC, 2020). The increase of the population will go with increase in demand of well-being infrastructure, including affordable housing and other public infrastructure. The satisfaction of this demand requires availability of adequate materials, not only in terms of quality and quantity, but also in terms of their affordability.

Local building materials refer to building materials that are sourced locally, either occurring naturally or manufactured with locally sourced raw materials. Building materials cost is a major component of construction cost, and one way to bring down the cost of materials in order to ensure affordable housing is a shift toward the usage of local materials.

The term "local" immediately evokes the idea of availability and proximity, and therefore savings, while the term "material" implies the idea of a raw material which has to be processed before being used, with possible reuse or recycling at the end of its life, which brings this concept in line with the more recent concept of a "short supply chain" (Dejeant et al., 2021). From early Rwanda, the use of local materials was the basic for the construction, especially in building grass-hatched houses. As the time went on especially from 2008, the government embarked on a campaign to improve housing, which included the eradication of grass-hatched houses (Nyakatsi) where by more than 6.5 billion Rwandan francs were used in the implementation of Nyakatsi eradication program

(Rutareka., 2011). By the current situation, there is a significant evolution made in Rwanda products related to construction. This required the change of people mindset on the use of locally available materials by understanding their adequacy compared to imported construction materials. A careful review of Sustainable Development Goals, notes “affordable housing” in the center of many of them like goals number 3, 6, 7, 9,11, etc. (UN, 2015). Also, according to the government`s vision 2050 under urbanization and agglomeration pillar, one of special considerations is the universal access to affordable and decent housing (MINALOC, 2020). The consideration of the use of local construction materials and housing topologies is therefore encouraged, as they are backbone for the roll out of affordable and decent housing countrywide. Whereas the use of local materials has been identified as one of ways to improve the affordability of building in Rwanda (Mbereyaho, 2014), their application requires however a systematic approach to make sure that selected materials are adequate. Based on current situation in some districts in Rwanda, like the district of Musanze, most of the buildings are constructed using local materials. Nevertheless, while the use of local building materials is encouraged, this has to be done following all respective guidelines for their selection to ensure the sustainability of implemented housing systems, as well as other structures.

### 1.2. Study Objectives

The main objective of the study is to assess local construction materials against all performance factors that should be used while selecting construction materials, in order to ensure the compliance of implemented buildings with the sustainability requirements. Among others, key specific objectives are:

a) to identify main construction materials locally available in the selected case study, b) to review of fundamental factors for their selection, considered as key performance characteristics for most used local materials, like durability, strength, aesthetics, and performance of key experiments, c) to establish the worldwide status of use of locally available materials in construction, and d) to check the suitability of local materials based on standard selection criteria.

Above objectives guided the study and adequate methodology was adopted for their achievement.

## 2. Literature Review

In recent years, there has been an increased research interest in local construction materials. Some demonstrated the importance of using local materials, others worked on the procedures for selecting and/or assessing their suitability for construction purposes. A survey made by Florez and Castro-Lacouture (2013) revealed that a number of studies on the attributes of building materials have been carried out, indicating the use of objective and subjective measures in defining the performance metrics of building materials. During their study about assessment of the use of locally available materials for building construction in Ado-Ekiti Nigeria, Alade K.T, et al. (2018) revealed that there were abundant materials but their usage was still low, and they recommended a more awareness campaign for their promotion. Ajiboye et al. (2024), among other observation, established that local material sourcing was advantageous over global sourcing in terms of quick delivery and cost savings on road projects, while global material sourcing was necessary for projects requiring advanced and higher-quality materials. In their study, Chaimae et al. (2024) concluded by advocating for a continued emphasis on sustainable building practices, integrating local materials as a fundamental component of civil engineering projects to enhance environmental outcomes and societal value. During his research, Yonatan Ayele Abera (2024) looked into a variety of materials, including bamboo, engineered wood products, recycled composites, and optimal concrete mixtures, and among other conclusions, he underlined the importance of ordinary mechanical properties for the structural integrity, but also gave useful insights into their practical applicability in real-world building projects by assessing the flexural strength of various materials. Wastles and Wouters (2008) described materials selection as a complex process that is impacted and influenced by vast qualifications, judgments and thoughts. Even though there are a lot of variables to be considered in the quest for selecting materials at both the design and construction phases, efforts should be put at choosing strong, cheap and readily available materials. The resource efficiency criteria for selecting green construction materials includes recycle content, natural and renewable, resource-efficient manufacturing process, locally available, salvaged, refurbished or remanufactured, reusable or recyclable, and durable (Constructor, 2013). During their study about timber application in construction industry and its promotion, Mbereyaho et.al (2019), it was established that such species like Eucalyptus, Grevillea, Red Wood and Pinus were the most used in local construction. Finally, the study about strength, sustainability and affordability of bamboo and mud bricks as materials used in local construction established that the considered bamboo and mud bricks, made in ordinary soils and reinforced by sisal fibres were reusable, environment friendly materials and energy efficient (Mbereyaho et al.;2019). Some studies have considered Aesthetics of a building as one of the principal aspects considered in construction. The appeal of a building covers the combined effects of a building's shape, size, texture, color, balance, unity, movement, emphasis, contrast, symmetry, proportion, space, alignment, pattern, decoration, culture and context. Aesthetics complement the buildings' usability and so enhance its functionality with attractive layouts (Anna, 2018). The purpose of this study is to investigate on potentials of local construction materials with regards to the above factors considered as selection criteria, and conclude on their suitability for application in local design and construction processes, that should ensure both constructions affordability and sustainability.

## 3. Materials and Methods

Local materials are being used in construction of all over the world; they can offer affordable housing systems and other infrastructure. However, in order to ensure the sustainability of those structures, the materials selection should be carried out carefully to fulfill the requirements for strong, durable aesthetics and sustainable constructions. There are 14 factors most influencing selection of construction materials: Strength, durability, cost, locally available materials, handling and storage, climate, required skills and availability, sustainability, recycling, the function of the building, appearance, maintenance, specifications, guarantee (Pinconsult Associates Limited, 2022). In the next section materials available in Rwanda in general, and in Musanze District, specifically are identified and their performance is analyzed using key of mentioned factors.

### 3.1. Case Study Description

MUSANZE is a district in the northern province of Rwanda, which is divided into 15 sectors. Musanze has become a touristic city, and it has been quickly growing into a bustling metropolis. This district was selected as a case study because it is also one of secondary cities implemented to support the main country city of Kigali. Infrastructures in Musanze city, like buildings, roads and other public facilities have been growing and mainly local materials were being used, like volcanic aggregates, clay burnt bricks, stones, sand, bamboo, timber, etc. There are some industries in Musanze district which are adding value to those local materials through their processing before being used. Examples of those industries include Prime Cement Industry for cement manufacturing, and Kimonyi Grading company which is used to shape volcanic stones in defined shapes, before they can be used. As a secondary city, Musanze is required to set adequate strategies to achieve transformations required for a such city. The decision makers have been strengthening mobilization process and making awareness of planning at high level, to speed up the urbanization process especially by increasing the level of understanding of local population for the Musanze city master plan implementation.

### 3.2. Study Materials

The field visit conducted in Musanze, established different types of local materials, which are presented in this section with their general description.

#### 3.2.1. Cement

One manufacturer, Prime Cement Limited (PCL) was identified and visited. It is one of cement manufacturers in Rwanda. The main factories of PCL are located in Musanze Industrial Zone, in Kimonyi Sector, Musanze District, in the Northern Province of Rwanda. This is approximately at 97 kilometers from Kigali, the capital of Rwanda. It is worth to note that the industrial commercial production began on 1st September 2020, and from then it is being used in quite all regions in Rwanda. Figure 1 shows Prime Cement factory.


**Figure 1.** Prime Cement factory (Source: Author)

#### 3.2.2. Sand

As sand is an important construction material, it is always desirable to use the good quality sand. To judge the quality of available sand, one must know the properties of good sand. Sand is a mixture of small grains of rock and granular materials which is mainly defined by size, being finer than gravel and coarser than silt, and ranging in size from 0.06 mm to 2 mm. Particles which are larger than 0.0078125 mm but smaller than 0.0625 mm are termed as silt. During the visit to Musanze District one area was visited, Giciye River Sand Quarry (Figure 2). It was communicated that the most used sand in this district was extracted from Giciye sand quarry which is allocated in the neighboring district of Nyabihu. During the visit, the sand sample was taken to assess its quality.

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**Figure 2.** Giciye sand extraction site (Source: Author)

### 3.2.3. Coarse aggregates

Coarse aggregates are irregular broken stones or naturally occurring round gravels that are used to make concrete. Aggregates larger than 4.75 mm in size are termed as coarse aggregates. These aggregates are obtained from stone quarries and stone crushers, the realized size are between 4.75 mm to 80 mm. Kimonyi Volcanic Rocks Grading company (Figure 3), was discovered to be source of course aggregates in Musanze District. The primary role of this company, also called by NYIRINKINDI Ernest ltd is the shaping of volcanic rocks into defined shapes for easy handling in construction. Locally volcanic rocks are graded well and used in paving yards, finishing works on facades for decorative purpose and sometimes are used as structural materials for walls.

**Figure 3.** Kimonyi volcanic grading stones (Source: Author)

Not only they are graded rocks into defined shapes but also they are crushed into coarse aggregates, exercise which is done manually (Figure 4). For the production of above graded stone, cutting machine is used and it is done with respect to standard dimensions depending on the area of future application and also on the wishes of clients. Currently, the graded and finished stones are provided with the following sizes: 30x10x2cm; 20x5x3cm and 20x10x2cm. Here also paving stones with size of 20x9x7cm are being produced.

**Figure 4.** Kimonyi crushed volcanic aggregates by hand (Source: Author)

Another plant, Crusher Plant at Nyakinama Sector (Figure 5), owned by a local construction company, NPD Ltd crushes the stone to convert into coarse aggregates in different sizes. Mostly the aggregates produced in this crusher plant are used in construction of roads in different area of the country.

**Figure 5.** Crusher Plant at Nyakinama Sector (Source: Author)

### 3.2.4. Bricks and Blocks

In Musanze District one brick manufacturing area, clay burnt brick manufacturing at Muko was visited (Figure 6). In addition to that, it was noted that Musanze district had a large area of soil with the components of clay, and therefore suitable for bricks production.

**Figure 6.** Clay burnt brick manufacturing areas (Source: Author)

### 3.2.5. Stones

A building stone may be defined as a sound rock that can be safely used in some situation in the construction as a massive dressed or undressed unit. Granites and marbles used in the form of finely dressed blocks or slabs or columns in monumental and costly buildings are good building stones. Marble, granite and sandstone are used for facing work of buildings. Limestone and sandstone are used for general building works. Fine-grained granite, marble, and soft sandstone are used for Carvings and ornamental works. Compact limestone and sandstone are used for fire-resistant masonry. The stones used for building construction should be hard, durable, tough, and should be free from weathered soft patches of material, cracks, and other defects that are responsible for the reduction of strength and durability. Stones for construction purposes are obtained by quarrying from solid massive rocks. There are different stones sites in Musanze district as well as in many other country districts.

## 3.3. Laboratory and other experiments

The overview of previous studies established key factors most influencing the selection of construction materials, in general. The analysis of those factors suggests that all local materials should meet at least the following requirements: Strength, durability, sustainability and aesthetics. It is in this line that, during the study some tests were conducted with local materials to establish their strength characteristics, analyze and conclude on their performance as construction materials. Following laboratory tests have been conducted: Sieve analysis test, water absorption, Los Angeles test, and compressive strength. Samples for sand, volcanic aggregate and clay brick were collected from the study area of Musanze district and respective laboratory experiments were conducted. Those experiments were carried out according to the different standards including IS2386, AASHTO T 96 and ASTM C 131. Details about the used procedures are presented in the following sections.

#### 3.3.1. Sand

In order to determine the quality of sand, some tests which include organic impurities test, silt content test, sieve analysis, among others are conducted. For this study, the sieve analysis was preferred.

**Sieve analysis test**

The sieve analysis determines the gradation (the distribution of aggregate particles, by size, within a given sample) in order to determine compliance with design, production control requirements, and verification specifications. The determination of particles size distribution for the fine aggregates clarifies whether or not the considered sand is suitable for use in concrete mixing. The implication of sieve analysis results is assessed by the fineness modulus of aggregate which is calculated, as follows:

$$FM = \frac{Cumulative\ retained\ \%}{100} \quad (1)$$

#### 3.3.2. Volcanic aggregates

Volcanic ash aggregation occurs when particles of volcanic ash collide and stick together during transport. This process modifies the size distribution of airborne particles, which affects both atmospheric dispersal and fallout patterns on the ground. This aggregation also impacts the dynamics of volcanic plumes, pyroclastic density currents, and their associated hazards.

In general, to determine the suitability of the volcanic aggregates, some tests include LA, strength test, soundness test, shape test, etc. are used. For this study, Los Angeles abrasion test was carried out.

**Los Angeles abrasion test**

Los Angeles abrasion test is a common test for abrasion resistance considered for multiple engineering applications. The Los Angeles (L.A.) abrasion test is a common test method used to indicate aggregate toughness and abrasion characteristics. Aggregate abrasion characteristics are important because the constituent aggregate in concrete mixture must resist crushing, degradation and disintegration in order to produce a high-quality concrete.

#### 3.3.3. Burnt brick

To determine the quality of a clay brick, different tests are conducted. Those tests include crushing strength test, water absorption test, hardness, soundness, among others. During this study, water absorption test and compressive strength was carried out.

**A. Water Absorption test**

Water absorption test on brick is conducted to determine the moisture absorbed by the brick when subjected to extreme conditions like rain. The absorption test can be used as an indicator of the durability properties of the brick such as quality, degree of burning and behavior of brick in weathering. The test can be briefly explained as follows:

Water absorbed by the brick specimen is given by the following formula:

$$W = \frac{M_2 = M_1}{M_1} \times 100 \qquad (2)$$

where, M1 = Dry Weight after oven drying of brick at 105-110 deg. C and M2 = Wet Weight of brick after immersion of brick in water for 24 hours.

The average water absorption shall not be more than 20 per cent by weight up to class 12.5 and 15 per cent by weight for higher classes.

**B. Compressive strength test**

The compressive strength is used to determine the capacity of bricks to support the vertical loading, without failure. During test, the load at failure is considered as the maximum load at which the specimen fails to produce any further increase in the indicator reading on the testing machine. The formula to calculate the Compressive strength is given below:

Compressive strength = maximum load at failure/Surface area of Brick (3)

### 3.4. Sustainability of local materials

The ability of local construction materials for meeting the needs of the present without compromising the ability of future generations to meet their own needs (United Nations Brundtland Commission, 1987) is analyzed using the three sustainability dimensions, environmental, social and economic. Then, the environmental dimension of materials sustainability is assessed by the way those materials extraction, manufacturing or just collection covers efforts to mitigate climate change, conserve biodiversity, safeguard ecosystems, and reduce pollution and waste. The social aspect of locally available materials is specifically checked by analysis on how availability of these materials contributes to the focus on the well-being and quality of life of concerned people and communities. Economic dimension of local materials sustainability is expressed through the ways related economic activities are contributing to the creation of a balance between economic growth, resource efficiency, social equity and financial stability (Enel group, 2024).

This factor was checked at visited sites, by discussions with practicing engineers, with local population and by cost estimation of some local materials on the market.

### 3.5. Aesthetics

The aesthetics of a building is one of the principal aspects considered in architecture. The appeal of a building covers the combined effects of a building's shape, size, texture, color, balance, unity, movement, emphasis, contrast, symmetry, proportion, space, alignment, pattern, decoration, culture and context (BRE Group.com). In general, the contribution of local building materials in building's aesthetics is checked in several ways (Vaia.com). The following are five aspects which were analyzed during this study:

- Local materials influence on the visual character to a building or infrastructure.
- Local materials role in building's connection to the local culture and its architectural heritage.
- Local materials creation of a harmonious integration between the built environment and the natural surroundings.
- Local materials role in implementation of traditional building techniques.
- Local materials role in conservation of the history and continuity with the past.

All results are presented in Section 4.

## 4. Results and Discussion

Below are results established during implementation of the presented methodology in Section 3.

### 4.1. Laboratory experiments results

Under this section sieve analysis test, Los Angeles abrasion test, compression tests

#### 4.1.1. Results for sieve analysis

In reference to the procedure described in subsection 3.3.1 and as per Figure 7, test was conducted and results are presented in Table 1.

**Figure 7.** Sieve analysis test (Source: Author)

**Table 1.** Sieve analysis test results

| Sieve No. | Sieve Opening (mm) | Mass Retained (g) | Cumulative retained (g) | Percent Retained (%) | Percent Passing (%) |
|---|---|---|---|---|---|
| 3/8" | 9.5 | 0.0 | 0.0 | 0.0 | 100.0 |
| 4 | 4.75 | 16.3 | 16.3 | 1.6 | 98.4 |
| 8 | 2.36 | 44.5 | 60.9 | 6.1 | 93.9 |
| 16 | 1.18 | 220.1 | 280.9 | 28.1 | 71.9 |
| 40 | 0.425 | 215.1 | 496.1 | 49.6 | 50.4 |

| | | | | | |
|---|---|---|---|---|---|
| 50 | 0.300 | 127.3 | 623.4 | 62.3 | 37.7 |
| 140 | 0.106 | 326.4 | 949.8 | 95.0 | 5.0 |
| 200 | 0.075 | 42.2 | 992.0 | 99.2 | 0.8 |
| ------ | Pan | 6.4 | 998.4 | 99.8 | 0.2 |
| **Total Cumulative retained percentage** | | | | **441.7** | NA |

Total cumulative retained of the sample Wc=1000g

Total Cumulative retained percentage= 441.7

Therefore, fine ness modulus of aggregate = (cumulative % retained) /100 = (441.7/100) = **4.4**

Fineness modulus of fine aggregate varies from 2.0 to 3.5mm, while the established value shows that the checked sample is all–in-aggregates or combined aggregates. The results graph is presented under Figure 8.

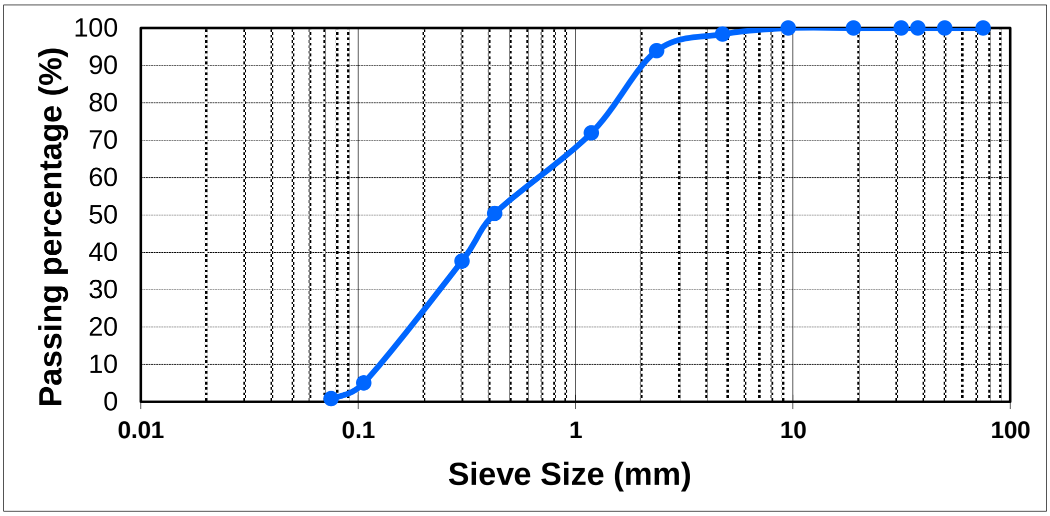


**Figure 8.** Sieve analysis results on graph

Coefficient of Uniformity and Coefficient of Curvature are calculation

Coefficient of Uniformity (cu)=$\frac{D60}{D10}$=$\frac{0.72178}{0.142582}$=5.34

Coefficient of Curvature (cc)= $\frac{D30XD30}{D10XD60}$=$\frac{0.224796*0.224796}{0.762178*0.142582}$=0.27

The above obtained results indicate that, the sample (sand) is suitable to be used in concrete mixing works (IS: 383 - 1970).

### 4.1.2. Results from Los Angeles abrasion test of volcanic aggregates

This test was conducted to indicate aggregate toughness and abrasion characteristics of volcanic aggregates as it was presented in subsection 3.3.2.

The grading test sample was Class B, the used sample was 5kg, where 2.5kg were retained in 12.5mm sieve and remaining 2.5kg were those retained on 9.5mm sieve. For Los Angeles test of class B aggregate, 11 steel sphere balls weights 4580±25 kg were required (Figure 9).

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**Figure 9.** Los Angeles abrasion test on volcanic aggregate (Source: Phone Camera)

As per procedure, both 5000g sample of volcanic aggregate and 11 sphere balls weights 4601.4 g were putted into machine to revolve 500 times, after that, materials were sieved on 1.7 mm sieve in order to obtain percentage loss (Figure 10).

**Figure 10.** Los Angeles abrasion test on volcanic aggregate (Source: Author)

**Results obtained**

Sample weighs C= 5000g

Retained on 1.7 mm sieve was Y= 2888.9g

Percentage loss= $\frac{(C-Y)}{C}$ x100

Percentage loss= $\frac{(5000-2888.9)}{5000}\text{x}100 = 42.22\%$

L.A abrasion value 42.22 % obtained indicates that the tested aggregate is suitable for concrete mixture used in construction, especially pavement construction [IS 2386 (Part IV) 1963; AASHTO T 96 or ASTM C 131].

**4.1.3. Results for water absorption test**

This test offers an idea on durability of materials when exposed to the external environment conditions. Bricks having more water absorption are more porous in nature and are generally considered unsuitable unless they are found to be acceptable based on strength tested through compressive strength test. In this study, the water absorption of bricks, as well as the volcanic graded stone used for finishing work, were tested, as per guidelines presented in subsection 3.3.3 (A), and as shown below (Figure 11).

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**Figure 11.** Water absorption test for materials (Source: Author)

Results obtained using the formula (2) are presented in Table 2.

**Table 2.** Water absorption test results

| No. | Sample Size (cm) | Dry Weight (before)/g (M1) | Weight After 24hrs/g (M2) | Water Absorption/% $=\frac{M2-M1}{M1}x100$ |
|---|---|---|---|---|
| 1 | Burnt Brick(20x9x5) | 1789 | 2212.9 | 19.15% |
| 2 | Burnt Brick(19x9x5) | 1276 | 1443.9 | 11.6% |
| 3 | Burnt Brick(19x9x5) | 1380.3 | 1570.8 | 12.12% |
| **Average Water Absorption of Brick**$=\frac{11.6+19.15+12.12}{3}$**=14.29%** | | | | |
| 4 | Stone(20x5x3) | 546 | 564.4 | 3.26% |
| 5 | Stone(30x10x2) | 1203.2 | 1239.3 | 2.9% |
| 6 | Stone(20x10x2) | 1062.6 | 1091.7 | 2.66% |
| **Average Water Absorption of Graded Rocks**$=\frac{3.26+2.9+2.66}{3}$**=2.94%** | | | | |

As it was mentioned earlier, low absorption (< 7 %) usually indicates a high resistance to damage by freezing, although some type of bricks of much higher absorption may also be frost resistance.

The water absorption tests for bricks and finishing stones found in Musanze district were performed and results were found to be 14.29% and 2.94%, respectively. As per standards requirement, water absorption of bricks should range between 12.5% and 15% but not exceeding 20%. The results prove that bricks manufactured in Musanze are suitable to withstand the weather condition, hence their durability is confirmed (Yan Li and Shuxia Ren, 2011).

### 4.1.4. Results for Compression Test

The procedure earlier presented in section 3.3.3(B) was followed, and used apparatus are presented in Figure 12.

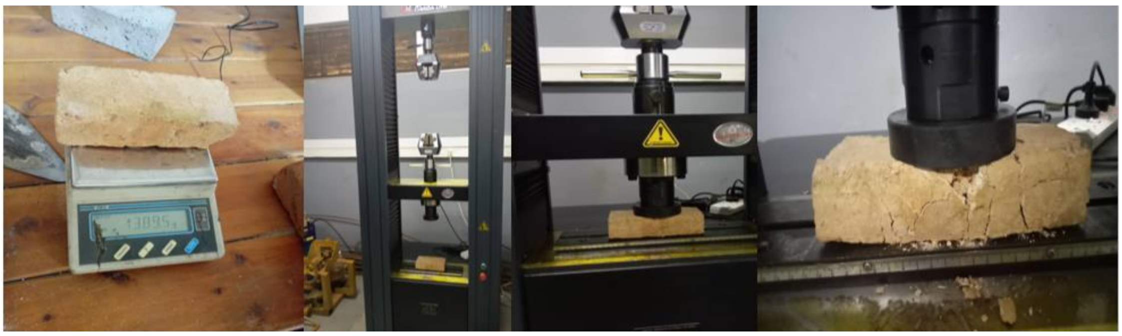

**Figure 12.** Compressive test for clay burnt brick (Source: Author)

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Results obtained applying the formula (3) are presented in Table 3.

**Table 3.** Brick compression test results

| No. | Sample identification cube ($mm^3$) | Surface area ($mm^2$) | Weight (g) | Failure Load (N) | Compressive strength (MPa) | Average compressive strength (MPa) |
|---|---|---|---|---|---|---|
| 1 | 190*90*50 | 17,100 | 1478.2 | 212610 | 12.43 | 12.45 |
| | 190*90*50 | 17,100 | 1389.5 | 224230 | 13.11 | |
| | 190*90*50 | 17,100 | 1690.9 | 202160 | 11.82 | |

Study results show that bricks manufactured in Musanze has compressive strength of around 12.5 MPA. The minimum average compressive strength of clay burnt brick should not be less than 7.5N/mm2 (IS: 3495- P (1)-1976). Therefore, Musanze bricks meet standards, and are able to withstand the vertical loading (AASHTO No.: T 32-70).

### 4.2. Material sustainability

During this study, it was observed that manufacturing and extraction companies were using guidelines set by the Rwanda Environmental Management Authority (REMA); this was therefore in line of respecting the environmental dimension of materials sustainability. In addition, a specific analysis regarding the economic aspect of construction materials was also conducted. During the site visit, the authors interviewed different engineers for gathering information about the cost of local construction materials mostly used. Table 4 shows the outcomes from the interview.

**Table 4.** Available local building materials and respective market price

| S/N | Local Material | Unit | Unit Price |
|---|---|---|---|
| 1. | Sand | Cum | 12, 000 |
| 2. | Prime Cement | Bag (50 kg) | 11, 000 |
| 3. | Volcanic finishing stones | Sqm | 12, 000 |
| 4. | Bricks | Piece | 35 |
| 5. | Stones | Cum | 10, 000 |
| 6. | Coarse aggregate from NPD | Cum | 30, 000 |
| 7. | Coarse aggregates from Kimonyi | Cum | 12, 000 |
| 8. | Volcanic graded pavers | Sqm | 13, 000 |


**Figure 13.** Parking area (Source: Author)

Another economic analysis related to construction materials was done, conducting a comparative analysis between the cost of pavers used for a parking area of $500m^2$ (Figure 13). A simple unit cost estimation showed that for paving using ordinary industrial pavers, or volcanic graded pavers would cost around 13000frw and 12000frw per $m^2$, respectively.

The above finding indicates that, for the parking yard of 500 $m^2$, a client who would use volcanic graded pavers, will see the cost reduced by 8% compared to the usage of ordinary industrial pavers.

With reference to the above analysis and earlier described methodology in section 3.4, all factors and sustainability dimensions were confirmed.

### 4.3. Aesthetics

During this study, by considering some of principles of aesthetics, it was realized that volcanic aggregates can provide a good finishing material with an outstanding aesthetical appearance to a building**.** That was one of reasons volcanic rocks were one of local materials being used for different construction purpose; some local companies, like MASS DESIGN GROUP were using those materials for decoration purpose. Below are the pictures showing buildings with finishes of local construction materials (Figure 14).

**Figure 14.** SABE Building in UR-CST (Source: Google)

More and more construction companies working in Rwanda have started using these volcanic materials for their aesthetical expression, confirmed through the five aspects presented in Section 3.5.

## 5. Conclusions

The main objective of this study was to analyze the performance of local construction materials, making reference to key factors affecting their selection. Musanze district, allocated in Northern Province of the Country was identified as a case study due to the presence in abundancy of different construction materials. Following the adopted methodology, the study confirmed the availability of different construction materials in the selected case study. Then through the literature review, the study observed the quite worldwide application of locally available materials. In Rwanda, these materials are used not only in Musanze district, but also in the whole country, in general. The local materials suitability for construction purposes was confirmed by checking their performance, using the materials selection and assessment criteria, where such factors like fineness modulus, water absorption, Los Angeles abrasion, compression strength, durability, affordability, aesthetics, and sustainability were evaluated. The study results demonstrated that local construction materials were suitable for different construction purposes, and therefore, the use of these materials can contribute in implementation of sustainable housing systems as well as other public infrastructure. The following suggestions would be very useful in line with materials' performance and application improvement:

✓ Any use of locally available materials should be preceded by a careful selection and check against relevant requirements to ensure the construction sustainability.

✓ The extraction process of some local materials like clay, aggregates and different raw materials of cement, and the use others like different species of timber should follow the available government regulations and policies for environment protection.

✓ Engineers should play a key role in guiding local population during the selection of quality local materials.

✓ As the affordability is an important factor of sustainability, researchers, engineers and other professionals working in construction industry are invited to contribute in ensuring affordable unit prices for locally available materials, through research, selection of adequate construction systems and structures types, etc.

✓ Researchers are also encouraged to continue with deep investigations regarding the strength and durability improvement of local construction materials, by adding their value through manufacturing, recycling processes and other ways so that their application can be extended to more important structures.

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The authors have declared that no competing financial, professional or personal interests exist.

**Consent for publication**

All the authors contributed to the manuscript and consented to the publication of this research work.

**Authors' contributions**

All the authors took part in literature review, analysis, and manuscript writing equally.

**Availability of data and materials**

Authors are willing to share data and material according to the relevant needs.

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