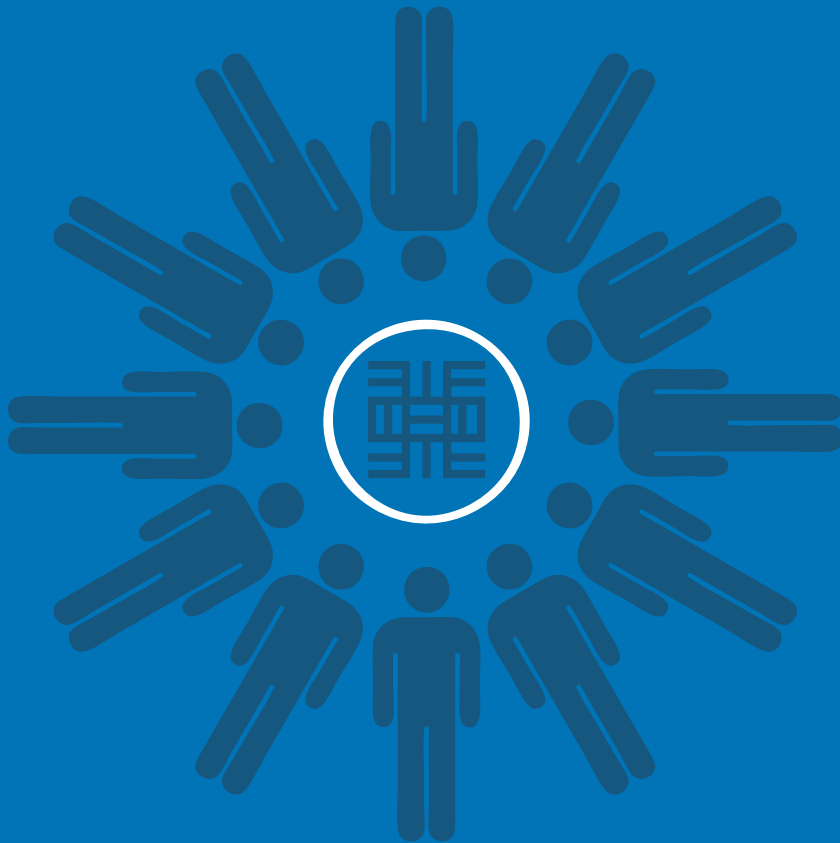




# WABER CONFERENCE

10th Anniversary Conference



## PROCEEDINGS WABER 2019 CONFERENCE

---

Editors:

S. Laryea

E. Essah

5-7 August 2019

Ghana Academy of Arts and Sciences

Accra, Ghana





**WEST AFRICA BUILT ENVIRONMENT RESEARCH (WABER) CONFERENCE**  
*Knowledge, Interaction, People & Leadership*

# **PROCEEDINGS OF THE WABER 2019 CONFERENCE**

**5<sup>th</sup>-7<sup>th</sup> August 2019**  
**Ghana Academy of Arts and Sciences**  
**Accra, Ghana**

## **EDITORS**

**Sam Laryea**  
Wits University, South Africa

**Emmanuel Adu Essah**  
University of Reading, United Kingdom

Proceedings of the West Africa Built Environment Research (WABER) Conference 2019

5th - 7th August 2019

Ghana Academy of Arts and Sciences, Accra, Ghana

© Copyright. WABER Conference.

The copyright for papers in this publication belongs to authors of the papers. Refer to copyright statement in publication for more details

ISBN 978 – 9988 – 2– 6010 – 1

First published in August 2019

Published by:

West Africa Built Environment Research (WABER) Conference  
C/o Sam Laryea  
School of Construction Economics and Management  
University of the Witwatersrand  
1 Jan Smuts Avenue, Johannesburg, South Africa  
Tel: +233 545 204 300 / +27 78 172 6106  
Email: info@waberconference.com / samuel.laryea@wits.ac.za  
Website: www.waberconference.com

Editors

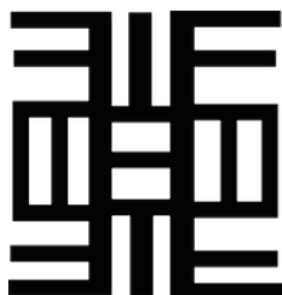
Sam Laryea, Wits University, South Africa  
Emmanuel Adu Essah, University of Reading, United Kingdom

Declaration

All papers in this publication have been through a review process involving initial screening of abstracts, review of full papers by at least two referees, reporting of comments to authors, revision of papers by authors and re-evaluation of re-submitted papers to ensure quality of content.

# TABLE OF CONTENTS

Table of Contents	ii
Foreword	iii
Copyright Statement	v
Declaration of peer review and scientific publishing policy	vi
Scientific Committee and Review Panel	vii
Sponsors and Partners	viii
Prizes to be awarded at the WABER Conference 2019	x
Profile of Keynote Speakers	xii
Programme for WABER 2019 Conference	xv
List of Papers in WABER 2019 Conference Proceedings	xxv
Keynote outlines / Plenary presentations	1
Conference Papers	20
Index of Authors	1188
Index of Keywords	1191



**NEA ONNIM NO SUA A, OHU**

***"He who does not know can know from learning"***

This is the Adinkra symbol of knowledge, life-long education and continued quest for knowledge. The Akan people in West Africa believe that the search for knowledge is a life-long process. This is evident from the Akan saying "Nea onnim sua a, ohu; nea odwen se onim dodo no, se ogyae sua a, ketewa no koraa a onim no firi ne nsa" which translates into "He who does not know can become knowledgeable from learning; he who thinks he knows and ceases to continue to learn will stagnate".

# FOREWORD

I would like to thank and commend the authors of all 84 papers in this Conference proceedings. If the research paper writing process was compared to a marathon, the authors of the 84 papers in this publication would be adjudged as the ones who have endured and finished the race.

We opened the call for papers for this Conference in September 2018 and 176 abstracts were submitted by authors. However, it is one thing to propose to write a paper, and it is quite another thing to actually write the paper. Therefore, I would like to congratulate all authors who succeeded in completing the process of getting published in this conference proceedings.

To enhance visibility and keep in line with current scientific publishing trends, one of the important steps we have taken in the past year is to register WABER Conference as a member of Crossref. Since the beginning of this year, we have been assigning Crossref DOIs to all papers we publish (journal papers and conference papers) in our two main outlets:

- African Journal of Built Environment Research (AJOPER) [www.waberjournal.com](http://www.waberjournal.com)
- WABER Conference Proceedings [www.waberconference.com](http://www.waberconference.com)

We register the metadata of all our journal and conference papers with Crossref. The metadata is then distributed widely by Crossref, helping with discoverability of your papers online. The metadata of all papers in the WABER 2019 Conference proceedings have been registered with Crossref and it is our expectation that this step will provide greater online visibility to all our authors.

This year's conference is our special 10th anniversary conference.

It is befitting that we have an excellent range of interesting topics in the 84 papers to be discussed at this conference.

We are honoured to welcome Professor SN Odai, Vice Chancellor of Accra Technical University, to give us a welcome address. We are also honoured to welcome Professor Kwesi Yankah again to give an opening address for this special 10<sup>th</sup> anniversary conference.

In the three days of this conference, we will be addressed by five experienced international academics. It is a pleasure to welcome you and I thank each of you sincerely for being with us.

- Professor Roger Flanagan, University of Reading, UK
- Professor Kabir Bala, Ahmadu Bello University, Nigeria
- Associate Professor Carmel Lindkvist, Norwegian University of Science and Technology, Norway
- Professor PD Rwelamila, University of South Africa
- Associate Professor Kathy Michell, University of Cape Town, South Africa

In addition to our five main speakers, we have several other speakers addressing various topics that should be of interest to many of us.

WABER Conference is about knowledge, interaction and leadership around research matters. I hope that you enjoy the conference, interact with colleagues to develop relationships, and engage with our exciting speakers and the diverse topics and over 150 people expected here for this 10th anniversary conference.

Sam Laryea  
University of the Witwatersrand, Johannesburg, South Africa  
Chairman of WABER Conference  
August 2019

## CONNECT WITH US


Visit our websites and social media sites for more information about our activities:

### **West Africa Built Environment Research (WABER) Conference**

 [info@waberconference.com](mailto:info@waberconference.com)

 [www.waberconference.com](http://www.waberconference.com)

 [@WABERConference](https://twitter.com/WABERConference)

 West Africa Built Environment Research Conference


 WABER Conference

### **WABER Professional Education**

 [info@waberprofessionaleducation.com](mailto:info@waberprofessionaleducation.com)

 [www.waberprofessionaleducation.com](http://www.waberprofessionaleducation.com)

 [@WABERProfEd](https://twitter.com/WABERProfEd)

 WABER Professional Education

### **African Journal of Built Environment Research**

 [info@waberjournal.com](mailto:info@waberjournal.com)

 [www.waberjournal.com](http://www.waberjournal.com)

For more information please email us at [info@waberconference.com](mailto:info@waberconference.com) or Call/SMS/WhatsApp us on +233 545 204 300

## **COPYRIGHT STATEMENT**

The copyright for papers published in the WABER Conference Proceedings belongs to authors of the papers.

Authors may reproduce and distribute papers published in the WABER Conference Proceedings for personal and educational purposes without written permission but with a citation to this source. No unauthorised reproduction or distribution, in whole or in part, of work published in the WABER Conference Proceedings by persons other than authors is allowed without the written permission of authors or organisers of the WABER Conference, whichever is applicable.

All authors of papers published in the WABER Conference Proceedings retain the right to re-publish their work in any format without the need for further permission from organisers of the WABER Conference. This includes making copies the final published pdf version of papers available on personal websites and institutional repositories and bibliographic databases. However, we ask authors to acknowledge that the original paper was first published by WABER Conference as part of the Conference Proceedings.

We have taken reasonable steps to comply with copyright obligations in the production of this Conference Proceedings. However, we make no warranties or representations that material contained in the papers written by authors does not infringe the intellectual property rights of any person anywhere in the world.

We do not authorise infringement of copyrights / intellectual property rights by authors. If you believe that any material in any paper published in this Conference Proceedings has been inappropriately used, please contact us by email: [info@waberconference.com](mailto:info@waberconference.com)

Our authors are responsible for ensuring good academic practice when conducting and reporting scientific research. It is the responsibility of authors to abide by the norms of academic ethics and integrity. WABER Conference accepts no liability for copyright infringements or inappropriate use of material in any paper published.

Correspondence relating to copyrights / intellectual property rights or requests for permission to use material from the WABER Conference Proceedings should be made to the Chairman of WABER Conference by email: [info@waberconference.com](mailto:info@waberconference.com)

# PEER REVIEW AND SCIENTIFIC PUBLISHING STATEMENT



5<sup>th</sup> August 2019

## TO WHOM IT MAY CONCERN

The scientific information published in peer-reviewed outlets carries special status, and confers unique responsibilities on editors and authors. We must protect the integrity of the scientific process by publishing only manuscripts that have been properly peer-reviewed by scientific reviewers and confirmed by editors to be of sufficient quality.

I confirm that all papers in the WABER 2019 Conference Proceedings have been through a peer review process involving initial screening of abstracts, review of full papers by at least two referees, reporting of comments to authors, revision of papers by authors, and re-evaluation of re-submitted papers to ensure quality of content.

It is the policy of the West Africa Built Environment Research (WABER) Conference that all papers must go through a systematic peer review process involving examination by at least two referees who are knowledgeable on the subject. A paper is only accepted for publication in the conference proceedings based on the recommendation of the reviewers and decision of the editors.

The names and affiliation of members of the Scientific Committee & Review Panel for WABER 2019 Conference are published in the Conference Proceedings and on our website [www.waberconference.com](http://www.waberconference.com)

Papers in the WABER Conference Proceedings are published open access on the conference website [www.waberconference.com](http://www.waberconference.com) to facilitate public access to the research papers and wider dissemination of the scientific knowledge.

Yours Sincerely,

A handwritten signature in black ink, appearing to read 'Sam Laryea', with a horizontal line underneath.

Sam Laryea, PhD  
Chairman of WABER Conference



## SCIENTIFIC COMMITTEE AND REVIEW PANEL

WABER Conference is very grateful to each of the following persons for your expert review of papers during the peer review process. Thank you.

Assoc. Prof. Sam Laryea, Wits University, Johannesburg, South Africa  
Assoc. Prof. Emmanuel Essah, University of Reading, UK  
Dr Eng L Ofetotse, Kingston University, London, UK  
Dr Haruna Musa Moda, Manchester Metropolitan University, Manchester, UK  
Dr Mehdi Shahrestani, University of Reading, Reading, UK  
Dr Collins Ameyaw, Kumasi Technical University, Kumasi, Ghana  
Dr Prince Senyo, University of Portsmouth, UK  
Dr Afolabi Dania, University College of Estate Management, Reading, UK  
Dr Noor Azeyah Khiyon, University of Reading-Malaysia, Johor, Malaysia  
Dr Bruno Lot Tanko, University of Reading-Malaysia, Johor, Malaysia  
Dr Sarfo Mensah, Kumasi Technical University, Kumasi, Ghana  
Dr Omokolade Akinsomi, Wits University, Johannesburg, South Africa  
Dr Kwadwo Oti-Sarpong, The University of Hong Kong, Hong Kong  
Dr Yakubu Aminu Dodo, Universiti Sains Islam, Malaysia  
Dr Emmanuel Selorm Adukpo, Oxford Brooks University, Oxford, UK  
Dr Hafizah Latif, Universiti Teknologi MARA, Perak, Malaysia  
Dr Obinna Ozumba, Wits University, Johannesburg, South Africa  
Dr Cynthia Adeokun, Colman Architects Ltd, London, UK  
Dr Laura Maffei, University of Reading, Reading, UK  
Dr Ronan Champion, University of Reading, Reading, UK  
Dr Oluseyi Odeyale, University of Ibadan, Ibadan, Nigeria  
Dr Razaq Sheriff, Abuja Metropolitan Management Council, Abuja, Nigeria  
Dr Jesse Nor, Abuja Metropolitan Management Council, Abuja, Nigeria  
Dr Shabnam Kabiri, University of Reading, Reading, UK  
Dr Ian Ewart, University of Reading, Reading, UK  
Dr Bismark Duodu, The University of Hong Kong, Hong Kong  
Dr Maxwell Antwi-Afari Fordjour, Hong Kong Polytechnic University, Hong Kong  
Dr Folake Ekundayo, Architect, Berkshire Healthcare NHS Foundation Trust, Slough, UK  
Dr Amos Darko, Hong Kong Polytechnic University, Hong Kong  
Asso. Prof Carmel Lindkvist, Norwegian University of Science and Technology (NTNU), Norway  
Asso. Prof Norhayati Mahyuddin, University of Malaya, Kuala Lumpur, Malaysia  
Dr Humphrey Danso, University of Education, Winneba, Ghana  
Dr Naa Adjeley Ashiboe-Mensah Doamekpor, University of Professional Studies, Accra, Ghana  
Dr Christopher Fapohunda, Federal University Oye-Ekiti, Oye-Ekiti, Nigeria  
Dr Sena Agbodjah Agyepong, Ashesi University, Accra, Ghana  
Dr. Moshood Olawale Fadeyi, Singapore Institute of Technology, Singapore  
Dr Oluwayomi Babatunde, Wits University, Johannesburg, South Africa  
Dr Lawrence Mbugua, University of Reading, UK  
Asso Prof Kemiki Olurotimi, Federal University of Technology, Minna, Nigeria  
Dr Ron Watermeyer, Infrastructure Options, South Africa  
Prof Roger Flanagan, University of Reading, UK  
Assoc Prof Kathy Michell, University of Cape Town, South Africa  
Assoc Prof Abimbola Windapo, University of Cape Town, South Africa  
Dr Sitsabo Dlamini, Wits University, Johannesburg, South Africa  
Prof Fidelis Emuze, Central University of Technology, Bloemfontein, South Africa  
Dr Faizah Mohammed Bashir, Universiti Teknologi, Malaysia  
Dr Joy Maina, Ahmadu Bello University, Zaria, Kaduna, Nigeria  
Dr Adedeji Afolabi, Covenant University Ota, Nigeria  
Dr Baba Adama Kolo, Ahmadu Bello University, Zaria, Kaduna, Nigeria  
Dr Gabriel Nani, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi-Ghana  
Dr Olajide Julius Faremi, University of Lagos, Nigeria  
Arc. Rosemary Nnaemeka-Okeke, University of Nigeria, Nigeria  
Prof Eziyi Ibem, Covenant University, Ogun State, Nigeria

## SPONSORS AND PARTNERS

Thank you to all sponsors and partners of the WABER Conference.

The following conference items are proudly provided by Pinsent Masons (the world's best law firm 2016 & best infrastructure law firm in 2016) to support this conference and human development on the African continent – USBs, Lanyards and Pens.

Website: <https://www.pinsentmasons.com>

IT support and services is proudly provided by Dataware Consult Ghana – WiFi internet, printing and photocopying services.

Website: <https://www.datawareghana.com>



Pinsent Masons





# ENHANCING THE PERFORMANCE OF WALLS BUILT WITH LATERITE-CEMENT BRICKS: A CONCEPTUAL DESIGN AND SPECIFICATIONS WRITING APPROACH

**Alao, T. O.<sup>1</sup> and Ogunbode, E. B.<sup>2</sup>**

<sup>1,2</sup>*Department of Building, Federal University of Technology, Minna, Nigeria*

The long term performance characteristics of buildings built with laterite-cement bricks to satisfy functional requirement of walls is desirable, particularly where walls are not rendered externally or not plastered internally. The paper aims to address performance enhancing issues arising from conceptual design solutions including component mixture selection to enhance better performance of laterite-cement bricks. The methodology adopted used a building surveying procedure to assess selected two failed housing schemes whose main load bearing walls failed as a result of poor component mixture specifications including selected buildings with identifiable conceptual design flaws within the study area. The development of the appropriate domain of mixture combinations to enhance better performance was developed using the Mixture Method developed by Scheffe to be able to select component mixture proportions for meeting prescribed requirements for both strength and durability. This study is applicable to the hydraulically compressed M7-Twin Hydraform machine exerting a compactive force of 10 MN/m<sup>2</sup>. The study has shown that eliminating conceptual design flaws and component mixture selections within a cement content of 8-20 percent would enhance better performance of walls built with laterite-cement bricks

Keywords: conceptual design, laterite-cement bricks, mixture design, specified requirements

## INTRODUCTION

One of the basic functional requirements of walls is strength and stability, (Ejeh and Adedeji, 1998). The wall is regarded as a continuous thin and vertical structure. It can also be regarded as a slender member because of its high ratio of the length to the thickness and must be stable when used to provide partitions for the interior of a building or as shelter against wind, rain and/or extreme seasonal weathers, (Hendry et al., 1987). Walls are so described according to structural requirements as load bearing or non-load bearing walls especially when they are used as partitions and the requirements for its design are covered by many design codes such as the BS 5628: Part 1 (2005). They could also be made to satisfy other

<sup>1</sup> [timothy.alao@futminna.edu.ng](mailto:timothy.alao@futminna.edu.ng)

<sup>2</sup> [ezekiel@futminna.edu.ng](mailto:ezekiel@futminna.edu.ng)

requirements such as thermal resistance. They exist based on different materials among which are: sandcrete, laterite-cement and clay bricks/blocks. They are also available in sizes to meet architectural or structural requirements.

The walling material described here is made from lateritic material which can be described as a class of pedogenics where the cementing materials are the sesquioxide contents which should normally constitute not less than 50 percent of the mineralogical composition (Gidigas, 1976). Tests on the mineralogical composition are carried out using the X-ray fluorescence test for the compounds. This class of material for walls also has very good thermal properties, impact, including shock and earthquake resistance (Hydraform, 2014). The material considered here is referred to as dry jointed or interlocking, requiring no bedding or jointing. They are normally preferred to be left unrendered externally and unplastered internally and should still be required to meet basic functional requirements of strength and stability including meeting durability requirements. Laterite as a material for building bricks is different from expansive clay with shrink-swell characteristics (Amadi et al, 2011). It has been used right from the pre-historic days and it is still becoming as popular especially because of the improvement in the mechanical stabilization process. Today, improvements have been made in developing uniaxial compression machines for mechanical stabilization of this laterite-cement bricks (Hydraform, 2014; NBRRI, 2014; Cinva Ram, 1999; Guetalla et al, 2015) with compactive effort ranging between 5-15MN/m<sup>2</sup>. The most common method of stabilization apart from mechanical stabilization is cement. The mineralogical compounds in laterite soils interact with fluids and determine other characteristics such as plasticity, swelling, hydraulic behavior and compressive strengths (Amadi et al, 2011).

In sourcing for laterites from burrow pits, the properties of the laterite soil could vary according to depth (Alao and Jimoh, 2017). Plasticity of a soil still remains a very important index in the selection of laterite sample for use in both Civil Engineering works and in the production of Building bricks. Plasticity of a soil is usually measured by indices such as Plastic Limit, Liquid Limit, Plasticity Index and Shrinkage limit. Typical test procedure is covered in BS 1377 (2016). Another method of providing standard basis for comparing laterite deposits include the Unified Soil Classification System (USCS) and the American Association of State Highways and Transport Officials (AASHTO). Unlike in other types of bricks, two types of bonds exist in laterite-cement bricks. They are: "plastic bonds" and "cement bonds". The bonding characteristics are therefore influenced by the sesquioxides content, cement content and compactive effort (Alao and Jimoh, 2017; Alao and Jimoh, 2018; Guetalla et al, 2015). Apart from cement as a binder, lime can also be added especially where Plasticity index are in excess of 20 percent to allow for flocculation of the particles because excess clay (Singh, 2006; Hydraform, 2014; Olutoge et al. 2018). Addition of pozzolanic materials however are intended to reduce cement cost.

In spite of advances in the manufacturing and availability of hydraulically compressed compaction machines for laterite-cement bricks, production of bricks meeting specified requirements still represents a challenge mainly as a result of component mixture selection. Similarly, certain conceptual design flaws which has led to a partial collapse of laterite-cement brick walls including concepts that

created maintenance concerns also presents a challenge that need to be addressed. The paper seeks to address these performance enhancing issues arising from conceptual design, and develop limits on the component mixture selection to enhance better performance of laterite-cement bricks in order to avert the ugly trends.

## **LITERATURE REVIEW**

### **Conceptual approach to design of laterite-cement brick walls**

Safe and efficient load bearing and non-load bearing walls can be built using laterite-cement bricks as compressive strength achievable can be as much as four (4) times in excess of the minimum strength of the conventional sandcrete blocks, (NIS, 2004; Hydraform, 2014; Alao and Jimoh, 2017) at just 8% cement content. Compressive strength achievable can be as much as 8N/mm<sup>2</sup>. This has also made it possible to use the material to construct buildings up to 2-storey without structural frames (Hydraform, 2014). Blockwall design procedure are similarly well established using the mathematically derived procedure of structural mechanics and are as well documented in several codes of practice for design of walls such as BS 5628: Part I (2005). The principle of conceptual design would translate (Fraser, 1981; Hsu and Liu, 2000; Mola, Mola and Pellegrini, 2011) to: Intuitive reasoning to allocate and maximize space for functionality, aesthetics and efficiency of a building. Details that would also impede durability concerns should normally be taken into consideration such as avoiding water retention on walls thereby causing dark patches.

- i) Permit development of adequate resistance to lateral forces in certain or foreseeable directions exposed to strong wind loads. This is particularly evident at vulnerable gable ends and therefore, a code of practice should not be a substitute for care and vigilance.
- ii) Avoid torsional effects and therefore avoiding undesirable stress distributions to ensure robustness of the building.
- iii) Redirecting load paths for optimal structural efficiency.

Laterite-cement brick walls design process should therefore be guided by both theoretical and practical considerations. In essence, it has to satisfy the limit state principles of ultimate and serviceability, remembering that a wall is a slender member which must both satisfy strength and stability requirements. Similarly, it must also avoid constructability problems and conceptual design flaws which could pose durability concerns. This would produce a balanced design. The main aim of a design ultimately is to function throughout the intended life without excessive deflection, cracking as well as without eventual collapse.

When brickwork is loaded in uniform compression, failure occurs by development of tension cracks parallel to the axis of loading (Ejeh and Adedeji, 1998; Hendry et al, 1987). It is also good to note that the strength of brickwork is usually smaller than the compressive strength of individual brick approximately, it is equal to the square of the nominal brick crushing strength for which it was built, (Hendry et al, 1987).

### **The building surveying procedure**

This essentially represents a report on the general condition of a building. A general practice procedure outlined by the Nigerian Institute of Building (NIOB) requiring expert knowledge of building inspection, identification of building defects, defects diagnosis, determining the causes and proposing appropriate remedies with the sole aim of restoring the economic value of the building. It could also be prepared for the purpose of purchasing a house to establish the condition and value of a property which may also be used as a document for a loan. The process as outlined (NIOB, 2002) include:

- i) Carry out reconnaissance survey of the building
- ii) Carry out detailed inspection to identify defects, determine causes and propose appropriate remedies
- iii) Prepare schedule of repairs, improvements, possible conversion, alteration and renovation
- iv) Prepare schedule of dilapidation and negotiating on behalf of the client and manage its execution
- v) Prepare a report on the general condition of the building

Among additional responsibilities include

- i) undertaking investigations into works with historical buildings, including its preservation and restoration
- ii) undertaking investigations into works associated with preservation of buildings and its amenities
- iii) assessing, negotiating and implementing improvement grants

Where expert knowledge is required for specialist diagnosis or input, it should be sought for and a supplementary report should normally accompany the building surveying report. In all of these, the report should accompany an estimate of the cost of the repairs.

Inspection of the structure should include both the visible exposed and inaccessible parts of a building and should all be carried out. It is however, advisable to adopt a logical sequence when surveying a property to minimize the risk of omission (Seeley, 1985).

### **Developing a procedure for component mixture proportioning for laterite-cement bricks**

In developing a domain of component mixture proportions and responses which will enable component mixture selection to be obtained to satisfy specification requirements for a laterite deposit, several methods can be employed. These include:

- i) Use of trial mixes using absolute volume method
- ii) Use of mixture experimental design methods which use factorial designs approach such as the Taguchi's Mixture method, Scheffe's Mixture method and the Response Surface Methodology

The Scheffe's experimental design method discussed here was used to select points within a triangular simplex for a three component mixture described in Figure 1. It

is particularly unique to produce mixtures at maximum compacted absolute volume equal to unity. In this case, laterite, cement and water. It can enable an empirical model to be fitted for each response of interest, particularly strength. Further refinements of the empirical models can be carried out by modifying a model after removing all insignificant terms in a model. A resulting final model now forms the response prediction equation. This should satisfy the condition that at least 95 percent of the results are expected to fall within the normal distribution curve. This could then form a basis for a quality control procedure and acceptance criteria process.

This methodology of fitting a polynomial can be used to define an experimental region or domain. The vertices of the triangle as shown in Figure 1 represent numerically, the three actual variable component mixtures (Montgomery, 2001). The vertices represent P1 equal 8%, P2 equal 14% and P3 equal 20% cement contents respectively or more precisely, ratio 1:12.5, 1:7.14 and 1:5 representing the ratio of cement to laterite mix. The first part represents the component part, water, the second part represents cement while the third part represents laterite. Similarly, the pseudo components at the vertices are represented by P1 equal (1, 0, 0), P2 equal (0, 1, 0) and P3 equal (0, 0, 1)

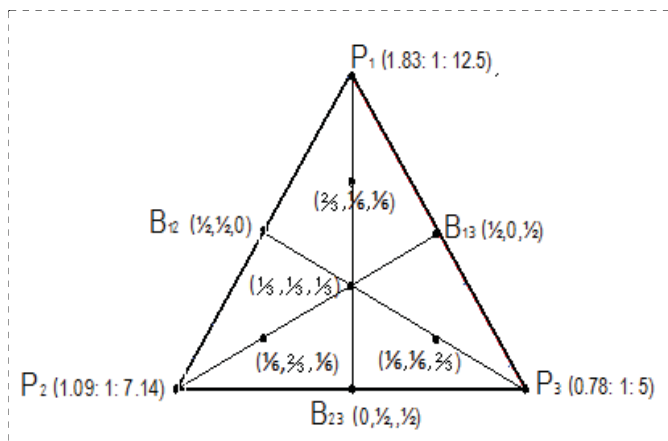


Figure 1: An augmented [3, 2] Simplex lattice

In order to satisfy the requirement of this Scheffe's mixture approach, the component materials are estimated in absolute volume using equation (1) which is fixed and constrained to be summed equal to unity.

\_\_\_\_\_

HHHHH                      HHHHHH                      HHHHHHHH

This represents a pre-condition for using this method of solution procedure (Simons et al, 1999; Montgomery, 2001). The components materials in this particular case are water, cement and laterite. The equality constraint of equation (1) estimated in absolute volume is therefore represented in equation (2), (Montgomery, 2001) as:

H  
 H H  
 H H H  
 and H

The standard form for the response prediction for water, cement and laterite mixture is represented by the second order-quadratic polynomial expressed as, (Montgomery, 2001):

$$\begin{aligned}
 & H & & H \\
 & & H H & & H H H H \\
 & H H H & & H H H & \\
 & & & H & & H & & H
 \end{aligned}$$

The expressions  $H H$ ,  $H H$ ,  $H H$  are the interaction terms while the expressions  $H H H$ ,  $H H H$ ,  $H H H$  represent coefficients of the interaction terms of water, cement and laterite respectively.

A transformation between pseudo and actual components is required for estimating the component proportions for all other design points in the interior of the [3, 2] Simplex lattice in the factor space. This is made possible because of the inverse relationship that exists between the vertices and the interior points as described by Onuamah (2015), Onwuka et al. (2011) and Alao & Jimoh (2018). These enable making predictions and explore the full properties within the Simplex.

The augmented [3, 2] Simplex lattice shown in Figure 1 consists of ten runs consisting of pure blend, binary blends, axial blends and the centroid, (Montgomery, 2001). This procedure is also implementable using Design Expert Software (Design Expert, 2000). However, the transformation procedure was implemented to keep the mixtures at a full absolute compacted volume.

**MATERIALS AND METHODOLOGY**

The Mandate 2003 and Harmony Estate housing schemes were studied, both built within Ilorin, Kwara State, Nigeria. The two housing schemes were built using laterite-cement bricks sourced within Ilorin environs. The two housing schemes were evaluated using the methodology of Building Surveying procedure outlined by the Nigerian Institute of Building to assess the condition of the buildings. In a similar manner, two other buildings within the study area built with the same walling material were also surveyed with a satisfactory performance in terms of the quality of the laterite-cement walling materials used but exhibiting certain conceptual design flaws. In all of these cases, the bricks were produced using the M7-Twin Hydraform brick moulding machine capable of exerting a compactive force of 10MN/m<sup>2</sup>. Samples from burrow pits of the two housing schemes were evaluated to determine the suitability of the deposit to provide answers for such a colossal failure of the two housing schemes. The methodology also tried to establish lack of quality control measures that was inherent in such a failed multi



million naira projects. This scenario, which has become a case of sanctions, liabilities and litigations as at the time of this survey. Table 1 shows the methodology adopted to enhance the performance of laterite cement brick walls

**Table 1: The survey method**

Develop component materials selection process	Determine suitability of laterite deposit  Develop component selection procedure for development of specifications writing
	Develop limits or bounds to mitigate against poor mixture combinations
Identifying conceptual design flaws	Identify defects and its diagnosis arising from conceptual design flaws  Suggest remedial measures

**Geotechnical and mineralogical properties of samples**

The physical, geotechnical and mineralogical properties of the laterite sample were obtained and tested in accordance with BS 1377 (2016). These properties include: Liquid limit (LL), 49%; Plastic limit (PL), 30.6%; Plasticity Index (PI), 18.4%. Other properties include: Specific gravity of (SG), 2.64; Linear shrinkage (LS), 10.1% and Maximum dry density (MDD) of the deposit was 1821kg/m<sup>3</sup>. Soil classification: A-2-7. The mineralogical properties include Fe<sub>2</sub>O<sub>3</sub>, 18.01% and Sesquioxide content of 42.21%. These indices showed that the properties conform with requirement for moulding laterite-cement bricks since  $PI \leq 20\%$  and  $SL \leq 15\%$ .

**Properties of brick samples**

The factored brick samples were produced, cured and tested at 7 and 28 days to obtain compressive strengths and other mechanical properties using a Testometric Universal Testing Machine Model FS300CT. The testing plan described by ASTM C 170-90 was used. The cement type used here can be termed as Portland Limestone Cement Table 2 shows the design matrix considered for this investigation.

The augmented [3,2] simplex in Figure 1 was used to produce the design matrix in Table 2 for developing specifications writing, specific for the laterite deposit used for the housing scheme. It consists of a 3-component mixture. Additional design points were also selected within the interior of the simplex which enables the possibility of detecting curvatures, (Simon et al., 1999; Montgomery, 2000). In a similar manner, the centre point was replicated in order to obtain statistical significance for model fitting for predicting responses of interest.

**Table 2: Design matrix with mixing water at Optimum Moisture Content using an augmented [3, 2] Simplex lattice by weight**

S/No.	Coordinate Points	Pseudo component ratios for selected design points			Actual components ratios			Actual component mixes, kg/m <sup>3</sup>		
		X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	X <sub>1</sub> Water	X <sub>2</sub> Cement	X <sub>3</sub> Laterite	X <sub>1</sub> Water	X <sub>2</sub> Cement	X <sub>3</sub> Laterite
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	P <sub>1</sub>	1	0	0	1.83	1.00	12.50	265.75	145.33	1816.63
2	VERTICES P <sub>2</sub>	0	1	0	1.09	1.00	7.14	264.69	243.32	1737.29
3	P <sub>3</sub>	0	0	1	0.78	1.00	5.00	261.26	334.06	1670.30
4	B <sub>12</sub>	½	½	0	1.46	1.00	9.82	265.66	181.90	1786.22
5	BINARY B <sub>13</sub>	½	0	½	1.31	1.00	8.75	265.45	202.25	1769.70
6	B <sub>23</sub>	0	½	½	0.94	1.00	6.07	263.55	281.44	1708.35
7	C <sub>1</sub>	⅓	⅓	⅓	1.16	1.00	7.68	265.03	227.79	1749.40
8	CONTROL C <sub>2</sub>	⅔	⅓	⅓	1.53	1.00	10.36	265.71	173.11	1793.44
9	C <sub>3</sub>	⅓	⅓	⅔	1.01	1.00	6.61	264.22	260.80	1723.88
10	CENTROID O	⅓	⅓	⅓	1.24	1.00	8.21	265.28	214.37	1760.00

*\*The highlighted are the upper and the lower limits on the domains of constituent proportions*

### Building surveying process

Two housing units consisting of 350 units each was surveyed. The building survey methodology adopted a logical sequence as required to minimize the risk of omission. Including general description, roof, openings (roofs and doors), fittings, external and internal walls, drainages, ceilings and foundations. This survey however, laid emphasis on the laterite-cement brick walling material. The clear distinction between the magnitude of serious defects and those of lesser consequences however led to conclusions leading to imposition of sanctions, liabilities and invoking legal implications at the time of this study. This is particularly evident where little remedial actions are least possible to restore the fabrics of the building to a useful state. Jambol (2012), advocated that these punitive measures arising from fraud and outright disregard for quality control would stem such a menace. This phenomenon poses a threat to sustainability in the use of laterite-cement bricks as a walling material for building construction. Appendices A and B show some level of defects and conceptual design flaws. Three basic conceptual design flaws were inherent from two identifiable buildings also within the study area and are as shown in Appendix B. They are:

- i) Inability to keep out water running down on walls
- ii) Inability to insulate wall from preventing condensation on wall
- iii) Collapse of gable end of wall through high wind pressure as a result of absence of lateral stability
- iv) Unstable wall

### ANALYSIS OF RESULTS

The mixture combinations shown in the design matrix of Table 2 was used to produce bricks using cement and laterite with water requirement at optimum moisture content. This produced responses of interest, compressive strength at 7 and 28 days using the second-order polynomial expression in Equation 3. The domain as highlighted in Table 2 can produce reasonable result. It can be used for



performance and safety of the walls built with laterite-cement bricks as shown in the surveyed structures in Appendix B.1 (a) – (c).

## **DISCUSSION AND CONCLUSIONS**

The study identified that despite the availability of hydraulically compressed brick moulding machines, component mixture selection specific for a laterite deposit can adversely affect the quality of the brick produced. The development of specification writing is suggested to accompany contract documents so as to stem the menace of poor performance. This will avoid the scenarios experienced in the two housing schemes surveyed. Component mixture proportioning, if adequately given attention is fundamental for producing bricks capable of meeting specified requirement of strength and durability. In using the second-order quadratic polynomial design in Table 2, indices which can serve as guides in the form keeping within specified boundaries can be achieved particularly using this innovative compression machine. Elimination of conceptual design flaws would enhance the performance of laterite-cement brick walls and avoid scenarios shown in Appendices A and B.

## **REFERENCES**

- Amadi, A. A., Aguwa, J. I. and Eberemu, A. O. (2011). "Variations in Plasticity Characteristics of Lateritic Soils Associated with Bentonite Treatment" *Nigerian Journal of Technological Research*. Federal University of Technology, Minna, Volume 6, No. 1.
- Alao, T. O. and Jimoh, A. A. (2017). Performance Criteria design of mixture proportions for laterite-cement bricks using the Schéffé Mixture Approach. *Journal of Research Information in Civil Engineering*. 14 (3), 1626-1649.
- Alao, T. O. and Jimoh, A. A. (2018). Development of specifications writing procedure for mixture proportions for laterite cement bricks using the Central Composite Design Approach. *Proceedings of the Nigerian Building and Road Research Institute (NBRI)*. 12-14, June.
- ASTM C170 (1990). *Standard Test Methods for Compressive Strength of Dimension Stone*. ASTM, Philadelphia, USA
- BS 1377-1 (2016). *Methods of test for soils for civil engineering purposes*. British Standard Institute, London.
- BS 5628-1 (2005). *British Standard Institution. Code of practice for the use of masonry. Structural use of unreinforced masonry*.
- Cinva Ram (1999). "A technical handbook/manual for the CINVARAM Brick Machine"
- Design-Expert (2000). Stat-Ease Corporation, Available at [www.stat-ease.com](http://www.stat-ease.com)
- Ejeh, S. P. and Adedeji, A. A. (1998). Strength Characteristics of Dry-jointed Sandcrete Block Assemblies under Vertical Loads. *Nigerian Journal of Construction Technology and Management, NJCTM* Volume (1): 102-108.
- Fraser, D. J. (1981). "Conceptual Design and Preliminary Analysis of Structures". Pitman Publishing Inc. London. Pages 178-193
- Gidigas, M. D. (1976). "Laterite Soil Engineering" Elsevier Scientific Publishing Company"

- Guettala, A., Abibsi, A. and Houari, H. (2006). "Durability Study of Stabilised Earth Concrete under Both Laboratory and Climatic Conditions of Exposure", *Construction and Building Materials*, Volume 20, pp. 119 – 127
- Heathcote, K. A. (2002). An investigation into the Erodibility of Earth Wall Units. Unpublished Doctor of Philosophy Dissertation, University of Technology, Sydney.
- Hendry, A. W., Sinha, B. P. and Davies, S. R. (1987). *Loadbearing Brickwork Design*. Second Edition. Ellis Horwood Ltd, England. Pages 77 – 91, 109 - 122
- Hsu, W. and Liu, B. (2000). Conceptual design: Issues and challenges. *Computer-Aided Design*. Volume 32, No. 14. Pages 849-900. Available at: <https://core.ac.uk/display/15353088> [May 31, 2019].
- Hydraform (2014). Available at [www.hydraform.com](http://www.hydraform.com). [June 10, 2014].
- Jambol, D. D. (2012). Curbing the incidences of Building collapse in Nigeria: Sanctions, Liabilities and Legal Imperatives. *The Professional Builder. Journal of the Nigerian Institute of Building*. Volume 3(2), December.
- Mola, F., Mola, E. and Pellegrini, L. M. (2011). "Recent Developments in the Conceptual Design of R. C. and P. C. Structures". 36th Conference on Our World in Concrete and Structures. Singapore, August 14-16.
- Montgomery, D. C (2001). "Design and Analysis of Experiments". 5th Edition, John Wiley & Sons, New York. Pp. 427 – 473.
- NBRRRI (2014). Available at [www.nbrrri.gov.ng](http://www.nbrrri.gov.ng) [July 10, 2014]
- NIOB (2002). *Nigerian Institute of Building Handbook*, 1st Edition
- NIS 87 (2004). "Standards for sandcrete blocks". Standard Organization of Nigeria, Lagos, Nigeria.
- Olutoge, F. A., Booth, C. A., Olawale, S. O. A. and Alebiosu, O. A. (2018). "Lateritic cement and lime-stabilised bricks and blocks for affordable housing". *Proceedings of the Institution of Civil Engineers – Construction Materials*. Volume 171, Issue 5. Pages 195-202. Available at: <https://doi.org/10.1680/jcoma.16.00062>. [May, 30, 2019]
- Onuamah, P. N (2015). "Modeling and Optimization of the Compressive Strength of Latertic Concrete Using Scheffe's Theory". *International Organization of Scientific Research (IOSR) Journal of Engineering*, Volume 5, Issue 05. Available at: [www.iosrjen.org](http://www.iosrjen.org). [November 20, 2015].
- Onwuka, D. O.; Okere, C. E.; Arimanwa, J. I. and Onwuka, S. U. (2011). "Prediction of concrete mix ratios using modified regression theory". *Computational Methods in Civil Engineering*, Volume 2, No. 1. Available at: <http://research.guilan.ac.ir/cmce>. [November 20, 2015].
- SANS 1215 (2008). "Concrete Masonry Units". South African National Standards
- Seeley, I. H. (1985). *Building Surveys, Reports and Dilapidations*. Macmillan Publishers. Pages 1-52
- Simon, M.; Snyder, K. and Frohnsdorff, G. (1999). "Advances in Concrete Mixture Optimization". *Advances in Concrete Durability and Repair Technology Conference*, University of Dundee, Scotland, UK. Thomas Telford Publishing, pp 21 – 32.
- Singh, A (2006) "Soil Engineering in Theory and Practice" Volume 1, Fourth Edition. CBS Publishers and Distributors. Pages 725-759.

## APPENDIX A: FAILURE ARISING FROM COMPONENT MIXTURE PROPORTIONING



*A.1(a): Total failure of load bearing walls and all fabrics of the building*



*A.1(b): Total failure of load bearing including sinking floor*



*A.1(c): External walls plastered and all roofing sheets replaced*



*A.1(d): Visible cracks on walls including spalling and eroding wall by rain*



*A.1(e): Collapse of external walls and internal partitions*



*A.1(f): Part of external walls replaced with sandcrete blocks*

## APPENDIX B: FAILURE ARISING FROM CONCEPTUAL DESIGN



*B.1(a): The gable end shown with a pointer collapsed and re-built by introducing vertical pier in the walls*



*B.1(b): The vertical wall shown with a pointer has dark patches as a result of undrained water from the cladding*



B.1(c): The vertical wall shown with a pointer has caved-in. Could have been prevented if lintel was introduced at window level

### APPENDIX C: MIXTURE PROPORTIONS (PER M<sup>3</sup>) AND RESPONSES- RUN ORDER

Std Order	Run Order	Block	Component 1 A:Water m <sup>3</sup>	Component 2 B:Cement m <sup>3</sup>	Component 3 C:Laterite m <sup>3</sup>	Response 1 fc 7 N/mm <sup>2</sup>	Response 2 fc 28 N/mm <sup>2</sup>
4	1	Block 1	0.266	0.058	0.677	6.09	8.406
6	2	Block 1	0.264	0.089	0.647	11.079	14.445
1	3	Block 1	0.266	0.046	0.688	7.627	8.4
7	4	Block 1	0.265	0.072	0.663	10.558	11.976
11	5	Block 1	0.265	0.068	0.667	8.22299	10.551
10	6	Block 1	0.265	0.068	0.667	10.349	10.359
3	7	Block 1	0.261	0.106	0.633	12.508	16.653
5	8	Block 1	0.265	0.064	0.67	8.792	10.432
9	9	Block 1	0.264	0.083	0.653	10.959	12.991
14	10	Block 1	0.265	0.068	0.667	8.47996	10.8807
12	11	Block 1	0.265	0.068	0.667	8.22299	10.551
2	12	Block 1	0.265	0.077	0.658	9.884	13.249
13	13	Block 1	0.265	0.068	0.667	8.73693	11.2104
8	14	Block 1	0.266	0.055	0.679	8.337	10.452