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The Republic of Trinidad and Tobago, West Indies
Tel: (868) 662-2002, ext. 83459; Fax: (868) 662-4414;
E-mail: uwije@sta.uwi.edu
Website: http://sta.uwi.edu/eng/wije/

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Editorial

This Volume 41 Number 1 includes eleven (11) research/ technical articles and a memorial written for the late Emeritus Professor Harry Phelps who was Head of Department of Civil Engineering (1972-1984) of The University of the West Indies. The relevance and usefulness of respective articles are summarised below.

E.F. Ochulor *et al.*, "Potential of Green Sand Rice Husk Ash Mould as Carbide Deactivator in Thin Wall Ductile Iron", explore the potential use of thin wall ductile iron (TWDI) components for automotive parts' applications. In this paper, they present the effects of 1-6 wt.% rice husk ash (RHA) additions to moulding sand on microstructure (Optical and SEM) and mechanical properties of cast 2 mm TWDIs. It was found that RHA significantly reduced carbide precipitates in microstructure of cast 2 mm TWDI parts, also castings with nodularity ratings ~ 90%, high nodule count > 1,000 nodules / mm^2 and high strength of 564 MPa were obtained at 4 wt. % RHA addition. High ductility of 4.7 occurred at 6 wt. % RHA addition.

In their article, "Predicting Student Performance in a Caribbean Engineering Undergraduate Programme", **R. V. Adams and C.A. Radix** examine the degree to which the Caribbean Examinations Council (CXC) Advanced Proficiency Examination (CAPE) entry-grades predict both student final-graduating and in-programme course performance in a Caribbean engineering undergraduate programme. The data set included graduation, course and entry data for 140 students who graduated from the programme between 2014 and 2016. The results suggest that the entry criteria serve as a means of predicting the probability of achieving success, rather than the actual success level.

O.A. Irondi, M.O. Nwagbara, and M.A. Okon, "Spatial Variability of Soil Thermal Conductivities within a Horizontal Gas Flaring Site Owaza, Southeast Nigeria", investigate the spatial patterns of soil thermal conductivity in agricultural meteorology. The study was conducted to determine the spatial pattern of soil thermal conductivities on sample distance points away from a horizontal gas flaring site. It was found that the geostatistical linear interpolation using kriging clearly conveys rare insight into the way predicted soil thermal conductivity varied within the horizontal gas flare site.

In the fourth article, "Spinach Pasta for Cerebral Palsy in Trinidad and Tobago", **N. Hosein *et al.***, present the findings from a pre-study that was conducted to determine whether caregivers of Cerebral Palsy (CP) children/patients in Trinidad and Tobago (T&T) were willing to use nutrient dense spinach pasta. Spinach pasta was developed for oral and tube fed persons. It was found that inadequate information on CP negatively impacted support through Government funding and quality of life for patients and caregivers. The influence on purchasing behaviour was nutritive value and not price, usually determined in consumer studies.

O.I. Oluwole, "Development of Oil Palm Fruit Fibre/Cementitious Based Composites for Building Applications", explores the development of composite using ceramic matrix based material reinforced with oil palm fruit fibre (OPFF). It was found that both treated and untreated OPFF reinforced composite samples showed improved properties. The rate at which the treated OPFF within 0-10 % reinforced sample absorbed water is lower than that of unreinforced sample. Untreated OPFF reinforced composite samples demonstrated better compressive and bending strength potentials when compared to their treated counterparts.

A.L. Adejumo, F.A. Aderibigbe and R.U. Owolabi, "Chemical Composition and Characterisation of Skin Gelatins from Two Different Freshwater Fish Species in Osun State of Nigeria: A Comparative Study", investigate into the extraction of gelatin from the skin of tilapia and catfish from Osun State of Nigeria. It was found that tilapia fish skin gelatin is more hydrogen bonded than that of catfish skin gelatin. The foaming properties of tilapia fish gelatin were higher than the foaming properties of catfish gelatin. Results show that gelatin from tilapia fish can act as better foaming agent as compared to gelatin extracted from its catfish.

In their article, "Design and Fabrication of a Moist Heat Therapy Device for Treating Non-specific Low Back Pain", **O.O.E. Ajibola, K.O. Fagbolagun, and O.P. Folorunso**, describe the design and fabrication of an electronic moist heat therapy device for administering heat therapy treatment for non-specific low back pain (LBP). Results show its advantages over the use of traditional hot water bottles which temperature cannot be regulated. The device is capable of maintaining target temperature required for effective heat therapy for non-specific LPB, without any concerns of heat loss or subsequent fall in temperature.

J. Ramkissoon and U. Persad, "Evaluating the State of Product Design in Trinidad and Tobago", describe a study of product design and manufacturing companies in Trinidad and Tobago. Design process and product audits were used to evaluate the current design practice and quality of the designed products. It was found that local design process capabilities and product quality are lacking within Small and Medium Enterprises (SME's). Recommendations included design education workshops to sensitise business owners about product design techniques and audits, and national incentives to encourage and support the business of product design through product design partnerships.

In the eighth article, "A Rapid Post-Hurricane

Building Damage Assessment Methodology using Satellite Imagery", **B. Ramlal, D. Davis and K. de Bellott.**, demonstrate the potential of Remote Sensing for rapid building damage detection using an automated approach in small island states in the Caribbean. Object-Based and Pixel based methods were compared with visually identified reference information from high resolution imagery for the 2004 Hurricane Ivan impact on Grenada. It was demonstrated that the object-based method achieved over 85% classification accuracy among a three damages grade classification scheme in two separate scenarios with different study area extents.

J. Barsatie and K.F. Pun, "Assessment of Smart Buildings in the City of Port of Spain, Trinidad and Tobago: Some Findings and an Approach" report the findings of a recent study on adopting a standalone versus integrated smart buildings (SB) strategy in Trinidad and Tobago (T&T). The findings provided some empirical ground for deriving a five-step SB assessment approach, comprising 1) building governance, 2) defining SB, 3) deriving SB indices, 4) developing component/attributes index, and 5) mapping building design. The proposed SB assessment serves as a practitioners-oriented approach to assess smart solutions of buildings in T&T.

M. Nathai-Balkissoon, "The Impact of an Occupational Safety and Health Module on University Students' Safety Attitudes", reports on how a taught safety module impacted the university student safety attitudes. The module addressed hazard identification and risk assessments, using face-to-face and online teaching and assessment modes along with real-world risk assessments. A t-test identified 15 statistically significant improvements to students' safety attitudes within five areas, namely attitudes to learning about safety, personal safety outlook and behaviours, focus on safety of others, outlook on safety and safety leadership, and state of safety knowledge.

G.S. Shrivastava and C.A.C. Imbert, "Professor Emeritus Harry Orville Phelps (1929-2018): A Memorial", speak about both academic and profession life, and recognise the commitments and contributions of late Professor Emeritus Harry Orville Phelps towards the development of civil engineering disciplines and professionals in Trinidad and Tobago and the wider Caribbean region.

On behalf of the Editorial Office, we gratefully acknowledge all authors who have made this special issue possible with their research work. We greatly appreciate the voluntary contributions and unfailing support that our reviewers give to the Journal. Our reviewer panel is composed of academia, scientists, and practising engineers and professionals from industry and other organisations as listed below:

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Potential of Green Sand Rice Husk Ash Mould as Carbide Deactivator in Thin Wall Ductile Iron

Ezenwanyi F. Ochulor [a,Ψ] Mohammed O. H. Amuda[b] , Samson O. Adeosun[c] and Sanmbo A. Balogun[d]

[a, b, c] Department of Metallurgical and Materials Engineering, University of Lagos, Nigeria; E-mails: fochulor@yahoo.com; samsonoluropo@yahoo.com; mamuda@unilag.edu.ng

[d] Department of Mechanical and Biomedical Engineering, Bells University of Technology, Ota, Nigeria. Email:sanmbo2003@yahoo.co.uk

[Ψ] *Corresponding Author*

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Abstract: *Thin wall ductile iron (TWDI) components are prone to massive carbide precipitates and non-nodular graphite in the as-cast microstructure. Precipitated carbide phase is brittle and damaging to mechanical properties of the iron matrix. The non-nodular graphite reduces nodularity ratings, ductility, tensile and fatigue strength. The use of cast 2 mm TWDIs for automotive parts' applications is limited owing to the above short comings. Moulding sand thermal characteristics is vital in defining the solidification kinetics of a cast part, which in turn determines the evolving microstructure and mechanical properties. Modification of the thermal properties of moulding sand mix for the production of sound 2 mm TWDI castings in automotive applications is expected to suppress these microstructural features that limit this profile application. Efficient monitoring of cooling rate of solidifying cast parts will be a useful step towards controlling and tailoring cast TWDIs properties to desired application. This study presents the effects of 1-6 wt.% rice husk ash (RHA) additions to moulding sand on microstructure (Optical and SEM) and mechanical properties of cast 2 mm TWDIs. RHA significantly reduced carbide precipitates in microstructure of cast 2 mm TWDI parts, also castings with nodularity ratings ~ 90%, high nodule count > 1,000 nodules / mm^2 and high strength of 564 MPa were obtained at 4 wt. % RHA addition. High ductility of 4.7 occurred at 6 wt. % RHA addition.*

Keywords: *Cooling rate, mould sand mix, microstructure, nodularity, mechanical properties, thermal properties*

1. Introduction

The mechanical properties of ductile iron (DI) depend primarily on developed microstructures during solidification (Sheikh, 2008). In most foundries, certain methods or techniques to modify the thermal properties of mould and cores are utilized. Iron or steel chills can be placed in moulds to increase heat extraction and local solidification rates. Special sands like zircon, chromite or carbon can be used singly or mixed with silica sand to change moulding sand thermal and physical characteristics (Showmann and Aufderheide, 2003). The cooling rate is largely dependent on the cast size, as the section thickness affects solidification and cooling rates through the austenite transformation range (Gorny and Tyrala, 2013). Solidification and cooling rates influence nodule count, carbides precipitation and the amount of ferrite and pearlite formed. Variation in cooling rates and solidification times can produce significant changes in the evolving structure and properties. For instance, die casting, which uses metal moulds, has faster cooling rate and produces higher-strength casts than those from sand mould with more insulating constituents (Abed, 2011).

The manufacturing of thin-wall sand casts presents unique problems traced to phenomenon arising from its high surface area to volume ratio. This results in very high solidification rates and can lead to mis-runs or other defects, undesirable microstructures and poor mechanical properties. Showmann and Aufderheide, (2003) reported the reduction of thermal conductivity in moulding sand using low density alumina silicate ceramic (LDASC) as an additive in thin wall sand casting technology. This concept was adopted by Labrecque et al. (2005) to reduce heat extraction capacity of the moulding material, thereby reducing the undercooling level and the cooling rate of the TWDI castings under investigation. In the study by Gorny and Tyrala (2013) on the effects of cooling rate on microstructure and mechanical properties of TWDI, varying proportions of LDASC were blended with silica sand to stimulate different cooling rates for casting TWDI samples. Their study established that by blending silica sand with varying proportions of LDASC, similar cooling rate, number of graphite nodules, ferrite fraction and mechanical properties as 13 mm thick reference casting in silica sand mould is achievable in TWDIs. To date, most methods used to produce thin wall castings focus on metal chemistry, inoculation and gating practice. Few practical methods have been available to reduce cooling and solidification rates in convectional sand moulds. This could be achieved by adjusting the density and thermal properties of individual mould and core components or inserts. The mould/core package can

be engineered to give optimum flow and cooling characteristics (Showmann and Aufderheide, 2003).

Modification of the thermal properties of the moulding sand mix is considered vital in ensuring sound 2 mm TWDI castings. Ochulor et al. (2017) investigated the effects of using rice husk ash (RHA) as an additive in silica sand on its moulding and thermal properties. The researchers observed a progressive reduction in thermal conductivity with increased weight percent of RHA additive, 30% reduction in thermal conductivity occurred at 6 wt. % RHA. During casting, heat transfer occurs between the hot liquid metal and the mould (i.e. the heat transfer medium) and the temperature decreases from that of the cast to the surrounding. The process involves three (3) successive stages namely; initial cooling of the melt, the solidification of the liquid metal and the cooling of the solid metal (Abed, 2011). The thermal properties of the sand mould have an influence on the solidification process and behaviour of the liquid metal in it. The process of solidification, the change of liquid to solid metal after pouring into the mould, is the defining event in the life cycle of the cast (Rihan, 2010).

The time involved in this transition may be as short as seconds or as long as hours depending upon the casting process, the size of the cast, the chemical composition of the metal being cast, the manner of solidification and the subsequent solid state treatment, which determines the ultimate microstructure and properties (mechanical and physical) of the cast (Schmidt, 2010). In the study of Ochulor et al. (2016), aluminium dross was incorporated into silica moulding sand mix, a reduction in thermal conductivity and diffusivity of the sand mix was observed. Cast TWDI samples using this mix showed undesirable graphite characteristics, decline in hardness and tensile strength. However, samples showed good percent elongation values.

The heat exchange in the metal-mould system is essential to the kinetics of cooling and solidification of a cast, especially in TWDI castings, which start to solidify during mould filling and determines the cooling rate (Gorny, 2009). The goal here is to control the solidification event, so that the desired microstructure (nodularity and nodule count, matrix type) for enhanced mechanical properties in the final product is obtained. The ultimate physical and mechanical properties of the cast metal depend on one hand on intrinsic factors such as chemical composition, cooling rate, heat and mechanical treatments after solidification. On the other hand, it depends on extrinsic factors namely; metal cleanliness, additives for microstructure control, cast design, riser and gating design, solidification rate control, and temperature control subsequent to solidification, which are present in each casting event and in the processing events subsequent to casting (Kalpakjian, 2008; Cantor, 2003). In the study of Ruxanda et al. (2002) on microstructural characterisation of TWDI castings, it is observed that high solidification / cooling rates, presence of carbide forming elements in the charge materials, low carbon equivalent and/or silicon content and poor inoculation are some parameters responsible for carbide formation.

The main constituents of the matrix of TDWI castings are ferrite, pearlite and carbides. Their actual ratio is highly dependent on the processing parameters that include cooling rate, liquid treatment, chemical composition, and pouring temperature. The mould thermo-physical property is a crucial variable that affects the chilling tendency of TWDI castings (Stefanescu et al., 2002). Moulds with high thermal conductivity remove heat faster from the molten metal, causing it to solidify early and stop flowing. Moulds with high heat diffusivity transfer heat faster from the molten metal and this causes it to freeze earlier than desired.

In this study, rice husk ash (RHA) - silica sand mix mould is used to cast 2 mm TWDIs to improve nodularity ratings, nodule count and strength and reduce carbide precipitation. RHA is used as a moulding sand additive to reduce its thermal conductivity and investigate impact on cast 2mm TWDI microstructure and mechanical properties. Hitherto, RHA has been used as a moulding sand additive to achieve moulding properties such as improved dry strength or decrease in moisture content requirement (Aribo, 2011; Aigbodion et al., 2008).

2. Materials and Methods

2.1 Materials Preparation

Fifty (50) kg of rice husk, a by-product of rice production in rice mills is obtained from Ifo in Ogun State, Nigeria. Combustion of this agro-waste was carried out in a Gemco CFR 90337 electric furnace at 700^0C in a controlled atmosphere for 10 hours at Federal Institute of Industrial Research Oshodi, Lagos. After combustion and cooling, sieve analysis is conducted and only RHA particles between 250-300 µm were used for the moulding sand preparation. This was done to ensure the use of similar particle size to that of silica moulding sand, as good surface finish is required in TWDI casts. A control composition of the green moulding sand is used to cast the 2 mm plates for comparism with that of the sand-RHA mixes. The sand constituents are mixed for 5 minutes using a Rhino model IRM-500 sand mixer located at Nigerian Foundries Ilupeju Lagos. Using this standard composition of moulding sand, six different compositions of the moulds are prepared by adding varying weight percentages of RHA to the moulding sand. Chemical analysis of RHA used and the control composition of green moulding sand are shown in Tables 1 and 2, respectively. Table 3 shows six different mould compositions as prepared by adding varying weight percentages of RHA to control moulding sand.

The choice of weight percentages of RHA used is based on a preliminary trial test conducted on 600 g of moulding sand. The test determined the upper limit (6

wt. %) of RHA to be used as higher weight percent of decline in the moulding sand properties. Moulding sand property test is conducted on moulding sand-RHA mixes to ensure that these properties are adequate and conform to established standard foundry practice.

Table 1. Chemical Composition of Rice husk ash

Const.	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO
Wt. % in RHA	93.15	0.21	0	0.21	0.41

Const.	MgO	K_2O	Na_2O	LOI
Wt. % in RHA	0.45	3.21	0	2.36

Table 2. Control Composition of the green moulding sand

S/No	Materials	Wt. Comp (%)
1	Silica Sand	96.4
2	Bentonite	2.2
3	Starch	0.8
4	Water	0.4
5	Coal Dust	0.2

Table 3. Sand Specimen with wt. % of RHA

S/No	1	2	3	4	5	6	7
Specimen	RH	RH1	RH2	RH3	RH4	RH5	RH6
Wt% of RHA	0	1	2	3	4	5	6

2.2 Thermal Property Test

The thermal conductivity and thermal diffusivity properties of the sand mixes were determined using the KD 2 Pro Thermal Conductivity Meter (see Figure 1a), during moulding after the pattern is removed, i.e. before coupling. The read temperature is 28.83^0C, the TR-1 (see Figure 1b) and SH-1 (see Figure 1c) sensors are used to measure thermal conductivity and thermal diffusivity, respectively.

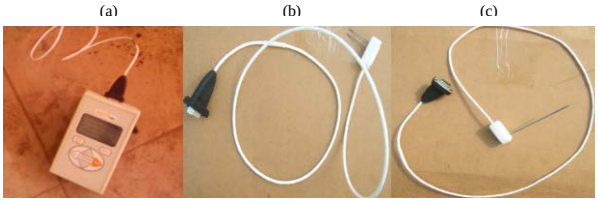

Figure 1. (a) KD 2 Pro Thermal Conductivity Meter, (b) TR-1 sensor (c) SH-1 sensor

The samples are cast using standard casting procedure after melting charge materials. Charge material composition is shown in Table 4.

2.3 Microstructural analysis

Samples for microstructural characterisation were cut, grounded and polished according to the standard procedure outlined in ASTM Standard E3 for metallographic analysis. The prepared samples were viewed in their unetched and etched (using 2% nital solution) conditions using both a CETI Optical Metallurgical Microscope Model No. 0703552 at magnification of X100 located at the Metallurgical laboratory at the University of Lagos, Akoka, Lagos and a Scanning Electron Microscope at magnification of X2000 located at the Mechanical Engineering Laboratory of the Covenant University, Otta Ogun State. Microstructural analysis (nodularity as in Equation 1, nodule count and matrix type) was carried out using manual procedure as outlined in ASTM A247 and E407 standard procedures. The latter technique (SEM) was used to enable a detailed observation of the matrix microstructure resulting from subsequent eutectoid reaction.

$$\text{Nodularity \%} = \frac{\text{area (number) of acceptable particles}}{\text{area (number) of all particles}} \text{ X } 100 \quad (1)$$

Nodule Count (graphite nodules / mm^2) is the quantity of nodules per square millimeter on a polished surface examined at X 100 magnification.

2.4 Hardness Test

Brinell hardness test is carried out using a 10/3000 kg indenter ball on tester model Foundrax/B.H.D/1003402 at the Nigerian Foundries Limited Ilupeju, Lagos in accordance with ASTM E10 standard.

2.5 Tensile Test

Tensile property test was carried out in accordance with ASTM E8 standard using a Universal Instron 3369 Tensometer, system identification number: 3369K1781, located at the Energy Centre of Obafemi Awolowo University, Ile-Ife, Osun State. Regression analysis of plots is done to correlate if significance relationships exist among the variables under investigation, equations and regression coefficients were also predicted.

3. Results and Discussions

3.1 Effect of RHA addition on Moulding Sand Thermal Characteristics

Spectrometric analysis of TWDI samples is shown in Table 5. Figures 2 and 3 show variation of thermal conductivity and thermal diffusivity of the sand mixes with wt. % RHA additive. These thermal properties reduced with increases in wt. % of RHA and this indicated that some level of thermal insulation of the sand mix was achieved. The thermal conductivity of control sample without RHA addition is 1.631 W/m.K and that with 6 wt. % RHA is 1.141 W/m.K. Using RHA

Table 4. Chemical composition of charge materials

Charge	wt. % (Kg)	% of Charge	C (Ch.Comp. %)	Si (Ch.Comp. %)	Mn (Ch.Comp. %)
Mild Steel	300	60	0.1	0.1	0.2
Ductile Iron Returns	80	34	0.1	0.1	0.2
Ferro Silicon	7	1.4	0.0	70	0.0
Graphite	23	4.6	70	0.0	0.0

as moulding additive declined the thermal conductivity by 30% (Ochulor et al., 2017). Showmann and Aufderheide (2003) had obtained similar results when low density alumino-silicate sand (LDASC) was used as sand additive/replacement in thin wall casting study.

Regression analysis shows that the relationship follows a downward exponential trend as in Equation 2.

$$\textit{Thermal Conductivity} = 1.6866e^{-0.0626(\textit{Wt.\% RHA})}$$
$$R^2 = 0.9711 \quad (2)$$

From the Regression analysis, the mould thermal diffusivity varied with wt. % RHA in a decline exponential manner as in Equation 3. Thermal diffusivity reduced by 42% ie0.954 mm^2/s and 0.549 mm^2/s for 0 and 6 wt. % RHA, respectively (Ochulor et al., 2017). These sand properties allow molten metal additional time to maintain its fluidity, hence solidification of melt is delayed in the mould, through reduction in cooling /heat transfer rate. This is expected to hinder metastable transformation that could favour carbide precipitation and other defects, which may occur during high cooling rates, rapid undercooling and high solidification rates.

$$\textit{Thermal Diffusivity} = 0.7757e^{-0.0585(\textit{Wt.\% RHA})}$$
$$R^2 = 0.9464 \quad (3)$$

Table 5. Spectrometric analysis of TWDI samples

Element	C	Si	Mn	S
Comp. (Wt. %)	3.550	2.390	0.230	0.008

Element	P	Mg	Fe	CE
Comp. (Wt. %)	0.017	0.048	93.757	4.350

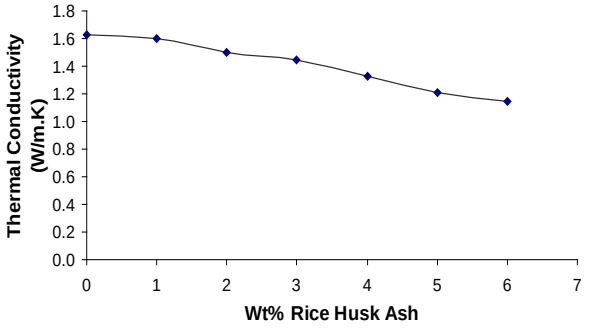

Figure 2. Thermal Conductivity of RHA-sand moulding mix
Source: Ochulor et al. (2017)

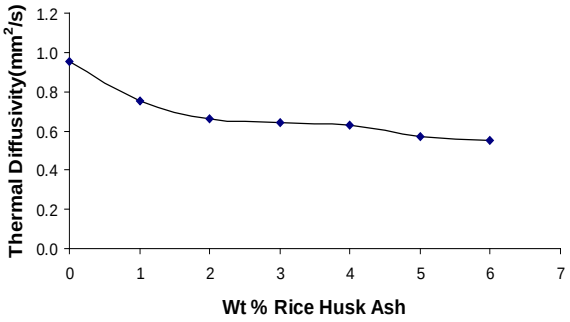

Figure 3. Thermal Diffusivity of RHA-sand moulding mix
Source: Ochulor et al. (2017)

3.2 Effect on Microstructure of Sand – RHA TWDI Cast Samples

Microstructural analysis was carried out using the Optical Microscope and Scanning Electron Microscope (SEM). Microstructure of TWDI cast samples is greatly enhanced through RHA addition to silica moulding sand (Plates 1-7). Excellent nodule characteristics namely; shape, size and number were observed with 4 wt. % RHA. These resulted in good nodularity rating and high nodule counts (Plates 5 –7). The nodule count continues to increase as the wt. % of added RHA increases and this enhances better TWDI properties.

Nodularity rating reached ninety percent (90%) for RH4, RH5 and RH6 samples while the nodule counts for RH5 and RH6 samples were high exceeding 1,000nodules/mm^2. Table 5 shows nodularity and nodule counts for 2 mm TWDI samples.

Table 5. Nodularity and nodule count results for RHA samples

No	Sample	Nodularity (%)	Nodule Count (nodules/mm^2)
1	RH-2	84	341
2	RH1-2	86	678
3	RH2-2	87	547
4	RH3-2	89	721
5	RH4-2	97	1376
6	RH5-2	97	1693
7	RH6-2	98	1974

These occurrences promote structure homogeneity as observed by Labrecque et al., (2005). The matrix consists of varying proportions of carbide, ferrite and pearlite for RH (control), RH1, RH2 samples while carbide free structure and mostly ferrite and pearlite of the bull-eye structure-type dominated the remaining cast

samples using higher weight percent of RHA. Pearlite structure is the highest in RH4 samples, but reduces in RH5 and RH6 samples due to increased carbon diffusion giving way to larger ferrite matrix proportion.

3.3 Nodularity, Nodule Count and Matrix type

Nodularity and nodule count is established during solidification and can only be modified by remelting. RHA additions to moulding sand result in thermal conductivity reduction owing to reduction in cooling rate and this enhances the nodule count and nodularity ratings. This occurrence is comparable with that obtained in the study by Showmann and Aufderheide, (2003) when low density alumino-silicate sand (LDASC) was used as sand additive/replacement. Nodularity ratings of ≥ 80% was observed for all samples cast using sand-RHA mix with peak value of 98% at 6 wt. % RHA addition. Nodule count also followed the same trend reaching its maximum of 1974 nodules/mm^2 at 6 wt % RHA addition.

The final microstructures consist of graphite nodules formed during eutectic solidification with the matrix phases of ferrite, pearlite or carbides formed from subsequent eutectoid decomposition. These transformations depend on rate of carbon diffusion.

Annex-1 contains Plates 1-7 that are the optical and SEM micrographs of 2 mm TWDI samples. The control sample produced from sand mould without RHA addition showed the presence of carbide precipitates as evident in Plate 1c. This carbide precipitates obtained from metastable transformation lowers ductility and tensile strength. During solidification of RH-2 sample in the sand mould of thermal conductivity of 1.631 W/m.K, there was rapid heat transfer from the melt, which inhibited the formation of significant number of graphite nodules before melt solidification. Matrix in RH-2 sample consists of ferrite, pearlite and carbides as in Plates 1a, 1b and 1c with nodule size of ~10µm.

Sand mould with 1 wt. % RHA addition has lower thermal conductivity (1.601 W/m.K) slightly less than 1.631 W/m.K which is that of the control sand mould ie 0 wt. % RHA (Ochulor et al., 2017). Thus, there was no significant change in microstructure as evident in Plates 2a, 2b and 2c, which do not differ much from those of Plates 1a, 1b and 1c. This trend is also observed in Plates 3a, 3b, 3c, 4a, 4b and 4c, though to a much lower degree in terms of volume of carbide precipitated as the thermal conductivity decline with increase in wt. % RHA. Matrix of the cast consists of ferrite, pearlite and carbides.

Plates 5a, 5b and 5c show improved nodularity and nodule counts with carbide free matrix containing large pearlite volume. Nodule size ranges from 5-10 µm, however for Plates 6a, 6b, 6c. 7a, 7b and 7c, large volume of ferrite phase was observed due to decreased carbon content in melt available for eutectoid reaction as most of this carbon formed nuclei for graphite nucleation during eutectic solidification, nodule size also ranges between 5-10 µm.

3.4 Hardness Analysis of Sand – RHA TWDI Cast Samples

The variation of hardness of TWDI cast produced from moulding sand-RHA mix is shown in Figure 4. The hardness values displayed a linear relationship with wt. % RHA, which decreases as wt. % RHA increases in the sand mix. Regression plots conform to this relationship as given in Equation 4. This pattern agrees with Gorny and Tyrala (2013) position, that cooling rate affects the maximum degree of undercooling at the beginning of graphite eutectic solidification and consequently, the structure of the iron in terms of the number of graphite nodules and metal matrix.

The BHN values for the samples that showed carbide free matrix namely; RH4, RH5 and RH6 are attributed to the large volume fraction of pearlite phase in the matrix for RH4 (Labrecque et al., 2005; Sangame and Shinde, 2013), which dropped at 5 and 6 wt. % RHA where increased ferrite volume was observed. The increased ferrite volume occurred as a result of more graphite segregation with cooling rate decline, leading to higher nodule counts (>1,000 nodules/mm^2). The control sample - RH corresponds to the highest BHN (207), which is attributed to the large volume of carbide precipitates as in Plate 1 followed by 195 as in Plate 2 for RH1 samples.

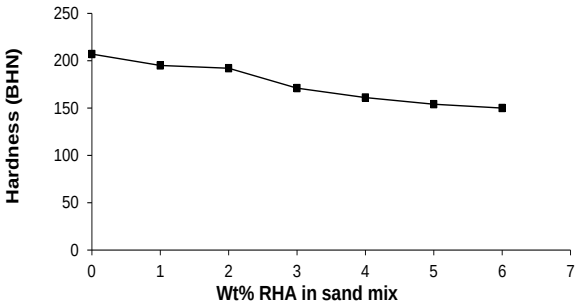

Figure 4. Variation of BHN of TWDI samples with Weight % RHA

Regression analysis shows that the relationship of wt. % RHA in sand mould on BHN follows a linear relationship governed by Equations 4.

$$BHN\ (_{2mm}) = -10.143(RHA\ _{Wt.\ \%}) + 206.14$$
$$R^2 = 0.9642 \quad (4)$$

3.5 Tensile Test of Sand – RHA TWDI Cast Samples

The UTS of the TWDI sample improves as RHA addition (Figure 5). The control samples cast in silica sand moulds gave UTS of 248 MPa, which corresponds

to lowest tensile strength in the plot. The highest UTS values of 564 MPa is observed for sample cast in 4 wt. % RHA silica sand mould at which the matrix is free from carbide precipitates. This is attributed to large volume fraction of pearlite phase in matrix as in Plates 5-7 (Labrecque et al., 2005; Sangame and Shinde, 2013). The percent elongation at fracture is highest for samples cast with 4-6 wt. % RHA in moulding sand. The highest value of 4.7 is observed for the samples at 6 wt. % RHA as in Figure 6. This is attributed to the increased ferrite volume, as cooling rate reduced in mould blend with 4-6 wt. % RHA. This finding agrees with that of Sangame and Shinde (2013) where pearlitic content of as-cast DI influences its nodule count. Increasing the nodule count decreases both the pearlite content and tensile strength while improving percent elongation.

The Regression analysis for the data shows a quadratic relationship of wt. % RHA in sand mould and UTS as in Equation 5.

$$UTS\ (_{2mm}) = -3.9155(RHA\ _{Wt.\%})^2 + 53.432(RHA\ _{Wt.\%}) + 229.22$$
$$R^2 = 0.8601 \quad (5)$$

As for the elongation, regression analysis shows linear relationship of wt. % RHA in sand mould with percent elongation as in Equations 6.

$$\%\ _{Elong.}\ (_{2mm}) = 0.4107(RHA\ _{Wt.\%}) + 2.025$$
$$R^2 = 0.9684 \quad (6)$$

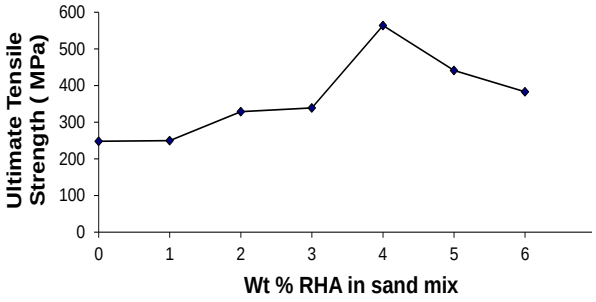

Figure 5. Variation of UTS of TWDI samples with Weight % RHA

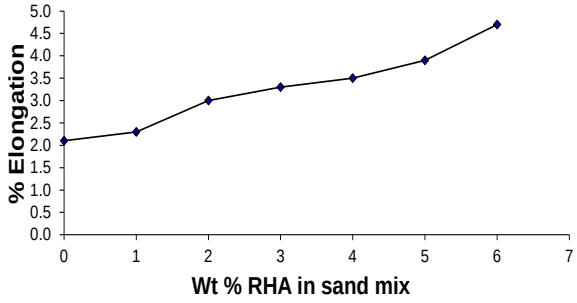

Figure 6. Variation of Percent elongation of TWDI samples with Weight % RHA

Samples cast using sand-RHA mix showed improved microstructures and mechanical properties over the control samples (0 wt.% RHA). This is mainly attributed to ability of mix to lower thermal conductivity (see Figure 4) as the quantity of RHA increased. The controlled heat transfer with reduction in undercooling during the eutectic solidification process favoured formation of stable transformation products namely; graphite structures instead of metastable product of carbide precipitates.

The matrix microstructure in DI is the result of austenite decomposition, which is further influenced by chemical composition and cooling rate, as-cast microstructure is known to be directly influenced by alloy content and cooling rate (Sangame and Shinde, 2013). The cooling rate is affected by the section thickness and rate of heat removal. This in turn depends on mould geometry, mould material, treatment and pouring temperature. Thus, the mechanical properties of TWDI are influenced by graphite shape characteristics and matrix type.

Tensile strength and BHN values showed similar trend for all samples cast using the different sand mixes with improvement in these properties observed up to 4 wt. % RHA in sand mould before dropping slightly at 5 and 6 wt. % RHA mould additive. These values are due to increased graphite segregation. Increased graphite segregation results from increased solidification time, which favours more active nuclei for graphite nodule formation vis-a-vis the case of reduction of solidification time for moulds with higher thermal conductivity and diffusivity. This leads to increased nodule count, better structure homogeneity (Labrecque et al., 2005), increased volume of ferrite phase and percent elongation (better ductility) but at expense of a decline in UTS and BHN at 5 and 6 wt. % RHA samples. At 6 wt. % RHA addition, the mechanical properties meet ASTM property standard specification (Spec. No. A536-80 (80-50-06)) for automotive application.

3.6 Conclusion

This study has shown that the addition of RHA to silica moulding sand led to the achievement of desired microstructure in cast 2 mm TWDIs. . As the weight percent of RHA increased in the sand mould, sufficient time is allowed for formation of potent nuclei for graphite nodule formation, thereby impeding carbide precipitation. Besides, it is possible to obtain carbide free, good nodules and nodule counts in TWDI castings through modification of the thermal properties of moulding sand. This is targeted at reduction in cooling rate with increased solidification time.

The results show that samples cast in 4, 5 and 6 wt. % RHA - moulding sand mix, show good nodularity ratings > 90%, high nodule counts >1,000 nodules/mm^2 with high tensile strengths of 564 MPa and ductility of

4.7 for 2 mm thick samples from 4 and 6 wt. % RHA additions, respectively.

This study is targeted at improving the mechanical properties of Thin Wall Ductile iron (TWDI) used for automotive part manufacture by control cooling to avoid excessive carbide precipitation with improved nodularity and nodule count. This has been achieved using the sand-RHA mix which shows lower thermal conductivity than the silica moulding sand.

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References:

Abed, E.J. (2011), "The influence of different casting method on solidification time and mechanical properties of Al-Sn castings", *International Journal of Engineering and Technology* (IJET-IJENS), Vol.11, No.6, pp.26-33

Aigbodion, V.S., Hassan, S.B., Olajide, S.O., Agunsoye, O.J., Abdulrahaman, A.S. and Okafor, G.E. (2009), "The use of rice husk ash as an aggregate for foundry sand mould production", *Journal of Metallurgy and Materials Engineering*. Vol 4, No. 2, pp 11-17

Aribo, S. (2011), "Effect of varying corn cob and rice husk ash on properties of moulding sand", *Journal of Minerals and Materials Characterisation and Engineering*, Vol.10, No.15, pp.1449-1455.

Cantor, B. (2003), *Solidification and Casting*, Series in Materials Science and Engineering, CRC Press. United Kingdom

Gorny, M. (2009), "Temperature drop in liquid iron in thin wall channels during mould filling", *Archives of Foundry Engineering*, Vol.9, No.1, pp.137-142

Gorny, M. and Tyrala, E. (2013), "Effect of cooling rate on microstructure and mechanical properties of thin wall ductile iron castings", *Journal of Materials Engineering and Performance*, Vol.22, No.1, pp.300-305

Ochulor E. F, Amuda M.O. H, Adeosun S. O, Balogun S. A (2017) "Effect of aluminum dross and rice husk ash on thermal and moulding properties of silica sand", *Nigerian Journal of Technology*, Vol.36, No.3, pp 794-800

Kalpakjian, S. (2008), *Manufacturing Processes for Engineering Materials*, Fifth Edition, Pearson, USA

Labrecque, C., Gagné, M. and Javaid, A. (2005), "Optimising the mechanical properties of thin-wall ductile iron castings", *AFS Transactions* (Schaumburg, IL USA), Vol.05-116, No.5, pp.1-10

Ochulor, E.F., Amuda, M.O.H., Adeosun, S.O. and Balogun, S.A. (2016), "Mechanical properties of thin wall ductile iron cast in moulding sand aluminium dross mix", *The West Indian Journal of Engineering*, Vol.39, No.1, pp.17-24

Rihan, Y. (2010), "Numerical study on the effect of solidification parameters during the continuous casting of Al-Si alloys", *The Online Journal on Mathematics and Statistics* (OJMS), Vol.1, No.1, www.infomesr.org.

Ruxanda, R.E., Stefanescu, D.M. and Piwonka, T.S. (2002), "Microstructure characterisation of ductile thin wall iron castings", *AFS Transactions*, Vol. 110, pp.1131-1147.

Sangame, B.B. and Shinde V.D. (2013), "The effect of inoculation on microstructure and mechanical properties of ductile iron", *IOSR Journal of Mechanical and Civil Engineering* (IOSR-JMCE), Vol.5, No.6, pp.17-23.

Schmidt, D. (2010), Solid Cast, Effective Casting Simulation, Solidification Time. Finite Solutions Incorporated. Version 8.0.93.

Sheikh, M.A. (2008), "Production of carbide-free thin ductile iron castings", *Journal of University of Science and Technology Beijing*, Vol.15, pp.552-555

Showman, R. and Afderheide, R. (2003), "A process for thin wall castings", *AFS Transactions*, Vol.111, pp.567-578

Stefanescu, D.M., Dix, L.P., Ruxanda, R.E., Corbitt-Coburn, C. and Piwonka, T.S. (2002), "Tensile properties of thin wall ductile iron", *AFS Transactions*, Vol.110, pp.1149-1162.

Annex-1:

Optical and SEM micrographs of 2 mm TWDI samples

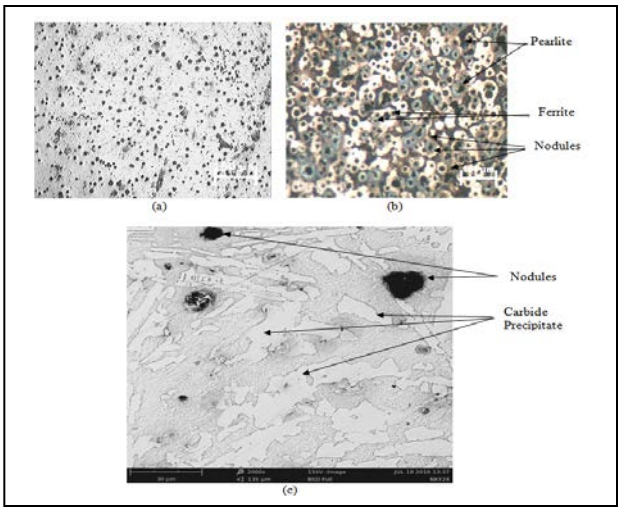

Plate 1: RH- 2 mm Micrograph (a) unetched Optical (b) etched Optical (c) etched SEM

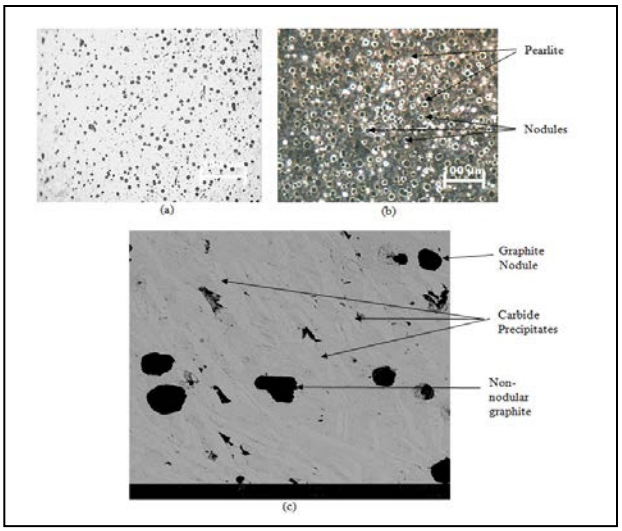

Plate 2: RH1- 2 mm Micrograph (a) unetched Optical (b) etched Optical (c) etched SEM

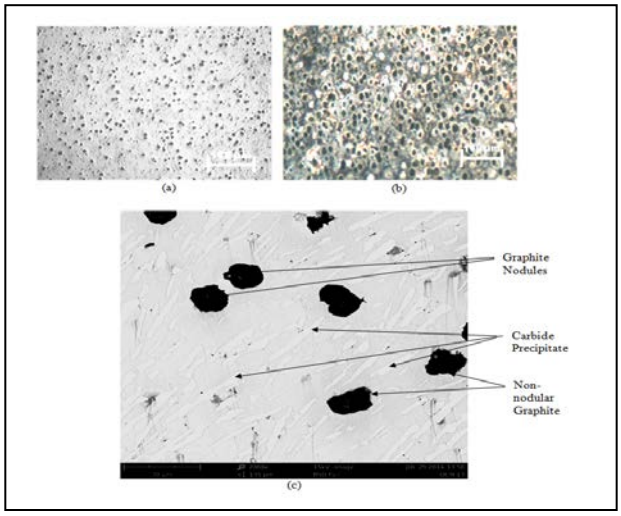

Plate 3: RH2- 2 mm Micrograph (a) unetched Optical (b) etched Optical (c) etched SEM

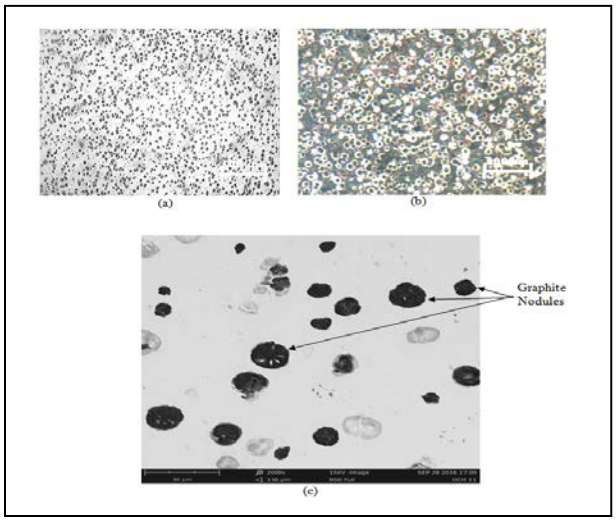

Plate 6: RH5- 2 mm Micrograph (a) unetched Optical (b) etched Optical (c) etched SEM

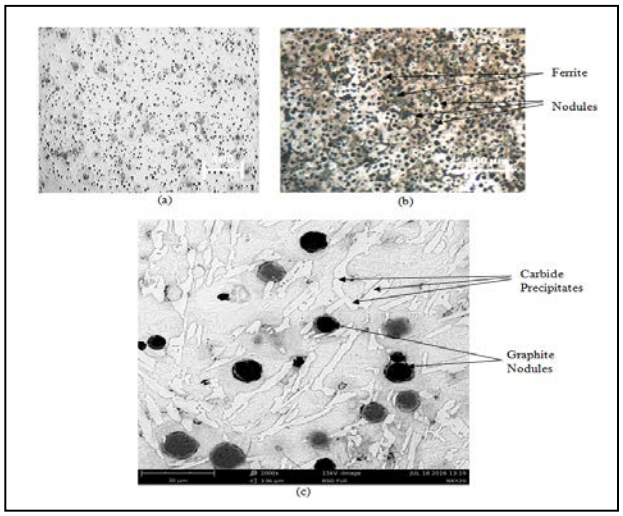

Plate 4: RH3- 2 mm Micrograph (a) unetched Optical (b) etched Optical (c) etched SEM

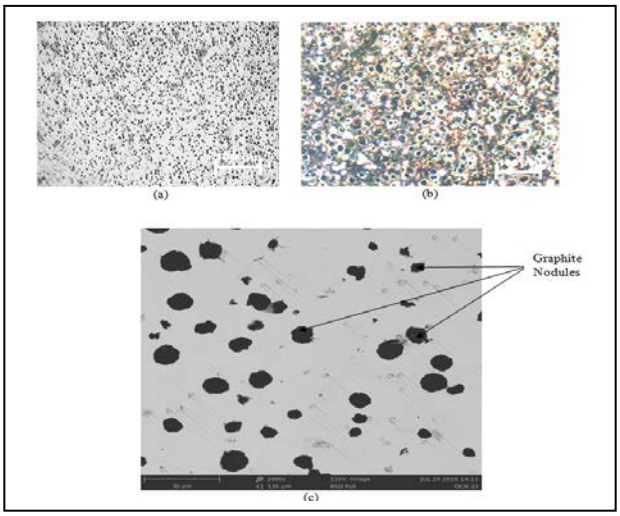

Plate 7: RH6- 2 mm Micrograph (a) unetched Optical (b) etched Optical (c) etched SEM

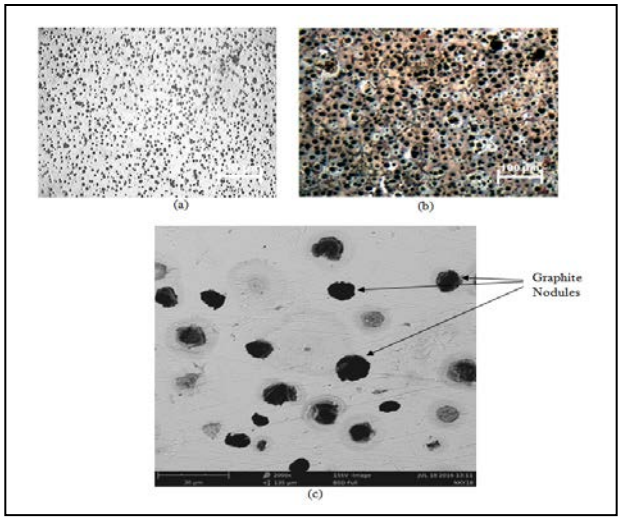

Plate 5: RH4- 2 mm Micrograph (a) unetched Optical (b) etched Optical (c) etched SEM

Authors' Biographical Notes:

Ezenwanyi Fidelia Ochulor *is a faculty member of the Department of Metallurgical and Materials Engineering, University of Lagos, Nigeria. She holds a Master's of Science and Ph.D. degree from the same department, and Bachelor's degree in Engineering from the Federal University of Technology Owerri (FUTO), Nigeria. Her areas of research include materials processing, development and characterisation.*

Mohammed Olawale Hakeem Amuda *is an Associate Professor/Reader in the Department of Metallurgical and Materials Engineering, University of Lagos, Lagos, Nigeria. He holds a PhD in Materials Science and Engineering from the International Islamic University Malaysia, a Master's of Science in Mechanical Engineering, University of Lagos, Nigeria and Bachelor's degree in Metallurgical and Materials Engineering from the Obafemi Awolowo University, Ile-Ife, Nigeria. His research interests span materials development and processing for emerging technologies such as low energy fusion welding processes and surface modification of metallic materials for*

improved corrosion and thermal efficiency. Professor Amuda is currently working on laser cladding of aerospace grade titanium alloy with premix carbide+boride ceramics for extreme conditions. Other works include characterisation of flow behaviour in AA 7075 aluminum alloy during hot deformation, and optimisation of design parameters of flame torch melting for surface modification. He was a visiting scholar at the University of Johannesburg and the International Islamic University Malaysia.

Samson Oluropo Adeosun *is a full Professor in the Department of Metallurgical and Materials Engineering, University of Lagos, Nigeria. His works are in the area of materials development, processing and characterisation. He currently works on biodegradable polymer composites for orthopaedic applications and ferrous/non-ferrous alloy and its composites for high temperature and wears applications.*

Sanmbo Adewale Balogun *is currently a contract Professor in Bells University of Technology, Ota. Nigeria. He holds a Bachelor's, Master's and PhD degrees in Industrial Metallurgy and Management Techniques. He started his academic career in 1972, and was appointed Full Professor in the University of Lagos in 1983. Professor Balogun received training in Iron and Steel production in various steel plants in the old Soviet Unio,n and was a visiting research fellow to the Steel Casting Research & Trade Association (SCRATA), Drop Forging Research Association (DFRA) in England and the Central Metal-Forming Institute (CMFI) and the Hindustan Machine Tool Co. Limited Hyderabab, India. He serves as Chairman of Technical Committee on Iron and Steel of the Standard Organisation of Nigeria, Chairman of the Examination and Certification Board of the Nigerian Society of Engineers, and Chief Interviewer of the Council for the Regulation of Engineering in Nigeria for Mechanical, Production, Chemical and Materials Engineering fields. He is a Chartered Engineer, a fellow of the Nigerian Society of Engineers and the Nigerian Academy of Engineering.*

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Predicting Student Performance in a Caribbean Engineering Undergraduate Programme

Richelle V. Adams [a,Ψ] and Cathy A. Radix[b]

Department of Electrical and Computer Engineering, Faculty of Engineering, The University of the West Indies, St. Augustine, Trinidad and Tobago, West Indies
[a]E-mail: Richelle.Adams@sta.uwi.edu
[b]Email: Cathy.Radix@sta.uwi.edu

[Ψ] *Corresponding Author*

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Abstract: *In the Caribbean context, entry into university is primarily based on Caribbean Examinations Council (CXC) qualifications, and specifically the CXC Advanced Proficiency Examination (CAPE). The goal of this work is to examine the degree to which CAPE entry-grades predict both student final-graduating and in-programme course performance in a Caribbean engineering undergraduate programme. The data set included graduation, course and entry data for 140 students who graduated from the programme between 2014 and 2016. Students in the sample had grades in the four CAPE units associated with Pure Mathematics and Physics upon entry into the programme. The data set was analysed using cross-correlation, linear regression, classification and logistic regression. We note that a significant correlation of 0.40 to 0.51 exists between the scores of the four CAPE units. However, the multiple linear regression models reflect the relatively low influence of two of the CAPE units on graduating and course GPA. Despite the poor fit of the regression models (i.e., R^2 of 17% for graduating GPA and R^2 of 7% for course GPA) we were able to demonstrate clear patterns in the success rates, based on entry bands (e.g., approximately 45% of top-scoring entrants graduate with First Class Honours degrees, whereas 12.5% of lower-scoring entrants achieved same). There was no inherent bias by gender or entry band in any of the models generated. The results suggest that the entry criteria serve as a means of predicting the probability of achieving success, rather than the actual success level.*

Keywords: *Entrance qualifications, performance prediction, undergraduate engineering education*

1. Introduction

Globally, universities are focused on improving their student intake, whether by expanding the range of input standards they are prepared to accept, or improving access mechanisms for under-represented populations (Bridgeman et al., 2008). The increased variability in the student background requires academic institutions to be deliberate in their efforts to ensure that there is no concomitant impact on throughput/success levels due to students being unable to perform appropriately (Lee et al., 2008; Badr et al., 2016). That said, the ability of the entrance scores, based on varied criteria, to predict performance has increasingly been called into question (Barry and Chapman, 2007), with some authors suggesting that depending on the degree discipline, specific subject/pre-test scores (Othman et al., 2012), or first-year course scores provide better predictors (Badr et al., 2016; Lee et al., 2008).

In the Caribbean context, entry into university is primarily via assessments by the Caribbean Examinations Council (CXC) – specifically, CXC Advanced Proficiency Examinations (CAPE) (CXC 2015). The goal of this work is to examine the ability of CAPE entry grades to predict both student final-graduating and in-programme course performance in a Caribbean engineering undergraduate programme.

For entry into Bachelor of Science (BSc) (Engineering) - Electrical and Computer Engineering programme at The University of the West Indies, St. Augustine Campus, applicants must fulfil the University's general matriculation requirements, as well as have suitable grades in Chemistry, Pure Mathematics and Physics. Success in the programme is defined as being able to achieve Chartered Engineering status (IET, n.d.) post-BSc graduation, by entry into a matching-section Masters programme, which nominally requires a GPA $\geq$ 2.0. A highly successful student would be a student with a First Class Honors degree, which requires a GPA $\geq$ 3.6

2. Related Caribbean Works

Over the period 1990-2003, the College of Engineering at the University of Puerto Rico in Mayaguez (Gonzalez-Barreto and Gonzalez-Quevedo, 2005) examined the GPA that their freshmen achieved at the end of their first-year with a number of entry variables such as gender, school type (whether or public or private), high school grade-point average (GPA), performance in the Mathematics and Spanish verbal aptitude tests by the Puerto Rico and Latin America College Entrance Examination Board (CEEB), as well as three (3) other CEEB variables, namely Mathematical Knowledge,

English Language Knowledge and Spanish Language Knowledge. These are components that comprise their admission criteria. The admission index (called IGS) comprises the high-school GPA, the CEEB Verbal and Mathematics aptitude scores. Prior to 1995, these three criteria contributed equally to the IGS, but thereafter, the weighting became 2:1:1. The authors attempted to determine the suitability of using such a weighting for the IGS, and to propose more optimal ones. Excluding gender and school type, models comprising subsets of the variables which served as predictors were created. The bases for comparing the quality of the models were the minimum mean square error and the Cp Mallows statistic. One of the findings is that the set of predictors comprising the best three-variable model differed from what was currently being used in the IGS, and even that "best" model was not sufficient to describe the First-Year GPA (FYGPA) variability, thus alluding to other factors contributing to the students' first year performance.

Muddeen and Mallalieu (2016) discussed steps taken by the Department of Electrical and Computer Engineering (DECE) at The University of the West Indies (UWI), St. Augustine Campus, to specifically address the declining performance in first year Engineering Mathematics as part of a comprehensive curriculum review undertaken by the department. There were no predictive models developed in this study, but rather a qualitative discussion of the factors attributing to the poor performance in Mathematics such as the entry qualifications of the students, the content of the Mathematics courses being offered to students in the department, as well as the assessment and delivery strategies employed within the Mathematics courses. The authors also described the interventions to improve the Mathematics performance, as well as the result of those interventions.

The study by Pottinger et al. (2009) was based at The UWI, Mona Campus. The main objective was to compare the performance (in terms of GPA), social adjustment and academic challenges of students who did not have a hidden (nonphysical) disability (such as, Attention Deficit Hyperactivity Disorder (ADHD) and Psychiatric Disabilities (PD)) with those who did, particularly in their second year, given that all of the students would have met the criteria for entry into their respective programmes at the university. Besides discovering that the students with hidden disabilities did perform more poorly academically than their peers due to their learning challenges, they also discovered through their intake checklist, that regardless of having a disability, students' ability to manage time was important to achieving academic success.

Golding and Donaldson (2006*a*) conducted a study at the University of Technology, Jamaica (UTECH) and their aim was to determine the relationship between academic performance (final GPA) of students in the Bachelor of Science in Computing and Information Technology (BSCIT) Degree program and their matriculation requirements as well as their performance in first-year courses. They proposed that the results of this study be used in restructuring their admission policies. The three hypotheses they sought to test were: 1) Mathematics and English CXC and GCE O' Level grade quality do not have a direct impact on students' academic performance; 2) performance in 1st year Programming and Computer Science courses does not have an impact on students' performance; and 3) gender and age do not determine the level of students' success in Computer Science. Using simple linear regression, they found that English CXC was not a strong factor, and CXC Mathematics was a poor predictor. They were able to isolate one of their gateway courses that can help predict students' future performance, thereby rejecting the second null hypothesis. They also found that gender and age had no impact on their students' performance.

Mlambo (2011) investigated the factors that affect student performance in a specific course: "Introduction to Biochemistry" (Agri 1013). Exploratory variables included age (young, mature), gender (male, female), learning style (Visual, Aural, Read/Write, Kinesthetic, Multimodal), entry qualifications (CAPE, GCE A' Levels, Associate Degree, CXC only, Other, Diploma in Agriculture). He found that none of these factors significantly impacted academic performance in that course.

Sastry et al. (2007) described the authors' experiences in establishing and administering joint degree programmes between the University of the West Indies and the University of Trinidad and Tobago, specifically, the Bachelor of Technology Degrees in Mechanical and Electrical Engineering which targets engineering technicians and technologists, which traditionally would not likely have CAPE A' Level grades as entry qualifications. No explicit admission criteria were stated and no models were employed.

3. Background to the Study

The study of admission criteria for validity and as suitable predictors of university performance has been pursued at many institutions around the world (e.g., Australia (Whyte et al., 2011), Bulgaria (Kabakchieva 2013), Canada (Cyrenne and Chan, 2012), Jamaica (Golding and Donaldson, 2006), Kingdom of Bahrain (Alnasir and Jaradat, 2011), New Zealand (Shulruf et al., 2008), Thailand (Vuttipittayamongkol, 2016), the United Kingdom (Whyte et al., 2011; Kevern et al., 1999), the USA (Abele et al., 2013, Cohn et al., 2004, Maruyama, 2012, Venezia and Voloch, 2012, Sedlacek, 2003, Garton et al., 2000)), across a variety of programmes and disciplines such as Nursing (Whyte et al., 2011, Abele et al., 2013, Kevern et al., 1999), Information Technology (Golding and Donaldson, 2006), Medicine (Alnasir and Jaradat, 2011), Agriculture (Garton et al., 2000) and Business (Rothstein et al. 1994, Kuncel et al., 2007), and

at both the undergraduate and graduate levels (Rothstein et al. 1994; Kuncel et al., 2007, 2001).

The main reasons for conducting these studies have been to determine how to improve (Whyte et al., 2011) or optimise (Golding and Donaldson, 2006) the student selection process for entry into the programme; to identify students who should be denied admission (Alnasir and Jaradat, 2011); to determine how to make scholarship decisions so those who would most likely succeed in college would receive the help to do so (Cohn et al., 2004); to predict those will be matched behaviorally to the programme of study (Kuncel et al., 2007); to improve recruitment, retention and to reduce wastage (Kevern et al., 1999; Kuncel et al., 2001); and to protect the field of study from weakening (Kuncel et al., 2001). In Shulruf et al. (2008), different formulations of the entrance qualifications were used to see if the profile of eligible applicants would change.

Some researchers, however, have suggested that the motives for conducting such studies on entrance qualifications be more developmental, for example, to identify students who may be at risk of failing (Whyte et al., 2011; Crede and Kuncel, 2008), so that additional assistance may be given to these prospective students prior to entering the programme (Abele et al., 2013). The results of these studies can aid students to determine for themselves their own level of readiness for college and may help them improve in this regard (Maruyama, 2012). These studies can inform effective strategies to help students transition successfully to the college/university environment (Venezia and Voloch, 2012). Also, by using the results of these analyses, counseling and teaching staff can proactively identify ways to address learning differences and challenges among students of an incoming cohort (Crede and Kuncel, 2008; Garton et al., 2000).

Triggers for these studies included, for example, programmes facing an increase in the number of applicants (Golding and Donaldson, 2006) vying for a limited number of places. On the other hand, another trigger would have been high attrition rates encountered by particular programmes (Abele et al., 2013) possibly due to a lack of alignment between the demands of high school and college/university (Venezia and Voloch, 2012). Another trigger could be unexpected student failures in spite of these same students having good entrance qualification scores (Crede and Kuncel, 2008).

Although the main interest among the studies is admission criteria, their objectives varied. For example, Whyte et al. (2011) wanted to predict the probability of student success in a number of subjects given the entrance qualifications and other factors. However, Abele et al. (2013) wanted to identify those courses that can predict student success. In the work done by Cohn et al. (2004), it was the degree to which SAT scores, high-school GPA and class rank could predict success in college that was examined. Cyrenne and Chan (2012) wanted to examine the usefulness of high school grades as a predictor of university performance, and Maruyama (2012) wanted to determine if the ACT scores are satisfactory indicators of college readiness at the aggregate level. In Shulruf et al. (2008), alternative models for university entrance were explored.

4. Methodology and Findings

The goal of this work is to examine the degree to which CAPE entry-grades predict:

- Student final-graduating GPA (i.e., the predicted value and whether it will exceed 2.0)
- In-programme course performance, and
- Time from entry to graduation

for students in the B.Sc. Electrical and Computer Engineering programme. The methodology used in the study is based on methods described in Bridgeman et al. (2008), Barry and Chapman (2007), Badr et al. (2016), and Lee et al. (2008). The statistical computing software, R version 3.1.3 (2015-03-09) (R Core Team, 2015) was used to carry out the analysis. Specifically, the major functions used were **lm** and **cor.test** from the **stats** package to perform the linear regression and correlation analyses; **regsubsets** from the **leaps** (Lumley and Miller 2004) to perform the model reduction; and **clm** from the **ordinal** package (Christensen, 2015) to perform the logistic regression.

The input data set was based on graduation, course and entry data for 140 students who graduated from the program between 2014 and 2016.These students had Caribbean Advanced Proficiency Examinations (CAPE) grades in Pure Mathematics and Physics upon entry into the programme. The highest grade in any CAPE unit is one, and this assigned a score of five points; the second-highest is two and this assigned a score of four points and so on. The lowest score of one point is assigned a grade of five. The average score of Physics Unit 1 and Physics Unit 2 is added to the average score of Pure Mathematics Unit 1 and Pure Mathematics Unit 2 to determine the overall entry score for each student. Additional Mathematics may also be considered but it is not a mandatory qualification. The data set is summarised in Table 1.

91.7% of the students graduated with a GPA greater than 2.00 and 27.9% graduated with a GPA greater than 3.60. The ratio of male to female graduating students was 2.9 to 1, whereas the ratio of male to females graduating with a GPA greater than 3.60 narrowed to 2.25 to 1. It should be noted that no student who entered the programme having an entry score greater than ten (10) points graduated with a GPA less than 2.00. In fact, a higher proportion of the students in this “greater than 10 point” entry-band graduated with a GPA greater 3.60 (i.e., 29/65), than in any other entry- band (i.e., 7/56, and 3/19).

Table 1. Summary table: Input data-set students graduating between 2013/14 to 2015/16

	Entry Score									**Full**		
	>10 points			**>8 and <10 points**			**≤ 8points**					
Gender	Male	Female	Overall	Male	Female	Overall	Male	Female	Overall	Male	Female	Overall
No. of students	44	21	65	44	12	56	16	3	19	104	36	140
Average Graduating GPA	3.42	3.58	3.48	2.94	2.96	2.95	2.82	2.91	2.83	3.12	3.32	3.17
Average ECNG 2001 GPA	2.85	3.42	3.03	2.69	2.39	2.63	2.33	2.67	2.37	2.70	3.01	2.78
No. of students with GPA<2.00	0	0	0	2	0	2	2	0	2	4	0	4
No. of students with GPA>3.60	18	11	29	1	6	7	3	0	3	27	12	39

For each entry-band, females, though fewer in number, scored higher graduating GPAs than their male counterparts, on average. The same could be said for their performance in the course ECNG 2001: Communication Systems I, except for the "8 to 10 point" entry-band.

In comparison, the datasets used for the studies in the literature (Bridgeman et al., 2008; Barry and Chapman, 2007; Badr et al., 2016; Lee et al., 2008) are either larger, or involve a different number of cohorts, where Bridgeman et al.(2008) looked at 3 cohorts of students across multiple programmes and 26 colleges. Badr et al.(2016) looked at 6 cohorts of students (200 students) from a single programme, and Lee et al.(2008) examined a single cohort of students (133 students) from a single program. This suggests that the methods used are not dependent on the specific programme, and/or the number of cohorts involved, and that the quantity of data available for this study is sufficient.

Lee et al. (2008) and Barry and Chapman (2007) outlined the creation of linear regression models to establish the significance of predictive factors in course performance models. In this work, linear regression models were developed for both graduating GPA and achievement level in a mathematically-based second-level course (ECNG 2001) using the CAPE Pure Mathematics and Physics grades as the predictors. The models are summarised in Table 2 where the individual coefficients, their respective p-values and levels of significance are provided. It has become almost standard practice to use traditional regression analysis in studies of similar type to characterise the relationship between an outcome that serves as a measure of student performance and a set of controlled variables or predictors (e.g., entrance scores). Besides, Lee et al. (2008) and Barry and Chapman (2007), other studies that employed linear regression include Vuttipittayamongkol (2016), Shulruf et al., (2008), Whyte et al., (2011), Cohn et al., (2004), Alnasir and Jaradat (2011), and Rothstein et al. (1994).

For the graduating GPA the regression model was $0.05P_2 + 0.17P_1 + 0.20M_2 - 0.03M_1 + 1.40$, where P_1 denotes the Physics Unit 1 grade, P_2, Physics Unit 2 grade, M_1, Pure Mathematics Unit 1 grade and M_2, Pure Mathematics Unit 2 grade. The p-value of 5.254e-05 for the overall model suggests that the overall relationship between the graduating GPA and the regressors taken together was statistically significant. However, the p-values for the individual regressors suggest that Pure Mathematics Unit 1 and Physics Unit 2 were not found to be statistically significant, whereas that of Pure Mathematics Unit 2 and Physics Unit 1 were. The coefficient of determination (R^2) was 17%, meaning that the regressors under study only accounted for 17% of the variability in graduating GPA. For the ECNG 2001 course GPA, the regression model seemed to not have as good a fit. In fact, the coefficient of determination was 7% and the p-value was borderline (i.e. 0.03772). The only variable with a significant coefficient was Pure Mathematics Unit 2.

Table 2. Multiple linear regression models for course and graduating GPA

	Variable	**Coefficient**	**Standard error**	**t**	***Pr* (> |*t*|)**	**Significance**
Graduating GPA	Intercept	1.40624	0.47345	2.970	0.00352	0.01
	Maths Unit 1	-0.03469	0.11579	-0.300	0.76495	nil
	Maths Unit 2	0.19941	0.08100	2.462	0.01508	0.05
	Physics Unit 1	0.17322	0.08302	2.087	0.03881	0.05
	Physics Unit 2	0.05065	0.08780	0.577	0.56501	nil
	R-squared: 0.1674; Adjusted R-squared: 0.1427; p-value:5.254e-05					
Course GPA	Intercept	0.94871	0.94426	1.005	0.3168	nil
	Maths Unit 1	0.03828	0.23093	0.166	0.8686	nil
	Maths Unit 2	0.33591	0.16154	2.079	0.0395	0.05
	Physics Unit 1	-0.21224	0.16557	-1.282	0.2021	nil
	Physics Unit 2	0.23329	0.17511	1.332	0.1850	nil
	R-squared: 0.07203; Adjusted R-squared: 0.04454; p-value:0.03772					

To examine the relationships further, the cross-correlations among the variables and between each variable and the outcome (i.e., graduating GPA and ECNG 2001 course GPA) were determined. These are listed in Table 3. All the variables posted significant correlations with graduating GPA. However, Physics Unit 2 and Pure Mathematics Unit 1 were not as strong in correlation as the other two variables. Only the grade in CAPE Pure Mathematics Unit 2 was reasonably (and positively) correlated with the performance in ECNG 2001.

There were two (2) other interesting observations. The first was that there was very high correlation between ECNG 2001 performance and the graduating GPA. The second was that there were comparatively significant positive correlations among the predictor variables, i.e., CAPE units, than between these individual CAPE units and the graduating GPA. The correlation among the predictor variables ranged from 41% to 54% with the highest being between Physics Unit 1 and Physics Unit 2, and the second highest being between Pure Mathematics Unit 1 and Pure Mathematics Unit 2 (51%). This multi-collinearity can significantly increase the standard errors of the coefficients which, in turn, can reduce the overall effectiveness of the regression model.

Badr et al. (2016) outlined the creation of a predictive-model based tool to predict performance in a specific course using data-mining methods to identify the relevant performance predictors, and quantify their influence. The data-reduction process was used to identify the most relevant factors for each outcome. In this work, a model reduction technique is employed. This is particularly useful to alleviate the effects of the aforementioned multi-collinearity. Correlated predictors provide redundant information. Therefore, removing a subset of these can improve the model's performance. The reduced models are summarised in Table 4. Utilising the **regsubsets** function in R, model selection by exhaustive search is performed (rather than by forward/backward stepwise or sequential replacement). All four (4) predictor variables were initially considered, and the "best" three-variable model, two-variable model and single-variable model were obtained. In this case, "best" meant the model having the highest adjusted R^2 value. The "best" reduced model for the graduating GPA involved only two predictors (specifically Pure Mathematics Unit 2 and Physics Unit 1) with an adjusted R^2 of 15.27%. These candidate models for the ECNG 2001 course GPA had only one significant single predictor (specifically Pure Mathematics Unit 2), and the adjusted R^2 was consistently very low.

Badr et al. (2016) utilised a data-normalisation process that involved classifying the input and output factors to improve model robustness. Graduating GPA can be classified as "Highly Successful"/"Not Highly Successful", and the input grades can be classified as "Good" (above four points) and "Bad" (four or less points). Here, a student is deemed "Highly Successful" if he/she achieves a graduating GPA of 3.60 or above (see Tables 5 and 6). The counts by unique combinations of predictor values found in the actual data set are shown in Table 7. Note that "Good" is denoted as simply "G" and "Bad" as "B". For example, 29 students entering

Table 3. Correlations with their p-values among potential predictors and outcomes

	GPA	**ECNG2001**	**Physics Unit 1**	**Physics Unit 2**	**Maths Unit 1**	**Maths Unit 2**
GPA	1	0.625901 p-value =2.22e-16	0.338825 p-value =4.22e-16	0.279905 p-value=0.00081	0.220709 p-value=0.008782	0.354682 p-value=1.71e-05
ECNG 2001		1	0.048409 p-value=0.570046*	0.181869 p-value=0.03151*	0.121432 p-value=0.152941*	0.234095 p-value=0.005373
Physics Unit 1			1	0.539861 p-value=5.85e-12	0.479893 p-value=1.98e-09	0.460096 p-value=1.07e-08
Physics Unit 2				1	0.409959 p-value=4.9e-07	0.496512 p-value=4.41e-10
Maths Unit 1					1	0.514071 p-value=8.23e-11
Maths Unit 2						1

Table 4. Model reduction for course and graduation GPA linear regression models

	Model	**Intercept**	**Physics Unit 1**	**Physics Unit 2**	**Math Unit 1**	**Math Unit 2**	**Adjusted R^2**	**p-value**
Graduating GPA	Original	1.40624	0.17322	0.05065*	-0.03469*	0.19941	0.1427	5.254e-05
	Three-variable	1.3188	0.1667	0.0483*		0.1913	0.148	1.61e-05
	Two-variable	1.39363	0.18453			0.20528	0.1527	4.345e-06
	One-variable	1.8422				0.2887	0.119	1.71e-05
ECNG2001 GPA	Original	0.94871*	-0.21224*	0.23329*	0.03828*	0.33591	0.04454	0.03772
	Three-variable	1.0452*	-0.2050*	0.2359*		0.3449	0.05137	0.01713
	Two-variable	0.768*	0.145*			0.294	0.0468	0.0139
	One-variable	1.125*				0.360	0.048	0.00537

Table 5. Normalised model for "Highly Successful" vs "Not Highly Successful" students - all predictors

Categorical Predictors:	**Estimate**	**Std. Error**	**z value**	***Pr*(<|t|)**	**Significance**
CAPE Physics Unit 1	0.166	0.398	0.42	0.677	—
CAPE Physics Unit 2	0.87	0.432	2.01	0.044	0.05
CAPE Pure Math Unit 1	0.108	0.471	0.23	0.819	—
CAPE Pure Math Unit 2	0.723	0.443	1.63	0.102	—
Threshold coefficients:	**Estimate**	**Std. Error**	**z value**		
NO|YES	1.632	0.351	4.65		
Model quality:	**Log-likelihood**	**AIC**	**Condition number on Hessian Matrix**		
	-73.7	157.4	16		
Model prediction:	**Accuracy**	**No Information Rate (NIR)**	**P-Value [Acc >NIR]**	**Sensitivity**	**Specificity**
	0.721	0.721	0.543	1	0

Table 6. Normalised model for "Highly Successful" vs "Not Highly Successful" students - single predictor

Categorical Predictors:	**Estimate**	**Std. Error**	**z value**	***Pr*(<|t|)**	**Significance**
CAPE Physics Unit 2	1.201	0.367	3.27	0.0011	0.01
Threshold coefficients:	**Estimate**	**Std. Error**	**z value**		
NO|YES	1.35	0.26	5.19		
Model quality:	**Log-likelihood**	**AIC**	**Condition number on Hessian Matrix**		
	-75.92	155.84	5.6		
Model prediction:	**Accuracy**	**No Information Rate (NIR)**	**P-Value [Acc >NIR]**	**Sensitivity**	**Specificity**
	0.721	0.721	0.543	1	0

Table 7. Counts by combinations of predictor values for actual and predicted outcomes

Physics 1	**Physics 2**	**Pure Math 1**	**Pure Math 2**	**Highly Successful**			
				Actual		**Predicted**	
				NO	**YES**	**NO**	**YES**
B	B	B	B	9	2	11	0
B	B	B	G	5	1	6	0
B	B	G	B	9	1	10	0
B	B	G	G	11	0	11	0
B	G	B	B	4	0	4	0
B	G	B	G	1	1	2	0
B	G	G	B	4	0	4	0
B	G	G	G	4	3	7	0
G	B	B	B	0	0	0	0
G	B	B	G	3	0	3	0
G	B	G	B	5	0	5	0
G	B	G	G	3	1	4	0
G	G	B	B	1	0	1	0
G	G	B	G	2	0	2	0
G	G	G	B	4	1	5	0
G	G	G	G	36	29	65	0
				101	39	140	0

with "Good" grades in these four units were "Highly Successful", whereas 36 were "Not Highly Successful" (see the last rows of Table 7.)

The normalised model for "Highly Successful"/"Not Highly Successful" prediction is summarised in Table 5. To perform this logistic regression, the cumulative link model with logit link (**clm**) function in the ordinal package in R was used. It can be seen that the sole statistically significant predictor was CAPE Physics Unit 2. This contrasts with the predictors identified in the linear regression models obtained earlier. Another logistic regression was run but with CAPE Physics Unit 2 as the only predictor. The significance of the coefficient increased, but the overall fit marginally improved, i.e., the Akaike Information Criteria (AIC) drops from 157.4 to 155.84 and the log-likelihood ratio of -73.7 to -75.92. However, the accuracy of both models was low at 72.1%. The counts by unique combinations of predictor values for the predicted outcome can be found alongside that for actual data in Table 7. The models never predicted a positive outcome. This may be attributed to the skewness of the data set which had a higher proportion of negative outcomes than positive ones for each combination of input. Based on

Table 8: Over-/Under prediction according to full linear regression model

	Entry Score									**Full**		
	>10 points			**>8 and <10 points**			**≤ 8points**					
	Male	Female	Overall	Male	Female	Overall	Male	Female	Overall	Male	Female	Overall
Graduation GPA	0.0658	0.229	0.119	-0.151	-0.234	-0.168	0.0966	0.0579	0.0905	-0.021	0.0607	-2.28e-16
ECNG 2001 GPA	-0.0738	0.494	0.11	-0.0827	-0.459	-0.163	0.0526	0.392	0.106	-0.0581	0.168	-3.72e-16

these observations, using a normalised model may be ineffective. Bridgeman et al. (2008) examined whether there was bias in the prediction models (e.g. by gender, background and the nature of the course) by examining the prediction error for sub-groups of the population.

According to Bridgeman et al. (2008), if the actual performance of a sub-group is consistently better than their predicted performance then there is under-prediction, and a group that actually performed worse than predicted is over-predicted. Calculated as the mean of the difference between actual and predicted values, a substantially negative number implies over-prediction and a positive number implies under-prediction. The prediction errors by gender and entry score groups are summarised in Table 8.

Bridgeman et al. (2008) examined the relative impact of related factors by examining the percentage of successful students within each band of entry grades. The percentage of "Highly Successful" students by the range of entry score are summarised in Table 9. It demonstrates that the proportion of students achieving "Highly Successful" status is different for students with entry scores of ten versus those with less than ten. For example, of those students who had entry scores greater than ten (i.e., 65 (see Table 1)) 44% of them graduated with GPAs greater than 3.60, and 100% of them had a graduating GPA greater than 2.00. However, of the 56 students who had entry scores within the range of eight to ten points, only 12.5% of them graduated with a GPA greater than 3.60. The differences in percentages across entry-score bands is much starker when considering the "Highly Successful" threshold (i.e., GPA of 3.60) than for the "Successful" threshold (i.e., GPA of 2.00).

Table 9: Percentage of "Highly successful" and "Successful" students by the range of entry score

Entry Score	**% Highly Successful**	**% Successful**
10	44.6	100
>8 and <10	12.5	96.4
<8	15.8	89.5
Overall	27.9	97.1

5. Discussion

There is a need to reflect on the true purpose for entrance standards and thresholds in higher education. Are they variously:

1. A proxy for student's knowledge of pre-requisite content?
2. A way to determine a student's ability to learn?
3. A means to predict student success?

In this work, inspired by the work of Maruyama, (2012), Golding and Donaldson,(2006), Bridgeman et al.(2008), the entrance standards and thresholds of the Department were questioned with regard to their underlying assumptions as well as their ability to fulfil all three functions identified above.

For most entrants, CAPE grades were exclusively examined, and high-school performance ignored. These grades in themselves have been reported as reliable measures of student knowledge (Griffith, 2017), with no discernible bias reported between gender (CXC, 2015). The entry score is based solely on grades achieved in four specific CAPE units: Pure Mathematics Unit 1, Pure Mathematics Unit 2, Physics Unit 1, and Physics Unit 2. The grade achieved for an entire unit is considered without looking at the performance in the individual components comprising each unit. The units are treated in isolation, without considering the simultaneous workload or other subjects undertaken by the student.

In this study, it was found that a significant correlation of 0.40 to 0.51 existed between the grades of the four units (see Table 3). Despite this, the multiple linear regression models (full and reduced) (see Table 4) reflect the relatively low influence of two of the CAPE Units on graduating and course (ECNG 2001) GPA. That there are high correlations among the CAPE units in spite of them covering differing content may indicate that there could be some common underlying aspects (e.g., mode of delivery, assessment format and strategies) that not only assist the students in mastering the content but also the examination process itself. These could be vastly different at the University.

Further the linear regression models (shown in Table 2), the cross-correlations (shown in Table 3) and the reduced models (shown in Table 4) for both graduating GPA and course GPA based on the CAPE grades have low (adjusted) coefficient of determination (R^2), suggesting that there may be a disconnect between expectations of pre-requisite knowledge and the grades which were intended to act as proxies for that knowledge. One may even be tempted to conclude that, particularly for the ECNG 2001 course, the theory covered by the CAPE Pure Mathematics and Physics

syllabus may be irrelevant. On the contrary, it may be that this course demands not only a strong handle of prerequisite knowledge which these CAPE units do provide, but also much higher order cognitive usage of this knowledge. Probably CAPE Pure Mathematics Unit 2 comes closest to this demand or maybe the course ECNG 2001 draws most heavily on knowledge gained in Pure Mathematics Unit 2. Across these models, the low R^2 may also indicate that there are other factors not identified in this study that contribute significantly to a student's success in the programme, probably (e.g., his/her study-skills, socio-economic status, to name a few).

Furthermore, some pre-requisite content has more impact on performance than others. The negative correlation between the Pure Mathematics Unit 1 grade and graduating performance, suggests that students may in fact need to "unlearn" some of what they have been taught prior to entering the programme. CXC has reported that students have challenges with certain topics in Calculus (CXC, 2013) and these same topics align with the pre-requisite knowledge of the syllabus. Muddeen and Mallalieu (2016) have previously reported the Department's efforts to address the underlying Mathematics issues reflected by this observation, and the observation that while Pure Mathematics Unit 2 is the strongest predictor of graduating GPA (see Table 2), it is much less significant than the influence of a single course within the programme, ECNG 2001 (see Table 3).

The ability of the linear regression models shown in Table 2 to over and under predict performance were examined by gender and entry score for both graduating GPA and course GPA in Table 8. There does not seem to be any consistently inherent bias in the model by either factor.

For the students whose performance was reviewed in this study (see Table 1), slightly under half entered the programme with the maximum CAPE derived entry score of 10 points. However even with the high entry scores, only half of this group were "highly successful" at graduation. This strengthens the argument that there are other factors that may be impacting a student's performance which may not have been previously evident to either the student or the Department but which nevertheless should be addressed earlier in the programme.

College readiness was discussed by Venezia and Voloch(2012). They suggested that the discontinuity in academic performance that exists between high school and post-secondary institutions is due the lack of content alignment between high school performance and college entrance exams. Further work by Bridgeman et al. (2008, 2004) and Lee et al. (2008), highlighted significant differences in university success rates by entrance bands, while corroborating the discontinuity in performance. This is substantiated by the prediction models explored in this work for the BSc (Eng) Electrical and Computer Engineering programme, where despite poor linear and logistic regression models (see Tables 2 and 5) we were able to demonstrate clear patterns in the success rates (see Table 9). This suggests that at this time the entry criteria serve as a means of predicting probability of achieving success, rather than the actual success level.

These observations suggest that the use of the grades to derive entry score is neither a proxy for pre-requisite content, nor as a means of discerning a student's ability to manage his/her learning process.

6. Conclusion and Future Work

Kuncel et al. (2007) mentioned that the admission systems can be divided into two parts: the first being the predictors or measures used to forecast future student performance (which was primarily addressed in this paper), and the second being the method by which the predictors are actually combined to make the admission decisions. With regard to the former, additional admission criteria, whether high-school performance (Bridgeman et al., 2008), or entrance examinations, essays, interviews (Alnasir and Jaradat, 2011; Mercer and Puddey, 2011), would be worthy of consideration. With regard to the latter, given the predictive models bias to specific CAPE units, a weighted entry score model (rather than the present equal weighting) could also be considered.

In the literature, non-academic factors, such as personality (Rothstein et al., 1994, Crede and Kuncel, 2008), learning styles (Garton et al., 2000), extra-curricular activities (Vuttipittayamongkol, 2016), time-management (Macan et al., 1990; Pottinger et al., 2009), study skills (Crede and Kuncel, 2008), motivation (Alnasir and Jaradat, 2011; Crede and Kuncel, 2008) and socio-economic status (Whyte et al., 2011, Lei and Li, 2015; Maruyama, 2012; Sackett et al., 2009; Shulruf et al., 2008; Schulz, 2005; Sirin, 2005), and class attendance (Cohall and Skeete, 2012) have all been treated with when determining how best to predict graduating performance at entry. A future study would attempt to ascertain which, if any, of these factors may be additional contributors to the students' graduating performance in this undergraduate programme.

This work focused on those students who entered the BSc (Eng) Electrical and Computer Engineering programme via the most common route (that is with CAPE passes), however approximately 20% students enter by a variety of other means. A comprehensive means of addressing multiple entry routes (CAPE included) needs to be investigated. One of the first tasks would be to formally explore the knowledge gaps (if any) between each entry route and the prerequisite knowledge required for the programme's courses.

In this paper, the effectiveness of existing admission criteria for an undergraduate engineering programme has been questioned. The results suggest that the entry

criteria can predict success, rather than actual success level. Based on the results of this analysis, closer attention to performance within the individual units may be required in order to predict academic success in this programme. The reported success rates among graduates, in spite of the relatively low correlations between CAPE qualification and graduating GPA, as well as regression models with low R^2, suggest that there are other major (unexplained) factors that contribute significantly to students' success.

References:

Abele, C., Penprase, B. and Ternes, R. (2013), "A closer look at academic probation and attrition: What courses are predictive of nursing student success?" *Nurse Education Today*, Vol.33, No.3, pp.258-261.

Alnasir, F.A. and Jaradat, A.A. (2011), "The effectiveness of AGU-MCAT in predicting medical student performance in year one of the College of Medicine of the Arabian Gulf University", *Education for Health*, Vol.11, p.447-456.

Badr, G., Algobail, A., Almutairi, H. and Almutery, M. (2016), "Predicting students' performance in university courses: A case study and tool in KSU Mathematics Department", *Procedia Computer Science*, Vol.82, pp.80-89.

Barry, S.I. and Chapman, J. (2007), "Predicting university performance", *ANZIAM Journal*, Vol.49, pp.36-50.

Bridgeman, B., Pollack, J. and Burton, N. (2004), "Understanding what SAT Reasoning Test™ scores add to high school grades: A straightforward approach", *ETS Research Report Series*, College Board Research Report No. 2004-4 (ETS RR-04-40), College Entrance Examination Board, New York.

Bridgeman, B., Pollack, J. and Burton, N. (2008), "Predicting grades in different types of college courses", *ETS Research Report Series*, College Board Research Report No. 2008-1 (ETS RR-08-06), The College Board, New York

Christensen, R.H.B. (2015), *Regression Models for Ordinal Data*, R package ordinal version 2015.6-28.

Cohall, D.H. and Skeete, D. (2012), "The impact of an attendance policy on the academic performance of first year medical students taking the Fundamentals of Disease and Treatment course", *The Caribbean Teaching Scholar*, Vol.2, No.2, pp. 67-75

Credé, M. and Kuncel, N.R. (2008), "Study habits, skills, and attitudes: The third pillar supporting collegiate academic performance", *Perspectives on Psychological Science*, Vol.3, No.6, pp.425-453.

CXC (2013), *Report on candidates' work in the Caribbean Advanced Proficiency Examination May/June 2013 Pure Mathematics*, The Caribbean Examinations Council, Barbados

CXC. (2015), "Analysis of performance of the regional candidate population in individual subjects as a whole and by gender: CAPE 2015", *Annual Report 2015: Appendix XIII*. Caribbean Examinations Council, Barbados

Cyrenne, P. and Chan, A. (2012), "High school grades and university performance: A case study", *Economics of Education Review*, Vol.31, No.5, pp.524-542.

Garton, B.L., Dyer, J.E. and King, B.O. (2000), "The use of learning styles and admission criteria in predicting academic performance and retention of college freshmen", *Journal of Agricultural Education*, Vol.41, No.2, pp.46-53.

Golding, P. and Donaldson, O. (2006), "Predicting academic performance", *Proceedings of the IEEE 36th Annual Frontiers in Education Conference*, San Diego, California, USA, October, pp. 21-26

González-Barreto, D.R. and González-Quevedo, A.A. (2005), "Student profile of the incoming First Year Class of the College of Engineering at UPRM and their academic performance after their first" *Proceedings of the 2005 American Society for Engineering Education Annual Conference and Exposition*, Portland, Oregon, USA, June, pp. 10.1159.1 - 10.1159.9.

Griffith, S.A. (2017), "Lessons from CXC for Caribbean higher education institutions", *Quality Assurance in Education*, Vol.25, No.2, pp.224-236.

IET (n.d.), "Section 7.6: Student to staff ratio", Institution of Engineering and Technology, Retrieved from http://www.theiet.org/academics/accreditation/policy-guidance/form_a_part2/7_6_student_ratio.cfm (Guidance on completing Section 7.6 of Form A part 2 - Student to Staff Ratio (SSR) for Accreditation. IET complies with UKSPEC https://www.engc.org.uk/ukspec)

Kabakchieva, D. (2013), "Predicting student performance by using data mining methods for classification", *Cybernetics and Information Technologies*, Vol.13, No.1, pp.61-72.

Kevern, J., Ricketts, C. and Webb, C. (1999), "Pre-registration diploma students: a quantitative study of entry characteristics and course outcomes", *Journal of Advanced Nursing*, Vol.30, No.4, pp.785-795.

Kuncel, N.R., Credé, M. and Thomas, L.L. (2007), "A meta-analysis of the predictive validity of the graduate management admission test (GMAT) and undergraduate grade point average (UGPA) for graduate student academic performance", *Academy of Management Learning and Education*, Vol.6, No.1, pp.51-68.

Kuncel, N.R., Hezlett, S.A. and Ones, D.S. (2001), "A comprehensive meta-analysis of the predictive validity of the graduate record examinations: implications for graduate student selection and performance", *Psychological Bulletin*, Vol.127, No.1, pp.162-181.

Lee, S., Harrison, M.C., Pell, G. and Robinson, C.L. (2008), "Predicting performance of first year Engineering students and the importance of assessment tools therein", *Engineering Education*, Vol.3, No.1, pp.44-51.

Lei, C. and Li, K.F. (2015), "Academic performance predictors", *Proceedings of the IEEE 29th International Conference on Advanced Information Networking and Applications Workshops (WAINA)*, Gwangju, Korea, March, pp. 577-581.

Lumley, T. and Miller, A. (2004), *Leaps: Regression subset selection*, R package version, 2.9.

Macan, T.H., Shahani, C., Dipboye, R.L. and Phillips, A.P. (1990), "College students' time management: Correlations with academic performance and stress", *Journal of Educational Psychology*, Vol.82, No.4, pp.760-768.

Maruyama, G. (2012), "Assessing college readiness: Should we be satisfied with ACT or other threshold scores?" *Educational Researcher*, Vol.41, No.7, pp.252-261.

Mercer, A. and Puddey, I.B. (2011), "Admission selection criteria as predictors of outcomes in an undergraduate medical course: A prospective study", *Medical Teacher*, Vol.33, No.12, pp.997-1004.

Mlambo, V. (2011), "An analysis of some factors affecting student academic performance in an introductory biochemistry course at the University of the West Indies", *The Caribbean Teaching Scholar*, Vol.1, No.2, pp.79-82.

Muddeen, F. and Mallalieu, K. (2016), "Examinations and remediation actions for the mathematics problem in electrical engineering at The University of the West Indies", *International Journal of Electrical Engineering Education*, Vol.53, No.4, pp.314-330.

Othman, H., Asshaari, I., Tawil, N.M., Ismail, N.A., Nopiah, Z.M. and Zaharim, A. (2012), "Analysis on mathematics fundamental knowledge for mathematics engineering courses based on a comparative study of students' entry performance", *Procedia-Social and Behavioral Sciences*, Vol.60, pp.365-371.

Pottinger, A.M., La Hee, F. and Asmus, K. (2009), "Students admitted to university who fail: hidden disabilities affecting students performance", *West Indian Medical Journal*, Vol.58, No.2, pp.pp.99-105.

R Core Team, (2015), *R: A language and environment for statistical computing*, R Foundation for Statistical Computing, Vienna, Austria

Rothstein, M.G., Paunonen, S.V., Rush, J.C. and King, G.A. (1994), "Personality and cognitive ability predictors of performance in graduate business school", *Journal of Educational Psychology*, Vol.86, No.4, pp.516 -530.

Sackett, P.R., Kuncel, N.R., Arneson, J.J., Cooper, S.R. and Waters, S.D. (2009), "Does socioeconomic status sxplain the relationship between admissions tests and post-secondary academic performance?" *Psychological Bulletin*, Vol.135, No.1, pp.1-22.

Sastry, M.K., Sankat, C.K., Exall, D., Srivastava, K.D., Khan, H., Copeland, B., Lewis, W.G. and Bhajan, D. (2007), "An appraisal of tertiary level institutional collaboration and joint degree programs in Trinidad and Tobago", *Latin American and Caribbean Journal of Engineering Education*, Vol.1, No.1, February, pp.27-34.

Schulz, W. (2005), "Measuring the socio-economic background of students and its effect on achievement on PISA 2000 and PISA 2003", *Proceedings of the Annual Meetings of the American Educational Research Association (AERA)*, Available at: http://files.eric.ed.gov/fulltext/ED493510.pdf

Sedlacek, W.E. (2003), "Alternative admissions and scholarship selection measures in higher education", *Measurement and Evaluation in Counseling and Development*, Vol.35, No.4, pp.263-272.

Shulruf, B., Hattie, J. and Tumen, S. (2008), "The predictability of enrolment and first-year university results from secondary school performance: The New Zealand National Certificate of Educational Achievement", *Studies in Higher Education*, Vol.33, No.6, pp.685-698.

Sirin, S.R. (2005), "Socioeconomic status and academic achievement: A meta-analytic review of research", *Review of Educational Research*, Vol.75, No.3, pp.417-453.

Venezia, A. and Voloch, D. (2012), "Using college placement exams as early signals of college readiness: An examination of California's Early Assessment Program and New York's At Home in College program", *New Directions for Higher Education*, Vol.158, pp.71-79.

Vuttipittayamongkol, P. (2016), "Predicting factors of academic performance", *Proceedings of the IEEE Second Asian Conference on Defence Technology (ACDT)*, Chiang Mai, Thailand, January, pp.161-166.

Whyte, D.G., Madigan, V. and Drinkwater, E.J. (2011), "Predictors of academic performance of nursing and paramedic students in first year bioscience", *Nurse Education Today*, Vol.31, No.8, pp.849-854.

Authors' Biographical Notes:

Richelle V. Adams *received the B.Sc. degree in Electrical and Computer Engineering in 1998 and the M.Sc. degree in Communication Systems in 2001 from the University of the West Indies, St. Augustine Campus, Trinidad and Tobago. In 2007, she received the Ph.D. degree in Electrical and Computer Engineering from the Georgia Institute of Technology, Atlanta, USA. In 2011, she was a Visiting Fulbright Scholar at the Institute for Crisis, Disaster and Risk Management, George Washington University, Washington, D.C., USA. Currently, she is a Lecturer in the Department of Electrical and Computer Engineering, The University of the West Indies and member of the Communication Systems group. She also is the departmental representative on the Entrance Committee of the Faculty of Engineering.*

Cathy Ann Radix *is a longstanding member of the IEEE, having actively participated in the creation of the country-chapter IEEE-TT. Her interest in instructional scaffolding and its impact has led to research in the use of visual organisers, concept inventories, and learning preferences for learning and assessment. She is part of the faculty-team responsible for teaching Embedded Systems, within the Department of Electrical and Computer Engineering, The University of the West Indies.*

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Spatial Variability of Soil Thermal Conductivities within a Horizontal Gas Flaring Site Owaza, Southeast Nigeria

Onyekachi A. Irondi[a,Ψ] Moses O. Nwagbara[b], and Michael A. Okon[c]

[a,b] Department of Soil Science and Meteorology, College of Soil and Crop Sciences, Michael Okpara University of Agriculture, Umudike, Nigeria; E-mails: kachi.irondi@gmail.com; monwagbara@yahoo.com

[c]Department of Soil Science and Technology, School of Agriculture and Agricultural Technology, Federal University of Technology Owerri, Imo State, Nigeria; Email: michaelaokon@gmail.com

[Ψ] *Corresponding Author*

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Abstract: *Knowledge of spatial patterns of soil thermal conductivity is of great importance in agricultural meteorology where problems of heat exchange at the soil surface are encountered. This is significant for the environment, site-specific soil and crop management, as well as soil heat movement through soil profile. The study was conducted to determine the spatial pattern of soil thermal conductivities on 14 sample distance points away from a horizontal gas flaring site using the well-known Campbell (1985) equation model. Geostatistics (kriging) were used to describe the spatial pattern of the predicted soil thermal conductivities from each sample point and depth using ArcGIS version 10.1. From the results, predicted soil thermal conductivity varied from 1.49 $Wm^{-1}K^{-1}$ to 4.89 $Wm^{-1}K^{-1}$, and the standard deviation ranged from 0.05-0.29 at 0-30 cm. The surface and subsurface predictive spatial distribution maps generated showed clear positional similarity across the field with higher thermal values in the direction of flaring site. The geostatistical linear interpolation using kriging clearly conveys rare insight into the way predicted soil thermal conductivity varied within the horizontal gas flare site. The predictive spatial maps could be an effective tool to farmers, soil scientist, engineers and other land users to make informed decisions on appropriate distances away from a horizontal gas flare station for site-specific soil management. It is compelling, to recommend the discontinuity of horizontal gas flaring in the study area in order to avoid the direct thermal pollution on arable soil ecosystem.*

Keywords: *Gas flaring, Spatial variability, Soil thermal conductivity, Kriging, Site-specific soil management*

1. Introduction

Soil thermal properties are component of soil physics that are required in many areas of agronomy, agro-meteorology, climatology, soil science and engineering. In agriculture, microbial activity and seed germination are affected by their surrounding climate, which is influenced by soil thermal properties, especially the thermal conductivity (λ) (Abu-Hamdeh, 2000; Anandakumar et al., 2001; Bristow, 2002; Ekwue et al., 2006; Danelichen et al., 2013; Gao et al., 2009). Soil thermal conductivity describes the soil properties which govern the flow of heat through the soil. Accurate estimate of soil thermal conductivity is of prime importance in the numerical simulation of heat transmission through soils, and is considered one of the most important thermal properties of plant environment (Hillel, 2003). Thermal conductivity of soils is generally affected by soil texture and structure; increase with bulk density and moisture content, and decrease with organic matter content (Nakshabandi and Kohnke, 1965; Ghuman and Lal, 1985; Abu-Hamdeh, 2000; Abu-Hamdeh and Reeder, 2000). Thermal conductivity is also known to increase with temperature (de Vries, 1963; Sepaskhah and Boersma, 1979; Hopmans and Dane, 1986; Campbell et al., 1994) and mineral composition (de Vries, 1963).

In situ monitoring of λ as a function of volumetric moisture content (θ) can represent a significant challenge. Consequently, much effort has been made to develop λ (θ) models based on easily measurable soil parameters (Kersten, 1949; de Vries, 1963; Johansen, 1975; Campbell, 1985; Cote and Konrad, 2005). Campbell et al. (1994) highlighted that λ increases dramatically with temperature in moist soil, reaching values three to five times the ambient value at 90° Celsius (C). The determination of these soil thermal properties is therefore a very important factor in understanding spatial distribution of soil heat processes especially, the control of thermal and moisture regimes of soil in the field and the individual crop field and larger areas (Usowicz, 1991; Oladunjoye et al., 2013).

Gas flaring is the controlled burning of natural gases associated with oil production. It is the use of vertical or horizontal flare to burn off unwanted associated gas that are extracted from the earth along with the crude (Evoh, 2002; ENS, 2005). It is known that gas flaring in Nigeria has raised the average global temperature by about 0.5°C (Penner, 1999). The heat, toxins and particulates from gas flaring adversely affect vegetation, soil, water,

humans, and livelihoods of the host communities. Typical gas flare in Nigeria oil field is located at ground level (horizontal flaring), and is usually surrounded by vegetation, farmlands and village huts 20-30 metres (m) away from the flare and the heat radiation is a function of the flare temperature; gas flow rate and geometrical design of flare jet (World Bank, 2009).

Information on the spatial variability of soil thermal conductivity of arable soils within a horizontal gas flaring site in Owaza is rare, hence the need for this present study designed to investigate and generate the spatial distribution maps of soil thermal conductivities of soils within the gas flaring site.

2. Materials and Methods

2.1 Study area

The study was carried out within the vicinity of horizontal gas flaring site of Shell BP gas flow station in Owaza, southeast Nigeria. The area is located within latitude 4^{o} $55^{'}40.35^{o}$N and longitude 7^{o} $10^{'}55^{o}$ E. All in-situ field work was carried out within and outside the bond wall of the horizontal gas flaring where spatial variability was predictable due to the obvious variable soil characteristics as a result of the gas flare heat emission. Farming is the main socio-economic activity of the rural population with the growing of cassava (*Manihot esculenta*), maize (*Zea mays*), and vegetables (fluted pumpkin) in small plots at varying kilometres away from the flare site. Oil exploration started in the area in early 60's with its resultant gas flaring. The geological material is coastal plain sand (Benin Formation) with a low land geomorphology of 50 m above sea level (Enwezor et al., 1990). The dominant soil is described as Typic Paleudult ranging from sandy to loamy textures (USDA-SSDS, 2003). The area is warm and humid. Isohyperthermic soil temperature and udic moisture regimes characterise the area (Chukwu, 2007). There are two distinct seasons in the study area, the dry and rainy season. These seasons are usually influenced by the tropical maritime air mass and the tropical continental air mass. The rainy season usually begins in March and is interrupted by a dry season in October. Annual rainfall ranges from 2,000-2,500 mm with mean temperature of 28-30^{o}C and relative humidity ranging from 55-85%.

2.2 Field studies and sample collection

Field reconnaissance survey was first carried out to determine the feasibility of the study and appropriate contacts and clarifications were given by the host community and Shell BP oil servicing company prior to several field trips to the gas flare site. The study was carried out in September 2016 when the soil was wet representing typical udic moisture regime. All data were taken when the horizontal gas flaring was on during noon between 1.00 to 3.00 pm local time, i.e. 13.00 to 15.00 Hours, Greenwich Mean Time (GMT) + 1.

Sampling procedure involved the use of a fibrous measuring tape (starting from the active point of the horizontal gas flaring jet), to mark out sample distance points at 50 m, 100 m, 200 m distances parallel to the active flaring point (sample points 1, 2 and 3), 50 m apiece distance to the left and right sides from the active flare point (sample points 4 and 5). Sample points 6 and 7 were taken behind the active gas flaring point at 50 m and 100 m respectively all within the bond wall of the gas flaring site whereas other sample points (sample points 8 through 14), were located outside the bond wall of the active flare point at varying distances (i.e. 400 m, 600 m, 800 m, 1 km, 2 km, 3 km and 4 k m) away from the active gas flaring point. These distances were taken to observe better the spatial scale variations of predicted soil thermal conductivities of the soils. All sample points were geo-referenced using a hand-held BHCNav GPS to generate their geographical coordinates for further geostatistical soil spatial analysis using kriging.

All data were collected at 0-15 cm and 15-30 cm sampling depths from each marked sample distance. These depths were chosen because they represent the moisture control section in the soil (USDA-SSDS, 2003). Also, these depths form the main root zone of most crops (Jang, 2004). Soil and air temperatures were estimated in situ using different mercury-in-glass thermometer at each sample point. Soil temperature data estimation involves immersing the bulb of the mercury thermometer 2-3 cm into 0-15 cm and 15-30 cm soil depths for five minutes each and readings (in degree Celsius) taken appropriately. The air temperature data were read for each sample point by using a hand held mercury thermometer at same points 26 m elevation from the ground level and readings (in degree Celsius) recorded after every five minutes.

Bulked soil samples from every sample point were collected using a cylindrical core sampler 3.5 cm in diameter and 6 cm in length. This involved driving the core samplers into the soil to collect undisturbed samples for soil moisture and bulk density determination. Disturbed samples were also collected from these points for analysis of selected physico-chemical properties of the soil using a hand held auger. A total of twenty-eight (28) soil samples from both sampling depths (0-15 cm and 15-30 cm) were collected for analysis of selected properties. All samples were bagged in a black polythene bag and properly labeled against each point.

2.3 Laboratory analysis

Samples were air dried, ground, and sieved through a 2 mm screen prior to analyses. Prepared samples were subjected to various analysis using standard procedures as described in the USDA Soil Survey Manual (USDA-SSDS 1993) at the Soil Physics Laboratory of National Root Crop Research Institute (NRCRI), Umudike, near Umuahia, Abia State, Nigeria. Particle size analysis was determined using the pipette method (Gee and Or, 2002).

Bulk density was analysed by the core sample method according to Blake and Hartage (1990) and gravimetric moisture content by the APHA (1985) method. Total porosity was calculated from the result of bulk density and particle density. Soil organic carbon was determined by the method of wet oxidation according to Nelson and Sommers (1982).

2.4 Determination of soil thermal properties

Soil thermal conductivities of the soil samples were predicted using the procedure of Campbell (1985) model following the example of Ekwue et al. (2005, 2006, and 2011). Parameter data were translated using pedo-transfer function of easily measured soil properties according to Bouma (1989). Soil dry bulk density, moisture content and percentage clay determined from the laboratory analysis were parameters inserted into the model equation. Using the Campbell (1985) model, the predicted soil thermal conductivities from different sample points were empirically determined using the model equation:

$$K = A + B\,\theta_v - (A - D)\exp[-(C\,\theta_v)^E] \quad (1)$$

where:

K = Soil thermal conductivity (W $m^{-1}\,{}^oC^{-1}$),
θ_v = Volumetric water content
ρb = Soil dry bulk density (Mg m^{-3})
Mc = Clay mass fraction from particle size analysis.

A, B, C, D and E are Soil dependent coefficients which are related to soil properties and are readily available. Campbell (1985) gave the values of the coefficients as:

$$A = 0.65 - 0.78\,\rho b^{2.5} \quad (2)$$

$$B = 1.06\,\rho b\,\theta_v \quad (3)$$

$$C = 1 + 2.6\,Mc^{-0.5} \quad (4)$$

$$D = 1 + 0.03 + 0.10\,\rho b \quad (5)$$

$$E = 4 \quad (6)$$

2.5 Data analyses

Descriptive statistics of mean, standard deviation and coefficient of variation were used to characterise the selected soil thermal properties using MS Excel spreadsheet (version 2013) software package according to Cruz (2013). Correlation analyses with the predicted soil thermal properties and selected physical properties were employed to measure the degree of relationship between soils using the procedure of Cohen *et al.* (2013). A more detailed geostatistical spatial analysis using geographic information system (GIS) analysis was carried out in the Cartographic/GIS Laboratory of the Department of Geography and Environmental Management, University of Port Harcourt, Port Harcourt. Kriging method was used in ArcGIS 10.1 environment to describe the structures of the spatial maps of the predicted soil thermal properties at different sample distance points away from the gas flaring site.

Attribute tables were created for each parameter and their coordinates in Excel format before importation in ArcGIS environment. The generated predictive maps were used to describe the spatial and temporal variability of the predicted soil thermal conductivities at 0-15 cm and 15-30 cm sampling depths.

3. Results and Discussion

3.1 Soil Physico-Chemical Properties

The organic carbon (OC) from the different sample distances ranged from 0.91 % to 2.81 %. Clearly, sample distances (1 through 5) within the flare bond wall exhibited increased values of OC unlike values outside the bond wall (see Table 1). The increased OC content at closer sample points to the flare point could be attributed to prolonged accumulation of carbon due to flaring that emits carbon compounds.

Table 1. Organic carbon (OC) and particle size distribution of different soil sample points at 0-30 cm depth

Sample Distance	Organic Carbon (%)	Particle Size Distribution			USDA Soil Textural Class
		Sand (%)	Silt (%)	Clay (%)	
50 m	2.81 ± (0.10)	87.35 ± (1.00)	5.80 ± (0.40)	6.85 ± (0.10)	Sand
100 m	2.62 ± (0.10)	87.17 ± (0.07)	6.47 ± (0.20)	6.35 ± (0.20)	Sand
200 m	2.72 ± (0.04)	86.75 ± (1.00)	6.90 ± (0.15)	6.35 ± (1.00)	Sand
50 m-R	2.58 ± (0.05)	86.60 ± (2.00)	6.15 ± (0.10)	7.25 ± (2.00)	Sand
50 m-L	2.21 ± (0.03)	85.53 ± (0.61)	6.63 ± (0.20)	7.85 ± (0.13)	Sand
50 m-B	1.65 ± (0.05)	83.97 ± (0.20)	7.17 ± (0.10)	8.85 ± (0.10)	Loamy sand
100 m-B	1.01 ± (0.06)	84.30 ± (0.25)	6.75 ± (0.35)	8.95 ± (0.05) `	Loamy sand
400 m	1.53 ± (0.03)	84.30 ± (2.05)	6.15 ± (2.00)	9.63 ± (0.10)	Loamy sand
600 m	0.91 ± (0.10)	81.37 ± (1.53)	5.17 ± (0.05)	10.05 ± (0.04)	Loamy sand
800 m	1.22 ± (0.05)	78.73 ± (1.00)	9.80 ± (0.17)	9.98 ± (0.30)	Loamy sand
1 km	1.31 ± (0.06)	75.70 ± (0.50)	13.32 ± (0.10)	11.46 ± (1.00)	Loamy sand
2 km	1.34 ± (0.04)	72.60 ± (0.30)	15.48 ± (0.20)	11.92 ± (0.20)	Loamy sand
3 km	1.40 ± (0.15)	77.30 ± (0.25)	10.70 ± (0.30)	12.0 ± (2.00)`	Loamy sand
4 km	1.44 ± (0.10)	77.77 ± (0.10)	9.69 ± (0.10)	12.54 ± (0.10)	Loamy sand

Keys: 50 m-R and 50 m-L = 50 m interval distance points to the right and left from the active flare point, 50 m-B and 100 m-B = 50 m and 100 m distance points behind the active flare point, Values in bracket = Standard deviation. All values are means of three replicate samples.

From the particle size analysis, the texture of sample points within the flare bond wall were predominantly sandy and loamy sand outside the bond wall. Sand content ranged from 77.30 % to 87.35 %. Silt ranged from 5.80 % to 15.48 % and was low at closer sample distances to the flare, with higher values away and outside the flare zone. Similarly, the clay content exhibited a similar trend like silt and ranged from 6.35 % to 12.54 % (see Table 1). The high sand content across sample distances within the flaring point could be attributed to increased soil temperature as a result of heat radiation from the flare which induced dehydration of 2:1 clay minerals in the soil leading to strong interaction among the clay particles which in turn yielded less clay and more of larger particles (Arocena and Opiom, 2003). Increased sand content within the flare vicinity agrees with previous research of Abu-Hamedh (2000) and Ekwue et al. (2005, 2006).

The soil bulk density through the sample distances varied from 1.42 Mg/m3 to 2.50 Mg/m3 from farthest point away from the flare to the closest point. In contrast, the total porosity varied from 6.0 % to 46 % at the closest to the farthest points, respectively (see Table 2). The bulk density values of the soil across sample distances within the flare vicinity went up too high (above normal values), which could be attributed to the extreme compaction of the soils near the flare site as a result of prolonged and continuous flaring (over 50 years) in the area.

The tremendous heat and emission of toxic compounds could have resulted in soil surface sealing, hence the rare increase in bulk density values of sample points within the flare site. Heat induces increase in bulk density through its influence on mineralisation, caking of soil and infiltration of heavy metals. Similarly, the decreased porosity towards the flare vicinity was a direct effect of high bulk density. The variation in gravimetric moisture content was low within the flare sample distances and varied from 5.25 % to 29.73 % (see Table 2).

Clearly, the low moisture content across sample distances around the flare zone could be attributed to high evaporation due to the enormous heat radiation from the flare site. This is in good agreement with previous work by Botkin and Keller (1998) which showed that increased soil temperature due to tremendous heat emission from gas flaring is the major cause of low soil moisture content within the flaring vicinity. Low soil moisture content leads to reduction in the rate of translocation of nutrients within the plant system as well as microbial activities. The soil temperature varied from 25.5^{o}C to 45^{o}C from the farthest sample distance away to the closest sample distance to the flare respectively. Induced flare radiation within the flare bond wall, must have raised the soil temperature (Orubu, 2002). Similarly, the air temperature varied from 26^{o}C to 48^{o}C (Table 2). The air temperature was the highest across sample points within the flare bond wall. This could be attributed to increased atmospheric temperature caused as a result of high thermal energy within the flare.

3.2 Predicted Soil Thermal Conductivity

Considering the studied depth (0-30 cm), the predicted soil thermal conductivity varied from 1.58 Wm^{-1} K^{-1} to 4.89 Wm^{-1} K^{-1} whereas the standard deviation (SD) ranged from 0.06 to 0.28 (see Table 2). High predicted soil thermal conductivity predominates sample points within the bond wall of the horizontal gas flaring site. Increased soil temperature at closer sample points and subsequent increase in soil bulk density, led to greater contacts between soil solid particles which resulted in increased predicted soil thermal conductivity within the flare site. This agrees with the findings of Campbell et al. (1994) and Smits et al. (2013) that soil thermal conductivity increases with rising temperature.

Table 2. Bulk density, total porosity, gravimetric moisture content, air/soil temperatures, thermal conductivity of different sample points at 0-30cm depth

Sample Distance	Bulk Density (Mg/m^3)	Total Porosity (%)	Gravimetric Moisture Cont. (%)	Soil Temp. (^{o}C)	Air Temp. (^{o}C)	Predicted Thermal Conductivity ($Wm^{-1}K^{-1}$)	Soil Coordinates Latitude (N)	Longitude (E)
50 m	2.50 ± (0.06)	6.0 ± (1.30)	5.25 ± (0.50)	45.0 ± (0.50)	48 ± (0.20)	4.89 ± (0.19)	4°58^{1}48.67°	7°10^{1}59.79°
100 m	2.45 ± (0.05)	8.0 ± (0.75)	5.35 ±(0.65)	43.5 ± (0.30)	46 ± (0.60)	4.69 ± (0.27)	4°58^{1}48.28°	7°11^{1}0.79°
200 m	2.38 ± (0.05)	11 ± (0.55)	5.60 ±(0.60)	42.5 ± (0.40)	44 ± (0.50)	4.33 ± (0.10)	4°58^{1}46.98°	7°11^{1}0.34°
50 m-R	2.15 ± (0.05)	15 ± (0.52)	7.82 ±(1.40)	40.5 ± (0.50)	42 ± (0.50)	3.40 ± (0.20)	4°58^{1}46.03°	7°11^{1}0.05°
50 m-L	2.07 ± (0.14)	22 ± (1.10)	8.53 ±(1.10)	39.5 ± (0.50)	41 ± (1.50)	3.10 ± (0.09)	4°58^{1}46.09°	7°10^{1}59.17°
50 m-B	1.59 ± (0.07)	37 ± (1.33)	13.41 ± (1.22)	34.0 ± (0.50)	35 ± (0.50)	1.65 ± (0.10)	4°58^{1}49.54°	7°10^{1}57.12°
100 m	1.57 ± (0.07)	36 ± (0.54)	15.54 ± (2.05)	32.5 ± (0.30)	34 ± (0.50)	1.65 ± (0.13)	4°58^{1}52.82°	7°10^{1}58.57°
400 m	1.55 ± (0.08)	34 ± (0.73)	19.69 ± (2.05)	35.5 ± (0.40)	37 ± (1.00)	1.72 ± (0.19)	4°58^{1}56.38°	7°10^{1}58.48°
600 m	1.54 ± (0.16)	36 ± (1.33)	21.93 ± (2.00)	31.0 ± (2.00)	33 ± (1.00)	1.76 ± (0.25)	4°58^{1}58.97°	7°10^{1}57.98°
800 m	1.54 ± (0.06)	42 ± (1.75)	21.85 ± (2.15)	31.0 ± (0.50)	30 ± (1.00)	1.73 ± (0.29)	4°58^{1}56.89°	7°10^{1}56.84°
1 km	1.45 ± (0.06)	45 ± (1.15)	23.56 ± (1.50)	28.5 ± (1.00)	30 ± (2.00)	1.54 ± (0.28)	4°58^{1}53.14°	7°11^{1}02.80°
2 km	1.42 ± (0.08)	46 ± (1.30)	25.79 ± (1.52)	26.5 ± (1.50)	28 ± (2.00)	1.49 ± (0.05)	4°58^{1}57.40°	7°11^{1}14.02°
3 km	1.44 ± (0.05)	46 ± (2.04)	26.79 ± (0.58)	25.5 ± (1.50)	28 ± (1.32)	1.57 ± (0.06)	4°58^{1}57.40°	7°11^{1}14.02°
4 km	1.42 ± (0.04)	46 ± (1.51)	29.73 ± (2.00)	23.5 ± (0.50)	26 ± (1.00)	1.58 ± (0.06)	4°59106.91°	7°11^{1}12.09°

Keys: 50 m-R and 50 m-L = 50 m interval distance points to the right and left from the active flare point, 50 m-B and 100 m-B = 50m and 100 m distance points behind the active flare point, values in bracket = Standard deviation. All values are means of three replicate samples.

Udoinyang (2005) further opined that the higher values of soil thermal conductivity closer the gas flare sample points could be as a result of intense heat and higher temperature generated by the flare. Similarly, Ikelegbe (1993) and Orubu (2002) observed that gas flaring generates tremendous heat, which is felt over an average radius of 0.5 kilometres thereby causing soil thermal pollution. Increased bulk density of soils closer to the flare point results in more intimate contact between the individual particles, and this brings about increases in thermal conductivity (Nakshabandi and Kohnke, 1965).

The soil thermal conductivity also increases with water content because the thickness and geometric arrangement of water layer around soil particles improve thermal contact between soil particles; hence increase in predicted soil thermal conductivity (Hillel, 1998). This is not in agreement from the result of this study as predicted soil thermal conductivity was the highest across sample points with low moisture content (see Table 2). Obviously, the increase in soil thermal conductivity within the gas flare vicinity could be as a result of increase in soil temperature and high bulk density due to high heat radiation. Furthermore, many authors indicted increase in bulk density and moisture content as a cause of increase in thermal conductivity (Oladunjoye and Sanuade, 2012; Rubio et al., 2009; Singh and Devid, 2000).

Figure 1 displays the variability pattern of soil thermal conductivity of the studied depths (0-15 cm and 15-30 cm) from different sample distances away from flare. Clearly, both depths exhibited increased thermal conductivity values from sample points within the flare point with 0-15 cm depth showing greater increase in predicted thermal conductivity values by sample distances within the flare site.

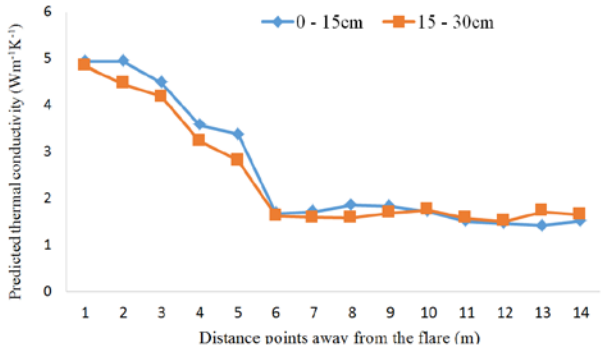

Figure 1. Studied depths and soil thermal conductivity variations across sample distance points away from the flare point

Similarly, Figure 2 shows higher soil thermal conductivity variability trend as influenced by soil temperature from different sample points. It could be observed that at increased soil temperature, the soil thermal conductivity subsequently increased within the flare bond wall in the direction of flaring and decreased sharply and continuously away from the flare zone. This agrees with the findings of Campbell et al. (1994) and Smits et al. (2013).

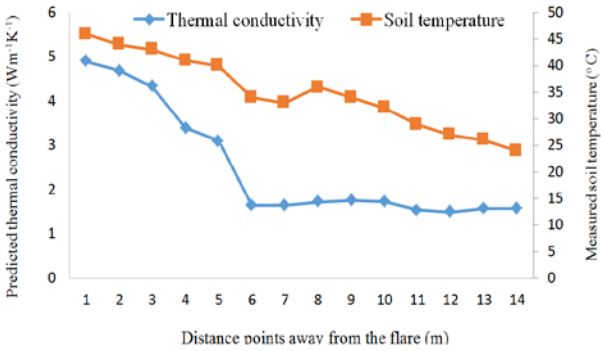

Figure 2. Soil temperature and thermal conductivity variations across sample distance points away from the flare point

The variations between bulk density and predicted soil thermal conductivity from different sample points away from flare clearly showed higher predicted soil thermal conductivity and bulk density trend across sample points within the gas flaring bond wall and decreased away (see Figure 3).

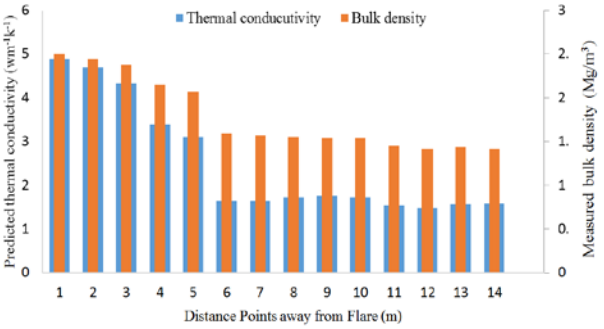

Figure 3. Bulk density and thermal conductivity variations across sample distance points away from the flare point

In contrast, the influence of moisture content on predicted soil thermal conductivity at closer sample distances towards the flare point was low (see Figure 4). That is, at low moisture content experienced within the flare vicinity sample points, the predicted soil thermal conductivity increased the highest. This results for bulk density agreed with many authors (Oladunjoye and Sanuade, 2012a; Rubio et al.,2009; Singh and Devid, 2000), but not with moisture content who stated that increased bulk density and moisture content results to increase in predicted soil thermal conductivity. This

could be attributed to the increased soil temperature and prolonged heat emission from the flare site which could have resulted in high evaporation at closer sample points to the flare vicinity.

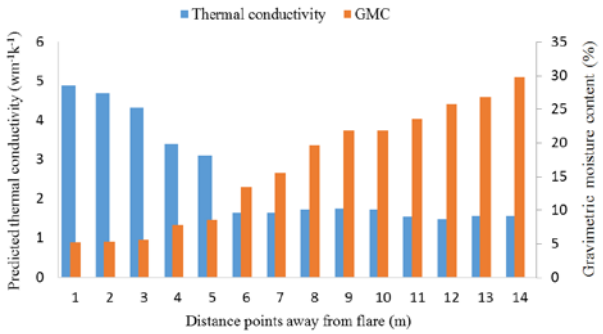

Figure 4. Moisture content and thermal conductivity variations across sample distance points away from the flare point

The predicted soil thermal conductivity versus bulk density relationship showed a strong positive linear correlation with r^2 = 0.98 (Figure 5a). In contrast, the predicted soil thermal conductivity relationship with moisture content exhibited a negative non-linear correlation with r^2 = 0.75 (Figure 5b), whereas the slope of the regression line and intercept are -0.13 and 4.62 respectively. That shows that at low moisture content, the predicted soil thermal conductivity increased and decreased with increasing moisture content.

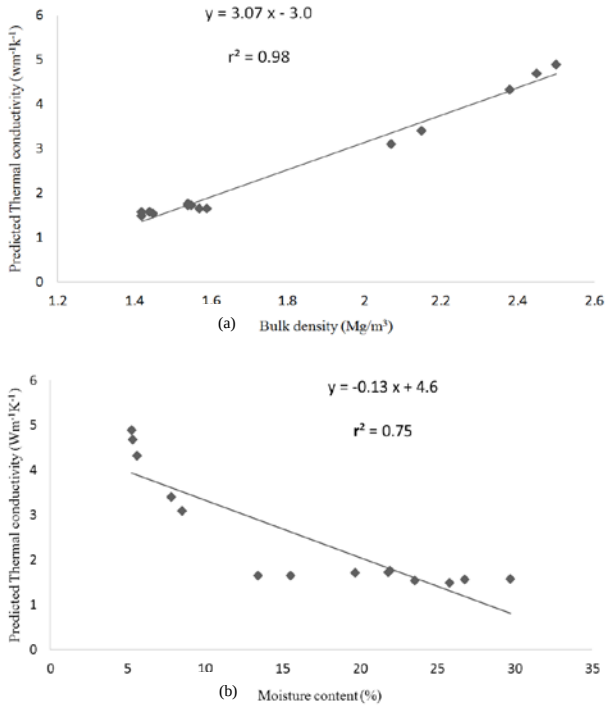

Figure 5. Predicted values of soil thermal conductivity with (a) bulk density (b) moisture content

3.3 Predictive variability maps of soil thermal conductivity

Krigged maps shows that the spatial distribution of predictive soil thermal conductivities from different sample distance points away from the active gas flaring point were the main output of the geostatistical spatial analyses. From the GPS readings, the coordinates of the active point of flare were situated north-west direction at $4^o\ 58'\ 47.35^oN$ and $7^o\ 10'\ 58.45$ at an elevation of 26 m. Regions in the map with darker colour represent zones with higher thermal conductivity values whereas regions with lighter colour represent moderate to low values (see Figure 6). High resolution of geostatistical maps has an edge in thorough characterisation of soils on site-specific basis than maps created for mapping units which implies that detailed and precise observation can be made on the spatial distribution of soil properties especially the thermal properties that cannot be routinely determined in the laboratory. Cruz-Rodriguez (2004), in agreement stated that detailed observations can be made on the distribution of soil properties when considering land use.

From a detailed observation of the spatial maps for predictive soil thermal conductivities at 0-15 cm surface depth (Figure 6a) and 15-30 cm sub-surface depth, (Figure 6b), the parameter was found to increase from north to west in the direction of flaring in both depths, but decreased with increasing distance away from point of flaring. There was obvious positional similarity in both depths of increase in predicted soil thermal conductivity concentrated in multi-regions in north-western direction of the map. The distribution map revealed that the parameter decreased from north to east, with a fairly uniform distribution with patches from east to south.

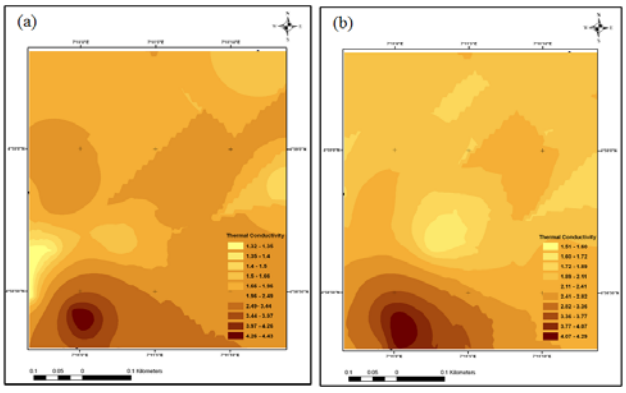

Figure 6. Kriged maps of predictive soil thermal conductivity from different sample distance points away the horizontal active gas flaring site at (a) 0-15 cm and (b) 15-30 cm depths

From the spatial maps, predictive soil thermal conductivity was generally high and above standard range of measurements (0.02-4 $Wm^{-1}K^{-1}$) for 50 m, 100

m and 200 m sample distances in surface and subsurface depth. Thus, predictive soil thermal conductivity was generally higher in the surface (0-15 cm) depth than the subsurface 15-30 cm depth.

Although, high predictive soil thermal conductivity was concentrated north-western within the flare point, the spatial variability appeared to be more continuous and uniform to the north-eastern section of the field. However, few mosaic patches appeared around the mid-northern zone in both depths especially the subsurface depth. It was, therefore, possible that the enormous heat radiation and dispersion from the horizontal gas flaring jet was the major cause of thermal fluxes and disruptions across sample distances that experienced above standard measurement range.

4. Conclusion

The spatial characterisation of soil thermal conductivity through ordinary kriging clearly conveys rare insight into the spatial patterns of predicted soil thermal conductivity within and farther distances from a gas flaring site. Results showed predicted soil thermal conductivity increasing at low moisture content, increased sand content, bulk density and soil temperature within the flaring site but decreased at increasing distance away from the site. On the contrary, the increased soil thermal conductivity values at low moisture content within the flare bond wall sample points disagree with previous assertions of increase soil thermal conductivity with increased moisture content. It could be inferred that tremendous heat from the horizontal gas flaring, justifies this divergent result of this present study.

The major implication of this study from the generated maps is that the predicted soil thermal conductivities map from sample points within the flare bond wall has been negatively disrupted resulting in soil fertility loss and reduced ecosystem services. The predictive spatial maps generated could be helpful to the farmers, soil scientists and other land users to make informed decisions on the appropriate distance (at least 4 km away) from a flare location for optimum land use plan for agriculture and residential buildings, taking into account the spatial heterogeneity of the maps. The findings of this study have established the need for site-specific soil quality status monitoring as required in precision agriculture.

Further studies could examine the in situ measurement of soil thermal conductivity using KD2 Pro thermal analyser and comparing with the predictive values using Campbell (1985) model.

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References:

Abu-Hamdeh, N.H. (2000), "Effect of tillage treatments on soil thermal conductivity for some Jordanian clay loam and loam soils", *Soil Tillage Research*, Vol.56, pp.145-151.

Abu-Hamdeh, N.H., and Reeder, R.C. (2000), "Soil thermal conductivity: Effects of density, moisture, salt concentration, and organic matter", *Soil Science Society of America Journal*, Vol. 64, pp.1285-1290.

Anandakuma, K., Venkatesan, R and Prabia, T.V (2001), "Soil thermal properties at Kalpakkam in coaster south India", *Proceedings of the Indian Academy of Science*, Vol.110, No.3, pp.239-245.

APHA (1985), *Standard Methods for the Examination of Waste Wate*r, 15th Edition, American Public Health Association, Washington DC.

Arocena, J.M., and Opio, C. (2003), "Prescribed fire-induced changes in properties of sub-boreal forest soils", *Geoderma*, Vol.113, No.1, pp.1-16.

Blake, G.R. and Hartage, K.H. (1990) In: Klute. A. (ed), *Methods of Soil Analysis Part and Physical and Mineralogical Methods*, Agronomy Monogram 9, 2nd Edition, The American Society of Agronomy/Soil Science Society of America, Madison, Wisconsin, p.363-375 .

Botkin, D.B. and Keller, E.A. (1990), *Environmental Science Earth as a living Planet*, 2nd Edition, John Wiley and Sons, Canada.

Bouma, J. (1989), "Using soil survey data for quantitative land evaluation", *Advances in Soil Science*, Vol.9, pp.177-213.

Bristow, K.L. (2002), "Thermal conductivity", In: *Methods of Soil Analysis. Part. 4. Physical Methods*, SSSA Book Series 5, Soil Science Society of America, Madison, Wisconsin, p.1209-1226

Campbell, G.S. (1985), *Soil Physics with BASIC: Transport Models for Soil–Plant Systems*, Elsevier, New York.

Campbell, G.S., Jungbauer, J.D., Bidlake, W.R. and Hungerford, R.D. (1994), "Predicting the effect of temperature on soil thermal conductivity", *Soil Science*, Vol.158, pp.307-313.

Chukwu, G.O. (2007), *Soil Fertility Capability Classification for Seed Yam (Dioscorea rotundata Poir) on Acid Soils of South-Eastern Nigeria*, Unpublished PhD thesis Submitted to Federal University of Technology, Minna, Niger State, Nigeria, 190 pp.

Cohen, J., Cohen, P., West, S. G., and Aiken, L.S. (2013), *Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences*, Routledge, London.

Côté, J., and Konrad, J.M. (2005), "A generalised thermal conductivity model for soils and construction materials. Canadian", *Geotechnical Journal*, Vol.42, pp.443-458.

Cruz, C.D. (2013), "Genes: A software package for analysis in experimental statistics and quantitative genetics", *Acta Scientiarum Agronomy*, Vol.35, No.3, pp.271-276.

Danelichen, V.H.M., Biudes, N.S., Souza, M.C., Machado, N.G., Curado, L.F.A. and Nogueira, J. (2013), "Soil thermal diffusivity of a gleyic solonetz soil estimated by different methods in the Brazilian Pantanal", *Open Journal of Soil Science*, Vol.13, No.3, pp.15-22.

De Vries, D.A. (1963). "Thermal properties of soils", in: Van Wijk, W.R. (ed.), P*hysics of Plant Environment*, North-Holland, Amsterdam, pp. 210-235.

Ekwue, E.I., Stone, R.J. and Bhagwat, D. (2006), "Thermal conductivity of some compacted Trinidadian soils as affected by peat content", *Biosystems Engineering*, Vol.94, pp.461-469.

Ekwue, E.I., Stone, R.J. and Bhagwat, D. (2011), "Thermal conductivity of some common soils in Trinidad", *West Indian Journal of Engineering*, Vol.33, pp.4 -11.

Ekwue, E.I., Stone, R.J., Maharaj, V.V. and Bhagwat, D. (2005), "Thermal conductivity and diffusivity of four Trinidadian soils as affected by peat content", *Transactions of the ASAE*, Vol.57, pp.1803-1815.

ENS (2005), *Gas Flaring in Nigeria: A Human Rights, Environmental and Economic Monstrosity*, Climate Justice Programme and Environmental Rights Action/FOE Nigeria, Netherlands, June, pp. 4-25.

Enwezor, W.O., Udo E.J., Ayorade, W.A., Adepuju, J. and Chude V.O, (1999), "A review of soil and fertiliser use research in Nigeria", In: *Literature Review on Soil Fertility Investigation in Nigeria*, Federal Ministry of Agriculture and Natural Resources, Lagos, pp.53-100

Evoh, C. (2002), *Gas flares, oil companies and politics in Nigeria*. http://www.waado.org/environmental/oil companies/gasflarespolitics.

Gao, Z., Fan, X and Bian, L. (2009), "An analytical solution to one dimensional thermal conduction-convection in soil", *Soil Science*, Vol.168, No.2, pp.99-107.

Gee, G.W. and Or, D. (2002), "Particle-size analysis", In: Dane, J.H. and Topp, G.C. (ed.) *Methods of Soil Analysis. Part. 4. Physical methods*, SSSA Book Series 5, Soil Science Society of America, Madison, Wisconsin, p.255–293.

Hillel, D. (2003), *Introduction to Environmental Soil Physics*, Academic Press, London, 484 pp

Hopmans, J.W., and Dane. J.H. (1986), "Thermal conductivity of two porous media as a function of water content, temperature and density", *Soil Science*, Vol.142, pp.187-195.

Ikelegbe, O.O. (1993), "Pollution in Nigeria, cause, effect and control", *Proceedings of the 20th Nigeria Geographical Association Conference*, Minna, Nigeria, November, pp.17-18

Jang, H.D. (2004), "Environment and crops", In: Uwehi, Z.S. (ed.), *Principles of Environmental Management*, ONAKS Press, Ibadan, pp.106-130

Johansen, O. (1975), *Thermal Conductivity of Soils*, Ph.D. dissertation. Norwegian University of Science and Technology, Trondheim (CRREL draft transl. 637, 1977).

Kersten, M.S. (1949), "Thermal properties of soils", *Bulletin 28: Engineering Experiment Station*, University of Minnesota, Minneapolis, MN.

Nakshabandi, G.A. and Kohnke, H. (1965), "Thermal conductivity and diffusivity of soils as related to moisture tension and other physical properties", *Agricultural Meteorology*, Vol.2, pp.271-279.

Nelson, D.W. and L.E. Sommers. (1982), "Total carbon, organic carbon, and organic matter", In: Page, A.L. et al. (ed), *Methods of soil analysis. Part 2*, 2nd edition, Agronomy Monogram 9, 2nd Edition, The American Society of Agronomy/Soil Science Society of America, Madison, Wisconsin, pp.539-579.

Oladunjoye, M.A. and Sanuade, O.A. (2012), "In situ determination of thermal resistivity of soil: case study of Olorunsogo power plant, southwestern Nigeria", *ISRN Civil Engineering*, Vol.2012, doi:10.5402/2012/591450.

Oladunye, M.A, Sanuade, O.A. and Olaojo A.A. (2013), "Variability of soil thermal properties of a seasonal cultivated agricultural teaching and research farm, University of Ibadan, South Western Nigeria", *Global Journal of Science Frontier Research Agriculture and Veterinary*, Vol.13, No.8, pp.1- 25.

Penner, J.E. (1999), *Aviation and Global Atmosphere: Inter Governmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK, pp 2-4.

Rubio, M.C., Cobos, D.R., Josa, R. and Ferrer, F. (2009), "A new analytical laboratory procedure for determining the thermal properties in porous media, based on the American standard D5334-05", *Estudios en la Zona no Saturada del Suelo*, Vol.IX, pp.18-20.

Sepaskhah, A.R., and Boersma, L. (1979), "Thermal conductivity of soils as a function of temperature and water content", *Soil Science*, Vol43, pp.439-444.

Singh, D.N. and Devid, K. (2000), "Generalised relationships for estimating soil thermal Resistivity", *Experimental Thermal and Fluid Sciences*, Vol.22, pp.133-143.

Smits K.M., Sakaki T., Howington S.E., Peters J.F. and Illangasekare T.H. (2013), "Temperature dependence of thermal properties of sands across a wide range of temperatures (30-70°C)", *Vadose Zone Journal*, Vol.12: doi 10.2136/vzj2012.0033.

ACE (1988), *Technical Manual: Arctic and Subarctic Construction: Calculation Methods for Determination of Depths of Freeze and Thaw in Soils, TM 5-852-6/AFR 88-19*, U.S. Army Corps of Engineers (ACE), Vol.6, Equation 2-1

Udoinyang, G.U. (2005), "The effects of gas flaring on sweet potato production in the Niger Delta, Nigeria", *Journal of Ecosystem*, Vol.10, pp.77-86.

USDA-SSDS (1993), Soil Survey Manual. Agricultural Handbook. No 18, USDA Soil Survey Division Staff/ U.S. Government Print Office. Washington, DC.

USDA-SSDS (2003), *Keys to Soil Taxonomy*, USDA Soil Survey Division Staff/ Department of Agriculture: Natural Resources Conservation Service.

Usowicz, B. (1991), *Studies on the Dependence of Soil Temperature on Its Moisture in Field*, Thesis, Academy of Agriculture, Lublin.

World Bank (2009), *Satellite Observations Show Declining Levels of Gas Flaring, Greenhouse Emissions*, News Release No. 2010/143, Global Gas Flaring Reduction Public-Private Partnership, Washington, D.C.

Authors' Biographical Notes:

Onyekachi A. Irondi *is a research student in the Department of Soil Science and Meteorology, College of Crop and Soil Sciences, Michael Okpara University of Agriculture Umudike, Nigeria. He recently completed his MSc program in Soil Physics and Conservation. His research interests are in environmental soil pollution and remediation, Soil and Water conservation, Agro-climatology and environmental management.*

Moses O. Nwagbara *is a practicing Climatologist and member of Nigerian Meteorological Society, Soil Science Society of Nigeria, Association of Nigerian Geographers, Nigerian Environmental Society and CLIVAR-GEWEX Africa Climate Panel. His research interests are Climate Change, Agro-climatology, Environmental Management, Biodiversity, Climate Trend Modelling, Climate-Water-Plant Relations and Soil Climate.*

Michael A. Okon *is a Lecturer II in the Department of Soil Science and Technology, School of Agriculture and Agricultural Technology, Federal University of Technology Owerri, Nigeria. He is currently a PhD student at the Department of Soil Science and Meteorology, Michael Okpara University of Agriculture Umudike, Nigeria. His research interest is in soil hydrology and soil water relations.*

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Spinach Pasta for Cerebral Palsy in Trinidad and Tobago

Nelisha Hosein[a], Tishara Charles[b], Leandra Ramoo[c], Patrice Prout[d] and Keisha T. Roberts[e,Ψ]

[a,b,c,d] Department of Agricultural Economics and Extension, The University of the West Indies, St. Augustine, Trinidad and Tobago, West Indies; E-mails: Nelisha.Hosein@my.uwi.edu; Tishara.Charles@my.uwi.edu; Leandra.Ramoo@my.uwi.edu; Patrice.Prout@sta.uwi.edu

[e] Healthy Options Consulting Ltd., Trinidad, West Indies Email: keishatroberts@hotmail.com

[Ψ] *Corresponding Author*

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Abstract: *Portion controlled spinach pasta was developed for Cerebral Palsy (CP) patients. This paper presents the findings from a pre-study that was conducted to determine whether caregivers of CP children in Trinidad were willing to use nutrient dense spinach pasta. Spinach pasta was developed for oral and tube fed persons. Sensory evaluation was conducted on members of the Cerebral Palsy Society of Trinidad and Tobago (T&T). Chemical, nutritional and statistical analysis was also conducted. It was found from a survey that 95.8% stated there was inadequate information on CP to Trinidadians and Tobagonians which negatively impacted support through Government funding and quality of life for patients and caregivers. Most parents, 62.5% were unemployed and 25% were single or divorced. Most persons, 79.2% would buy the product while 85.7% liked the product. A novel finding was that the influence on purchasing behaviour was nutritive value and not price, usually determined in consumer studies. Spinach pasta is an easy, nutrient dense option for inclusion in the diet. Also, marketing of products for this community should emphasise nutritional content.*

Keywords: *Cerebral palsy, spinach pasta, feeding difficulty, Trinidad and Tobago*

1. Introduction

Cerebral palsy (CP) is caused by faulty development or damage by oxygen deprivation, to the part of the brain that controls movement and posture. It occurs in 3.3 persons per every 1000 live births in the western hemisphere (NINDS 2013). Consequently, it is important to consider the lifestyle of children affected by cerebral palsy and improving their quality of life, rather than simply neglecting their individual needs. Quality of life deals with many factors including perception of an individual's status and participation in normal activities. Fauconnier *et al.* (2009) dealt with assessing the variations in participation in activities by children with different stages of cerebral palsy.

Many studies agree that disabled children experience complications in simple activities in life such as eating, using the restroom and sleeping. However, pain most often affects participation in normal activities than any other factors, followed by poor nutritional status. Fauconnier *et al.* (2009) also proved that children with abnormal feeding exhibited lower participation in activities. CP caused patients to have varying difficulties in chewing, sucking, and swallowing and depending on severity, digesting foods. Furthermore, children aged 1.5 – 17 years old with CP were found to have low serum concentrations of micronutrients, despite receiving supplementation (Hillesund, 2007). These micronutrient deficiencies are associated with poor health status, with one of the major concerns being vitamin D and calcium deficiencies; due to the effect on bone growth (Pruitt and Tsai, 2009).

Many children with CP also have eating and/or swallowing difficulties. Minor difficulties range from slow eating with excessive spillage, while severe difficulties include ill health and/or life threatening conditions (Krigger, 2006, Himmelmann and Uvebrant, 2011). Feeding difficulties often lead to poor nutritional status, growth failure, and esophagitis. It is therefore critical to consider the adequate nutrition and assessment of persons with CP, particularly children, so that their quality of life can match that of a person unaffected by this condition. An abundance of material is available on CP and its implications as well as classifications, however treatments are mainly limited to clinical and physiotherapeutic forms of research (Krigger, 2006). Furthermore, to these authors' knowledge there is a dearth of national, regional and international studies of this nature, where a product is specifically developed for CP, with the aim of providing a nutrient dense product where both macro and micro nutrients are considered. Most studies instead focus on the types of foods one should consume with CP, food consistency and menu planning for this condition.

A fact that is sometimes neglected is CP is a term used to describe a group of individuals whose primary handicap is physical, as opposed to mental. It is a non-progressive disorder of posture and movement caused by a defect or insult to the central nervous system. CP can be classified as 1) Mild: where patients can move without assistance and daily activity is not limited, 2) Moderate: where patients need braces, medication and or adaptive technology for normal daily activity, or 3)

Severe: where patients require a wheelchair and are severely challenged in accomplishing daily activities by themselves (NINDS, 2013).

Many researchers outlined the implications of varying impairments of children and young persons living with CP. A cross sectional study by Gates *et al.* (2010) showed that CP was the most common childhood congenital disorder of movement and posture causing activity limitation, attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. This study focused on the quality of life or wellbeing of the child and functionality or capabilities of the child, as well as health related quality of life. Gates *et al.* (2010) indicated parents' perceptions and patients' perceptions of their condition differed greatly, where the adolescents were more positive overall about their wellbeing and ability to improve. Patients with cerebral palsy may perceive their differences to that of other unaffected children to be less drastic than others. Therefore, when seeking information about the individual, it is recommended that both the parents and adolescents be interviewed, for the assessment of abilities.

Cerebral Palsy in Trinidad and Tobago has a prevalence of more than 1,000 cases (Metivier, 2013). There are 630 members of the Cerebral Palsy Society of Trinidad and Tobago (CPSTT) (Jones, 2013). However, many cases go unreported, which is due partly to the "shame" people associate with having a family member that has CP (Metivier, 2013). The management of this condition is further complicated by the absence of a structured, consistent Government programme to aid caregivers and those affected. Consequently, caregivers are usually parents of CP patients, who may need to stop working in order to facilitate the management of the disease. Moreover, there is little knowledge of the condition across the nation. Since CP patients require special nutritional attention and care, it poses difficulty to both the patients themselves and their parents.

Fung *et al.* (2002) argue that malnutrition is common in children with moderate to severe CP which is associated with poorer health status and limitations in societal participation. Mc Cullougha *et al.* (2013) described health status of 4-17-year-old CP patients and compared them with the general population through a longitudinal, clinical survey. The participants were able to independently walk 10 meters. The study further showed that young persons with CP had significantly poorer health status. Reilly *et al.* (1996) studied the prevalence of feeding problems and oral motor dysfunction in CP children, through a community survey. The study found that of the sample, 57% and 38% experienced sucking and swallowing problems respectively, in the first year of life. The study concluded that brief meal times together with oral dysfunctions made it difficult to obtain an adequate nutrient intake. Bell *et al.* (2010) also studied the relationships between growth, body composition, oral motor and feeding dysfunctions, diet intake, sedentary lifestyles, quality of life and health care. In contrast, evidences show that CP patients are also at risk of obesity due to sedentary lifestyles and disordered eating (overfeeding due to over estimation of energy needs).

No culturally relevant product has yet been developed in the Trinidad and Tobago market to cater for patients with CP. Furthermore, internationally there is a dearth of information on re-engineered foods for this condition. Spinach which is consumed internationally was used to produce pasta to allow for easy chewing and swallowing while maintaining jaw movement to ensure muscle exercise. The benefits of this included the texture and size of the pasta along with the fact that spinach is nutrient dense, as it provides many nutrients in a serving. Fauconnier *et al.* (2009) dealt with assessing the variations in participation in activities by children with different stages of cerebral palsy. These authors proved that children with abnormal feeding exhibited lower participation in activities. Therefore, it is prudent to provide CP patients with nutrient dense foods to facilitate an increased chance for health and participation in activities.

Given the difficulty in feeding and the nutritional requirements that these patients have, this study aimed to develop a product to cater the nutritional needs of patients with CP or patients with difficulty in chewing and/or swallowing. It was also developed to provide a simple meal preparation alternative for parents of the children with CP.

2. Materials and Methods

2.1 Formula / Recipe and Procedure

A formula / recipe for making the Spinach Pasta was used, comprising the ingredients below

1. 3 eggs
2. 2 ¾ cups white flour
3. 5 ounces Spinach (leaves and soft stems)
4. Salt to taste
5. Water to combine

A standard 6-steps procedure was adopted. These steps are:

1. Blanch Spinach leaves for 1 minute in hot boiling water.
2. Remove leaves from boiling water and blend in blender until mixture is smooth and leaves are pureed (additional water may be added up to a tablespoon)
3. Place spinach, eggs, flour and water into mixer with paddle attachment and mix until dough sticks together.
4. Remove dough from mixer and form into a ball and let rest for 15 minutes.
5. On floured surface, roll dough to 1/8 of an inch thick, using a knife or pastry cutter.
6. Cut strips of dough 0.5 cm thick into noodle shapes.

Moreover, for dealing with baked/dried pasta versus unbaked pasta for tube fed persons, additional steps are used. These are:

For baked/dried pasta

1. Place strips onto baking sheet (ungreased) without each noodle touching.
2. Bake in oven at 375^0C for 30 minutes until dried.
3. Cool, store in freezer, or boil for 10 minutes until desired al dente texture is achieved.

For unbaked pasta for tube fed persons

1. Boil Strips for 8 minutes until cooked throughout.

2.3 Sensory Evaluation

In an effort to ensure that the product meets the needs of the intended target population, it was pretested using a standardised sensory evaluation form. The product was first tested by the Staff and students of the Dudley Huggins building of The University of the West Indies. Based on this first pre-test sensory evaluation adjustments were made to both the sensory evaluation form and the pasta formula. Following this it was decided that two variations of the product should be produced. The first would cater for children who displayed minimum to mild chewing abilities while the second would address children who required tube feeding.

A sensory evaluation questionnaire was developed to evaluate participant ratings for appearance, texture, odour, taste, product preference, factors influencing purchase, purchase intention and overall liking for the product by way of a yes or no response.

On the day of the interview the products were pre-boiled with salt packaged in sealed labeled containers and transported to the Cerebral Palsy Society of Trinidad and Tobago (CPSTT) monthly meeting at the Caroni Food Production office on the Old Southern Main Road in Caroni. In attendance was the executive of the CPSTT and members along with their children. The parents (24 persons) were asked whether they would be able to determine and purchase the product for their children. Products were distributed without any condiments or accompaniments, along with questionnaires so persons could record their answers. Besides, a small number of caregivers showed up to the meeting to participate in the study. All members of the Cerebral Palsy Society were not able to attend as this was a monthly meeting to schedule the Society's events for the following week.

Participants were included within the study once they were the respective caregivers of children with CP and were able to provide oral consent. Persons were excluded if they were unable to provide consent, were vegetarian or were under the age of 18 years.

2.4 Chemical Analysis

Moisture content, crude protein and total fat were determined in the pasta following analysis procedures from the AOAC Official Methods of Analysis (Helrich, 1990). Moisture content was determined based on the AOAC Method 926.07, protein was determined based on AOAC Method 930.25, while fat was determined based on AOAC Method 925.12.

2.5 Nutritional Labelling Analysis

Nutritional analysis for the recipe developed was analysed by ESHA software. The recipe was inputted and reports were generated based on a 100g serving size. Reports were generated for label display, recipe card with multicolumn per 100g and protein quality.

3. Results and Discussion

Cerebral palsy is a health concern among children in Trinidad and Tobago. This health condition has with it a number of nutritional complications that require urgent attention. The information collected from the sensory analysis was then analysed using SPSS 12.0. It was found from the study that a large portion of children diagnosed with CP experience feeding difficulties as the condition results in the impairment of facial muscles, which further diminishes the child's ability to chew, suck or swallow. These critical impairments can place the child at increased risks for under nutrition, failure to thrive, malnutrition, growth retardation and digestive difficulties (Krigger, 2006; Himmelmann and Uvebrant, 2011).

The sensory evaluations conducted on parents was the first step to address the nutritional needs of children diagnosed with CP. Individuals with CP often have poor nutritional status caused by inadequate intakes, oral dysphagia, gastrointestinal reflux and chronic aspiration. Feeding difficulties range from self-feeding challenges, to those with severe disabilities who must be assisted during feeding. CP patients have trouble with sucking, chewing and swallowing. CP feeding of nutrient dense foods would assist with the management, and could improve the quality of life for these patients (Schoendorfer *et al.*, 2011).

This condition is stressful on both the caregiver and children alike. However, having a stable support system is critical in managing this condition; it is therefore not alarming that the majority of participants within the study population although married were unemployed. Table 1 illustrates the marital status of participants where 55% of participants were married, 25% reported being single, while 15% resided within a common law relationship and a minority (i.e., 5%) divorced. Table 2 shows the employment status of participants of which a total of 65.2% were unemployed, only 30.4% of caregivers were employed and 4.3% were students. Studies have indicated that mothers of children with cerebral palsy, whose children showing mild to severe motor impairment are vulnerable to parental stress. However, this was not reported among the study population.

Table 1. Marital Status of Respondents

Marital Status	Frequency	Valid Percent
Single	5	25
Married	11	55
Divorced	1	5
Common Law	3	15
Total	**20**	**100**
Missing	4	

Table 2. Employment Status of Respondents

Employment	Frequency	Valid Percent
Employed Full Time	7	30.4
Unemployed	15	65.2
Student	1	4.3
Total	**23**	**100**
Missing	1	

Low self-esteem, lack of family and social support, limited financial resources, feelings of frustration, and the daily overload of tasks caused by anxiety, stress and repercussions are common complaints of caregivers of children with CP. Due to the demanding nature of this condition parents/ caregivers are often forced to care for persons with CP as their principal activity and are often forced to work from home or in extreme cases not work at all. These findings were very compatible to those within our study population in which a high percentage of participants were unemployed.

These difficult but necessary decisions are often attributed to the lack of proper daycare and school facilities for CP children, in addition to the fact that caring for a child with CP requires much time and devotion which often does not afford parents the privilege of a full time job. The high rate of unemployment among this population often results in a financial burden to the government who may provide the caregivers of children with this condition a monthly stipend.

The concern for most parents and caregivers is what foods are acceptable for their children with this condition. Few parents have received training on methods to care for their children, including appropriate diet interventions. As shown in Table 3, it is therefore not surprising that the majority of respondents indicated that there is a lack of information in this area in Trinidad and Tobago. This not only has implications to the parent's ability to effectively care for their children, but also addresses the need for education relating to this health condition.

Table 3 addressed knowledge adequacy relating to Cerebral Palsy in Trinidad and Tobago. The majority of participants (95.8%) reported that there was a lack of information relating to this condition while 4.2% found that there was adequate information on the condition. The caregivers felt there was a lack of communication of information, to support their efforts to care for their charges, was of great importance.

Table 3. Respondents Views about Whether There is Adequate Information about Cerebral Palsy in Trinidad and Tobago

Enough Info on CP	Frequency	Valid Percent
No	23	95.8
Yes	1	4.2
Total	24	100

Therefore, when disseminating the product, information about the product was communicated to those participating in the product evaluation. Parents were given products in containers, as shown in Figure 1, except the product had been pre-cooked. Surveys were distributed with the product and parents were asked to indicate liking for appearance, texture, odour, taste, and factors that influence purchase, purchase intention and overall product rating.

Most of the participants found the product firm as shown in Figure 2 and the texture greatly reflected that of regular pasta. However the texture was in accordance to that of the recommendations for persons with CP. Dietary practitioners recommend textures and consistency of food be maintained at all times either by pureeing, chopping and grinding foods for a more palatable experience. Foods can be softened by adding broth, gravy, milk, or juices to accommodate constipation issues, while liquids can be thickened for ease in swallowing.

Figure 1. Picture of Spinach Pasta before Cooking

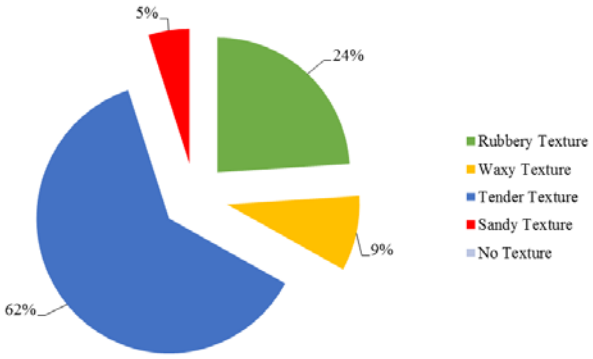


Figure 2. Responses about Texture of Spinach Pasta

Texture is a key component when preparing meals for children diagnosed with cerebral palsy. The majority of participants 62% found the product to be tender, 24% found it to be rubbery, another 9% reported the product had a waxy texture and 5% of participants found the product had a sandy texture.

According to the survey, the product was very well received by the caregivers of the children where 87.5% of participants stated they liked the product overall as shown in Figure 3. It can be concluded that participants generally enjoyed the products based on the needs of their children. Despite this, there seems to be a need for the improvement of the formula, especially where processing or characteristics affecting cooked appearance is concerned, as 56% of participants found the product had a firm appearance; another 20% found the product presented a mushy appearance, 14% indicated it was clumpy while 10% found the product to have a dry appearance (see Figure 4). However, major improvements do not seem to be required where product taste and odour are concerned.

This level of participant satisfaction was further deduced as the majority of participants stated they were willing to purchase the product if they were made available for purchase (data not shown).

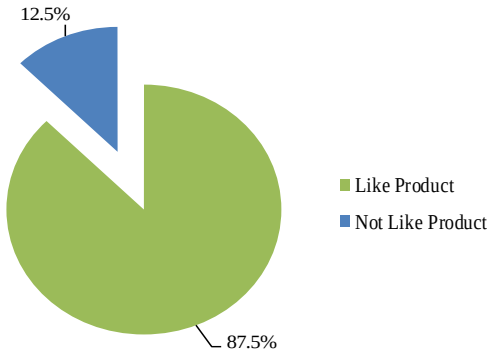


Figure 3. Responses about Overall Rating of Spinach Pasta

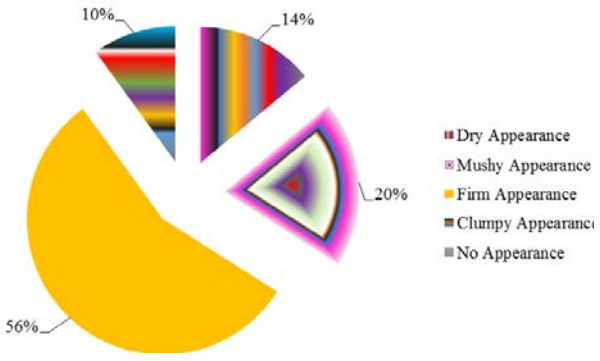


Figure 4. Responses about Appearance of Spinach Pasta

According to Figures 5 and 6, there were positive associations for product taste and odour respectively. This evaluated taste may serve as encouragement to CP patients, especially given the aforementioned challenges with feeding. For caregivers, using this product may translate to convenience and time management as the entire family may consume the product. Odour also received ratings which support the possibility of the spinach pasta being used by the CP patients and their caregivers.

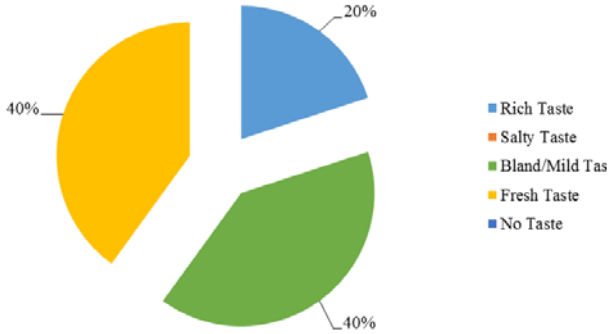


Figure 5. Responses about Taste of Spinach Pasta

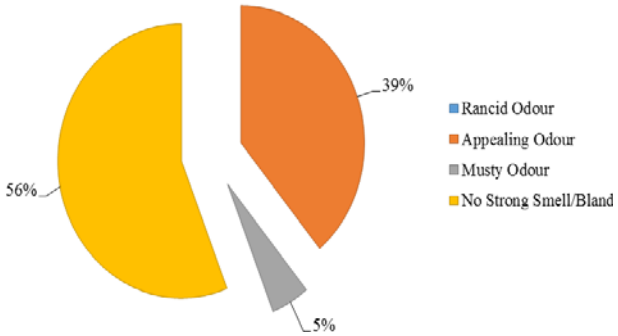


Figure 6. Responses about Odour of Spinach Pasta

Forty percent (40%) of participants found the product to have a bland or mild taste as well as a fresh taste. Twenty percent (20%) found the product to have a rich taste, while none of the participants reported the product as having a salt taste or no taste. The majority (56%) of participants found the product to lack a strong smell or odour and found there was a bland odour; 39% reported the product had an appealing odour and 5% found the product to have a musty odour.

This product may be beneficial to caregivers of children with CP to aid in providing nutritious meals, despite the difficulties experienced during feeding. The caloric intake of patients with CP is very important especially in children, as deficient dietary intakes may lead to growth impairments or development retardation. According to Soylu *et al.* (2008) malnutrition is in fact a major concern for CP patients. They evaluated the effect of nutritional support on clinical findings by analysing questionnaire responses and anthropometric measurements (skinfold, weight, and height).

The study found that after being on nutritional support for 6 months, there was no evident difference in the first and last height in those who completed the follow-up process. However, skinfold measurements and height and weight parameters improved; also there was a significant decrease in infections and constipation. This may indicate that although nutritional support may have provided adequate calories, the protein quality may have required improvement in order to significantly affect height improvements. Therefore, both good protein quantity (as shown in Table 4) and good protein quality are required for CP persons.

Table 4. Protein and Fat Values for an Average 100 grams of Sample (Dried)

	Crude Protein on DM basis	Fat
Totals:	6.86 g	1.99 g
% Daily Value (FDA)	13.72 %	3.06 %

ESHA evaluation shown in Figure 7 found the protein quality was good. For persons with CP, the provision of all these amino acids in only 100 grams of the spinach pasta as well as the protein efficiency ratio affords this population to have an inexpensive product that caters to their nutritional requirements. Also pasta is rarely consumed alone, and is frequently consumed with animal protein. Therefore, the protein complementarity from a meal of spinach pasta and meat will provide the essential amino acids. Adequate protein intake is essential for the building and repair of tissue, for adequate growth and development in childhood and to promote lean tissue gain. There is currently no evidence to suggest that protein requirements of children with CP differ to those of typically developing populations, and therefore recommendations for typically developing children can be applied (Bell and Sampson-Fang, 2013). Protein efficiency ratio also referred to as protein utilisation gives a ratio of the weight gained from consumption of the amino acids. Therefore, the gain of body mass through muscle requires the provision of high quality proteins, like those found in the spinach pasta.

A total of 13.72% of the product contained protein, indicating it is a good source of protein and 3.06% contained fat, which indicated the spinach pasta is a low source of fat.

Protein intake is an important part of the dietary intake of CP children, the amino acid ratios for spinach pasta was high at 181% for Tryptophan, 180% for Phenylalanine and Tyrosine, 163% for Isoleucine, Methionine and Cystine. Other scores included 154% for Valine, 133% for Leucine, 125% for Histidine, 120% for Threonine and 77% for Lysine. Therefore this spinach pasta scored high for the ratios of the amino acids.

Based on nutritional analysis conducted for the spinach pasta 100 grams provided just 190 calories, 2 servings of carbohydrates, 0 simple sugars and was low in fat, while being high in fibre, vitamin A and iron as shown in Tables 4 and 5. Walker *et al.* (2012) showed in their study which determined the relationship between Energy Intake (EI), macronutrient intake and body composition in preschoolers with CP compared to those of typical developing children (TDC) that a significant relationship between EI and fat free mass existed as fat free mass was larger in TDC than those with CP. Consequently, low fat nutrient dense products may be required. Moreover, it has been found that constipation is a frequent condition in persons with CP due to inadequate dietary fibre intake. The spinach pasta is both low in fat and a good source of fibre (see Figure 8). The nutritional content of the product is to be placed on the product label, following its analysis by ESHA.

This product can therefore provide nutritional support for minimum calories at both the macronutrient and micronutrient levels. Grammatikopoulou *et al.* (2009) investigated growth and nutrition in children and adolescents with CP in comparison with their healthy siblings. Those with CP were presented with lower intakes of Vitamin A, Biotin, Folate, Vitamin K and Copper compared to siblings. Asmah *et al.* (2015) further stated a deficiency of the micronutrients copper, zinc and selenium may result in disorders of the nervous system, while care must also be taken with supplement

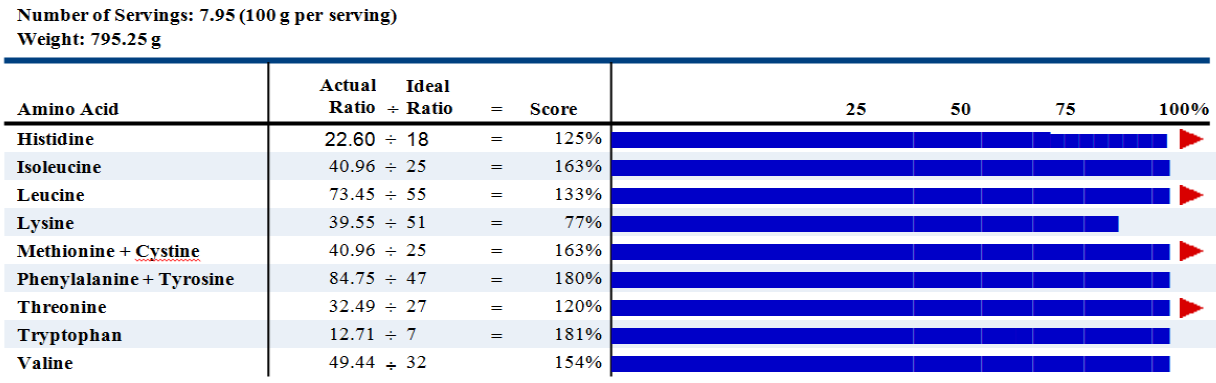


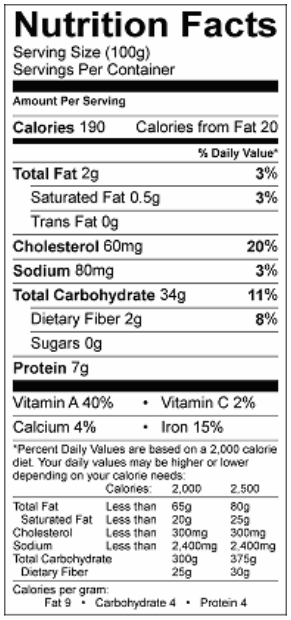
Figure 7. ESHA Protein Quality Analysis for Cerebral Palsy Spinach Pasta

Table 5. Nutrient Analysis for 100 grams of Spinach Pasta

Amount	Measure	Ingredient	Comments
3.00	Med	Eggs, raw	
2.75	Cup	Flour, all purpose, white, unbleached,	
5.00	Oz	Spinach, cooked, with salt, drained	
0.75	Cup	Water, tap	

Nutrient Analysis

Nutrient	Per 100g	Nutrient	Per 100g
Gram Weight (g)	100.00	Vitamin C (mg)	1.75
Calories (kcal)	185.18	Vitamin D - IU (IU)	13.61
Calories from Fat (kcal)	18.44	Vitamin D - mcg (mcg)	0.33
Calories from SatFat (kcal)	5.34	Vitamin E - Alpha-Toco (mg)	0.64
Protein (g)	7.08	Folate (mcg)	112.93
Carbohydrates (g)	33.77	Folate, DFE (mcg)	159.61
Dietary Fiber (g)	1.59	Vitamin K (mcg)	88.16
Soluble Fiber (g)	0.53	Pantothenic Acid (mg)	0.47
Total Sugars (g)	0.25	Calcium (mg)	40.69
Monosaccharides (g)	0.06	Chromium (mcg)	0.07
Disaccharides (g)	0	Copper (mg)	0.11
Other Carbs (g)	31.92	Fluoride (mg)	0.02
Fat (g)	2.05	Iodine (mcg)	8.80
Saturated Fat (g)	0.59	Iron (mg)	2.93
Mono Fat (g)	0.65	Magnesium (mg)	27.23
Poly Fat (g)	0.52	Manganese (mg)	0.47
Trans Fatty Acid (g)	0.01	Molybdenum (mcg)	2.82
Cholesterol (mg)	61.75	Phosphorus (mg)	89.53
Water (g)	56.38	Potassium (mg)	152.22
Vitamin A - IU (IU)	1958.67	Selenium (mcg)	20.02
Vitamin A - RAE (RAE)	120.07	Sodium (mg)	79.87
Carotenoid RE (RE)	187.03	Zinc (mg)	0.65
Retinol RE (RE)	26.56	Omega 3 Fatty Acid (g)	0.04
Beta-Carotene (mcg)	1121.23	Omega 6 Fatty Acid (g)	0.46
Vitamin B1 (mg)	0.36	Alcohol (g)	0
Vitamin B2 (mg)	0.33	Caffeine (mg)	0
Vitamin B3 (mg)	2.65	Choline (mg)	52.28
Vitamin B3 - Niacin Equiv (mg)	4.14		
Vitamin B6 (mg)	0.09		
Vitamin B12 (mcg)	0.15		
Biotin (mcg)	3.76		



Nutrition Facts
Serving Size (100g)
Servings Per Container

Amount Per Serving

Calories 190 Calories from Fat 20

% Daily Value*

Total Fat 2g 3%
Saturated Fat 0.5g 3%
Trans Fat 0g
Cholesterol 60mg 20%
Sodium 80mg 3%
Total Carbohydrate 34g 11%
Dietary Fiber 2g 8%
Sugars 0g
Protein 7g

Vitamin A 40% • Vitamin C 2%
Calcium 4% • Iron 15%

*Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:

	Calories:	2,000	2,500
Total Fat	Less than	65g	80g
Saturated Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

Calories per gram:
Fat 9 • Carbohydrate 4 • Protein 4

Figure 8. ESHA Label for Cerebral Palsy Spinach Pasta

use and nutrient - nutrient interactions as the overuse of zinc may reduce copper utilisation, leading to oxidative stress. Nutrition information to caregivers of persons with CP should facilitate the provision of dietary nutrients and not focus on the intake of supplements. Table 5 also shows the micronutrient benefits of the spinach pasta.

Malnutrition, including micronutrient deficiencies may lead to increased risk of infection, diminished cerebral growth and other conditions which may result in the CP person exhibiting lowered cognitive development, as well as abnormal behaviour (Kuperminc and Stevenson, 2008). The provision of micronutrients commonly associated as deficient in CP may reduce the risk of these developmental challenges in children. The spinach pasta (based on Table 5) is a good source of Vitamin A, Biotin, Folate, Vitamin K and Zinc, which were found to sometimes be deficient in CP children and therefore nutrients of concern.

Vitamin A which is important for immune function has a recommended intake (RI) of 700-900 mcg RAE, while the US FDA suggests a daily value of 5000 IU.

The spinach pasta provided 120.7 RAE and 1958.67 IU per 100 grams. Biotin has a suggested AI of 5-25 mcg depending on age and sex, while the spinach pasta provided 3.76 mcg per 100 grams. The RDA for folate is 200-300 mcg per day depending on sex and age with the pasta providing 112.93 mcg per 100 grams. Zinc which is important for immune function and required for normal growth and development during childhood and adolescence has an RDA of 2-11 mg, depending on age and sex, with the spinach pasta providing 0.65 mg. Also Vitamin K which is important for bone metabolism has adequate intakes of 30 mcg for children 1-3 years, 55 mcg for children 4-8 years and 75 mcg for persons 14-18 years, with the spinach pasta providing 88.16 mcg per 100 grams. This spinach pasta can provide micronutrients of concern at levels which may reduce the risk for deficiencies.

Nutritional stunting caused by macro and micro nutritional deficiencies can lead to short stature according to Wittenbrook and Parrish (2011). These authors stated that once adult size is reached, increasing energy and protein intake will have no effect on increasing height. In this study energy intake based on the needs of the individual was recommended, as no two persons with CP display the same characteristics. However, admittedly the nutritional needs for children with CP are difficult to estimate. Bell and Sampson-Fang 2013 emphasised the need to evaluate body composition, physical activity levels etc, when planning meals for this group. It was also advised that protein intake be estimated using the Recommended Daily Allowance (RDA) and Dietary Reference Intake (DRI) and the actual weight or appropriate weight for height used. This means 1.5-2g protein per kilogram body weight per day. The RDA and DRI are also relevant for micronutrients.

Arrowsmith *et al.* (2012) published a study which aimed to measure Resting Energy Expenditure (REE) and nutritional intake in children with severe CP in relation to body composition, as well as effects increased intake had on REE. It was stated that altered body composition and growth abnormalities are usually associated with cerebral palsy but equations to estimate energy requirements (REE) using body composition based on normal mentally healthy children tend to over-estimate needs for children with cerebral palsy.

Their study showed that once children are fed by gastrostomy and by oral means, the resting energy expenditure increased due to weight gain. It signified that most children with CP have too low an intake and their bodies adapt to low intake and therefore resulting in a low REE. It was also established that this is reversible in most children, so the use of a nutrient dense product like spinach pasta may have the ability to not only meet current nutritional needs of persons with CP, but also attenuate the negative effects which may have resulted from a previous nutrient poor diet. However, Arrowsmith *et al.* (2012) found weighed food records overestimated the intake by approximately one hundred and seventy percent for orally fed children. It may be difficult to monitor intakes in these patients but it is worth pursuing in order to maintain a healthy quality of life.

When sensory evaluation tests were conducted, the preferences and factors influencing purchase of a product were assessed with respect to the caregivers of the CP patients, as shown in Figure 9. The majority of respondents stated that nutritive value of the product was more of a concern than the price and availability. This is in contrast to consumer studies that consistently showed price to be a major concern and not nutrient content as the main factor in purchasing decisions.

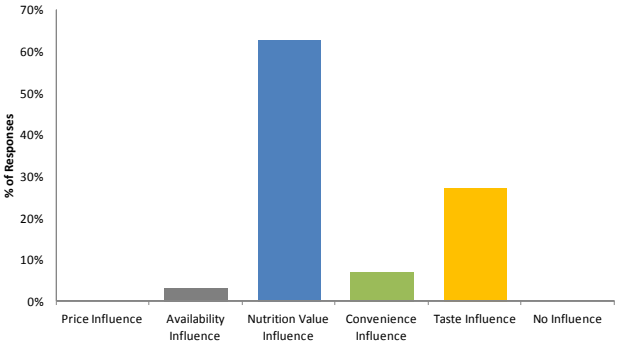


Figure 9. Factors Affecting Respondents Choice of Products

In addition to this taste was the second most important factor to respondents, followed by availability and convenience respectively. Marketing of products for this population must therefore emphasise nutritive value. This may be due to the fact that poor nutrition is associated with the inability of CP patients to participate in activities as well as negative effects on health.

The spinach pasta was found to be generally satisfactory and well rated by the caregivers who participated in the survey. There is therefore a need for future studies among this population as there is an evident gap in the information available to caregivers and patients as well as in the types of products that can be available to them. According to Schoendorfer *et al.* (2011), there is a paucity of information and studies on micronutrient deficiencies and appropriate interventions to mitigate dietary imbalances and the corresponding physiological effects to persons with CP.

4. Conclusion and Recommendation

This all natural spinach pasta was tested with parents and care givers of persons with CP who were in attendance at the meeting of the CPSTT. Of the persons in attendance, the majority stated they would purchase the product while others indicated they liked the product. From this evaluation, it can be concluded once this product is fully engineered to consider both organoleptic and postprandial glycemia there is grounds for a high

acceptance rate among the CP community. Parents and Caregivers are responsible for food choice for CP patients so their acceptance of the product is critical to the product being introduced to the CP community.

Future studies can be conducted using this spinach pasta, as it is both acceptable organoleptically and nutritionally, furthermore it has the potential to attenuate nutritional micronutrient and macronutrient deficiencies, once part of a well-constructed meal plan. In producing the pasta, the dough was rolled and cut by hand which prevented uniformity of the product and therefore, becomes an area for improvement, especially as this artisan method of production may affect product texture. In producing the product, the packaging which was originally determined, was replaced to accommodate a cheaper, more feasible alternative as this research was self-funded.

Some limitations of analysing the study include that no children with Cerebral Palsy were able to sample the product at the meeting due to ethical concerns and time concerns. The parents who are responsible for purchasing food and preparing meals for the CP persons were instead asked to sample, as they would be able to determine whether they would purchase the product for their children. Additionally, only a small number of caregivers showed up to the meeting to participate in the study. All members of the Cerebral Palsy Society were not able to attend as this was a monthly meeting to schedule the Society's events for the following week. Therefore the results do not express the views of the entire Cerebral Palsy Society of Trinidad and Tobago, but a few members.

In laboratory analysis of the product, the procedures used assumed that total Nitrogen of the sample reflected protein nitrogen, which may not necessarily reflect protein nitrogen alone. However, ESHA analysis found the protein quality to be high, with the protein efficiency ratio for 8 of the 9 amino acids above 100%. Furthermore micronutrients that are frequently a challenge in the diet of persons with CP were well represented in this product. Therefore this pasta is nutrient dense and may facilitate disease management and support an improved quality of life through enhanced nutritional status.

One of the main concerns that were presented in this study was the lack of information to parents and caregivers, which is necessary to ensure a good quality of life for persons with CP. It is recommended that diet sheets be developed for this population, similar to those given to persons with type 2 diabetes mellitus and hypertension. Parents can be presented with a recommended list of nutrient dense foods, from medical professionals. Also because the actual food intake to ensure health is specific to the individual with this condition, there should be a scheduled dietary intervention where parents are instructed on actual quantities and types of foods to be fed for example every 3 months. This dietary intervention should be based on the person with CP weight, height, body composition and specific factors on their condition. These types of interventions will not only aid both parents and CP persons to have a better quality of life but may also address the high unemployment issue, as CP patients will have an improved chance of functioning reducing the burden on parents.

References:

Arrowsmith, F.E., Allen, J.R., Gaskin, K.J., Somerville, H. (2012). "Nutritional rehabilitation increases the resting energy expenditure of malnourished children with severe cerebral palsy", *Developmental Medicine & Child Neurology*, Vol.54, No.2, pp. 170-175.

Asmah, R.H., Anyele, A., Asare-Anane, H., Brown, C.A., Archampong, T.N., Amegatcher, G., Badoe, E., Adjei, D.N., Dzudzor, B., and Ayeh-Kumi, P.F. (2015), "Micronutrient levels and antioxidant status in pediatric cerebral palsy patients", *Oxidants and Antioxidants in Medical Science*, Vol.4, No.2, pp 73-77

Bell, K.L., Boyd, R.N., Tweedy, S.M. et al. (2010). A prospective, longitudinal study of growth, nutrition and sedentary behaviour in young children with cerebral palsy. BMC Public Health, 10(179).

Bell, K.L. and Samson-Fang, L. (2013), "Nutritional management of children with cerebral palsy", *European Journal of Clinical Nutrition*, Vol.67, pp. S13-S16.

Fauconnier, J., Dickinson, H.O., Beckung, E., and Marcelli, M. (2009), "Participation in life situations of 8-12 year old children with cerebral palsy: Cross sectional European study", *The BMJ*, Vol.338, pp.b1458.

Fung, E.B., Samson-Fang, L., Stallings, V.A., Conaway, M., Liptak, G., Henderson, R.C., Worley, G., O'Donnell, M., Calvert, R., Rosenbaum, P., Chumlea, W. and Stevenson, R.D. (2002), "Feeding dysfunction is associated with poor growth and health status in Children with Cerebral Palsy", *Journal of the American Dietetic Association*, Vol.102, No.3, pp. 361-373.

Gates, P., Otsuka, N., Sanders, J. and McGee-Brown, J. (2010), "Functioning and health-related quality of life of adolescents with cerebral palsy: Self-versus parent perspectives", *Developmental Medicine and Child Neurology*, Vol.52, No.9, pp.843-849.

Grammatikopoulou, M.G, Daskalou, E. and Tsigga, M. (2009), "Diet, feeding practices, and anthropometry of children and adolescents with cerebral palsy and their siblings", *Nutrition*, Vol.25, No.6, pp.620-626.

Helrich, K. (1990), *Official Methods of Analysis of the Association of Official Analytical Chemists*, The AOAC International, Vol. 1-2.

Himmelmann, K. and Uvebrant, P. (2011), "Function and neuroimaging in cerebral palsy: a population-based study", *Developmental Medicine and Child Neurology*, Vol.53, No.6, .pp. 516-521.

Jones, C. (2013), "*Poverty Reduction Unit to partner with Cerebral Palsy parents.*" Available at: http://www.news.gov.tt/content/poverty-reduction-unit-partner-cerebral-palsy-parents#.UoqPkMSkpds (Accessed 18 Nov. 2013).

Krigger, K.W. (2006), "Cerebral Palsy: An overview", *American Family Physician*, Vol.73, No.1, pp. 91-100.

Kuperminc, M.N. and Stevenson, R,D. (2008), "Growth and nutrition disorders in children in CP", *Developmental Disabilities Research Reviews*, Vol.14, No.2, pp.137-146.

McCullougha, N., Parkes, J., Kerr, C. and McDowell, B.C. (2013), "The health of children and young people with cerebral palsy: A

longitudinal, population-based study", *International Journal of Nursing Studies*, Vol.50, No.6, pp.747-756.

Metivier, P. (2013), *Cerebral Palsy: Telephone Interview: Public Relations Officer*, Cerebral Palsy Society of Trinidad and Tobago, Trinidad and Tobago.

NINDS (2013), *Cerebral Palsy: Hope through Research*, National Institute of Neurological Disorders and Stroke. Available at: http://www.ninds.nih.gov/disorders/cerebral_palsy/detail_cerebral_palsy.htm (Accessed 20 Oct. 2013).

Reilly, S., Skuse, D., Poblete, X. (1996), "Prevalence of feeding problems and oral motor dysfunction in children with cerebral palsy: A community survey", *The Journal of Pediatrics*, Vol.129, No.6, pp.877-882.

Schoendorfer, N., Tinggib, U., Sharp, N., Boyd, R. Vitetta, L. and Davies, P.S.W. (2011), "Micronutrient intakes in enterally and orally fed children with severe cerebral palsy. e-SPEN, the European", *e-Journal of Clinical Nutrition and Metabolism*, Vol.6, No.6, pp.e259-e263.

Soylu, O.B., Unalp, A., Uran, N., Dizdarer, G., Ozgonul, F.O., Conku, A., Ataman, H. and Ozturk, A.A. (2008), "Effect of nutritional support in children with spastic quadriplegia", *Pediatric Neurology*, Vol.39, No.5, pp.330-334.

Walker, J.L., Bell, K.L., Stevenson, K.A., Weir, R.N., Boyd and Davies, S.W. (2012), "Relationships between dietary intake and body composition according to gross motor functional ability in preschool-aged children with cerebral palsy", *Annals of Nutrition and Metabolism*, Vol.61, pp.349-357.

Wittenbrook, W. and Parrish, C.R. (2011), "Nutritional assessment and intervention in cerebral palsy", *Nutrition Issues in Gastroenterology* Series #92, Available at: http://www.practicalgastro.com/pdf/February11/WittenbrookArticle.pdf (Accessed 18 Nov. 2013).

Authors' Biographical Notes:

Nelisha Hosein *is a graduate of the Human Ecology Programme, in the Faculty of Food and Agriculture, at The University of the West Indies, Trinidad and Tobago. She is also a member of the Trinidad and Tobago Association of Nutritionists and Dietitians.*

Tishara Charles *is a graduate of the Human Ecology Programme, in the Faculty of Food and Agriculture, at The University of the West Indies, Trinidad and Tobago.*

Leandra Ramoo *is a graduate of the Human Ecology Programme, in the Faculty of Food and Agriculture, at The University of the West Indies, Trinidad and Tobago.*

Patrice Rhonda Prout *is a Registered Dietitian and is currently employed as a Research Assistant at The University of The West Indies, St. Augustine Trinidad. Ms. Prout is currently pursuing a Masters of Philosophy in Human Ecology with a speciality in Nutrition.*

Tishara Charles *is a graduate of the Human Ecology Programme, in the Faculty of Food and Agriculture, at The University of the West Indies, Trinidad and Tobago.*

Keisha. T. Roberts *is a Director at Healthy Options Consulting Ltd providing nutrition, wellness and exercise prescriptions for athletes, and persons at all stages of the lifecycle. She is the immediate past president of The Trinidad and Tobago Association of Nutritionists and Dietitians (TTANDi). Dr. Roberts is also a certified fitness instructor with CANFIT PRO, Ontario Canada and a member of the Canadian Obesity Network.*

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Development of Oil Palm Fruit Fibre/Cementitious Based Composites for Building Applications

Oladele I. Oluwole

Metallurgical and Materials Engineering Department, Federal University of Technology Akure, Ondo State, Nigeria
E-mails: iooladele@futa.edu.ng; wolesuccess2000@yahoo.com

$^{\Psi}$ *Corresponding Author*

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Abstract: *In this paper, cement and red sand were used as the ceramic matrix based material reinforced with oil palm fruit fibre (OPFF) to develop composite for structural applications. The composite was produced by mixing red sand, cement and the fibres (treated and untreated) in predetermined proportions using open mould and hand laying process. Compressive, bending and water absorption properties were examined by carrying out these tests on the cured samples. From the results, it was observed that both treated and untreated OPFF reinforced composite samples showed improved properties. It was also observed that the rate at which the treated OPFF within 0-10 % reinforced sample absorbed water is lower than that of unreinforced sample. Untreated OPFF reinforced composite samples demonstrated better compressive and bending strength potentials when compared to their treated counterparts.*

Keywords: *Cement, sand, oil palm fruit fibre, composites, building application*

1. Introduction

Multifunctional cement–matrix composites are useful as structural materials that provide functional properties, which allow applications such as electrical grounding, electrical contacts for cathodic protection, deicing, electromagnetic interference (EMI) shielding, antistatic flooring and strain sensing. Multi-functionality is attractive for cost reduction, durability enhancement, large functional volume, design simplification and absence of mechanical property loss (which tends to occur if embedded devices are used in place of a multifunctional structural material) (Wen and Chung, 2007). Today's demand for smart structures, capable of detecting stimulus and responding adequately, has created the need for materials with not only good mechanical properties and durability, but also new additional functions. That is the reason why many researches have been focused on the development of multifunctional materials, which combine both structural properties and other functional applications. New functional properties include, for example, self-strain sensing, damage sensing (Baeza *et al*., 2013; Vilaplana *et al*., 2013), thermal control, vibration reduction (Muthusamy *et al.,* 2010) and electromagnetic wave reflection (Zornoza *et al*., 2010).

Natural organic fibres is a new area of research for applications in building materials, their natural abundance, ready availability, plentiful supply, relative cheapness and ability to be replenished are the strongest arguments for their utilisation in the construction industry. Previous research has shown that their use in building composites along with cement in the construction industry gives improved and favorable physical and mechanical properties. Many studies had been carried out on natural fibre, such as kenaf, bamboo, jute, hemp, coir, sugar palm and oil palm (Khairiah and Khairul 2006; Lee *et al*., 2005; Rozman *et al*., 2003;). The advantages of these natural resources are low weight, low cost, low density, high toughness, acceptable specific strength, enhanced energy recovery, recyclability and biodegradability (Myrtha *et al*., 2008). Natural fibre can be divided into four different types which are leaf, bast, fruit and seed. However, one of the major setbacks for these natural resources is their high affinity for water due to the presence of lignin in these natural composites. Oladele *et al*. (2010) showed in their study that chemical treatment can be used to reduce this major problem and improve both tensile properties and surface condition of the fibres for composite development.

Many researches have been carried out on the use of cement and some other ceramics like clay for various applications with the aim of improving their potentials for engineering applications. However, not much effort has been channelled towards improving the quality of red sand which has also been used historically as a building material despite its availability is abundant. Composite of red sand and natural organic fibres is a new area of research for applications in building materials, their natural abundance, availability, relative cheapness, good insulating property and ability to be replenished are the strongest arguments for their utilisation in the construction industry (Oladele *et al.*, 2015). The results of the research into the influence of natural rubber and coconut coir on the bending and water absorption properties of processed red sand

reinforced composites by Oladele *et al.* (2015) have revealed the possibility of blending these materials together for the development of ductile fracture materials for structural applications.

Ceramics in general carry flaws and micro-cracks both in the material and at the interfaces even before an external load is applied. Under the condition of an applied load, distributed micro-cracks would propagate, coalesce and align themselves to produce macro-cracks. The micro and macro-fracturing processes can be favourably modified by adding short, randomly distributed fibres of various suitable materials. Fibres not only suppress the formation of cracks, but also abate their propagation and growth.

In general, short fibre reinforced ceramic matrix composites exhibit what is known as quasi brittle behaviour characterised by a more ductile post peak softening in uniaxial tension compared with plain matrix. The class of short fibre reinforced ceramic matrix composites designed to exhibit pseudo strain hardening properties based on micromechanical principles has been referred to as engineered cementitious composites (ECC). The concerns with the inferior fracture toughness of concrete are alleviated to a large extent by reinforcing it with fibres of various materials. The resulting material with a random distribution of short, discontinuous fibres is termed fibre reinforced concrete (FRC). Fibre/matrix bond is of critical importance in FRC's and toughness or energy absorption capability is of primary interest. The major function of fibres in the matrix is in delaying and controlling tensile cracking of the matrix. This controlled multiple cracking reduces deformation at all stress levels, and imparts a well-defined post-cracking and post-yield behaviour. The fracture toughness, ductility and energy absorption capacity of the composite are then substantially improved. These technical benefits can be utilised both in semi-structural elements such as thin sheets, flat sheets, corrugated and cladding panel as well as in load bearing members (Oladele, 2009). The aim of this research is to improve the properties of red sand by blending it with cement and palm fruit fibre in both treated and untreated conditions.

2. Materials and Methods

The major materials used for the research were; Oil Palm Fruit Fibres (OPFF), red sand and a slow setting Ordinary Portland Cement which were purchased from Edo State, Nigeria.

2.1.1 Sieving of Red Sand

Red sand was obtained from Afuze in Edo State and sieved to obtain -150 + 106 µm using sieve shaker that operates at 1,500 rpm for 15 minutes as shown in Figure 1 to achieve a uniform fine particle size.

2.1.2 Fibre Preparation

The oil palm fibre used was obtained from Okomu palm oil mill in Edo State, Nigeria and was then washed with water and sun dried for 5 days at about 27 ± 2 ℃ before treatment. The sun dried oil palm fruit fibre was as shown in Figure 2.

Figure 1. Sieve Shaker and Sieves used in Seiving

Figure 2. Untreated Oil Palm Fibre

2.1.3 Chemical Treatment

The oil palm fibre was treated chemically with 1 molar solution of Sodium Hydroxide (NaOH). The treatment was carried out by weighing 120 g of NaOH and dissolving it in 3,000 ml of distilled water. This solution was used to treat 100 g oil palm fibre in a container that was placed inside shaker water bath at a temperature of 50 ^{0}C for 4 hours. The treated fibre was washed with tap water and rinsed with distilled water in order to ensure neutral status before it was sun dried for 5 days at about 27 ± 2 ℃. The fibre was later cut into 10 mm lengths for the production of randomly dispersed short fibre reinforced cementitious composites.

2.1.4. Mixing of Constituents

Prior to mixing, the fibre, red sand and the slow setting cement at room temperature condition were weighed with weighing balance to obtain both the quantity and

Table 1. Mixing Proportion for the Composites (%, g)

Samples	**Cement**		**Red sand**		**Fibre** (Treated and Untreated)	
	(%)	(g)	(%)	(g)	(%)	(g)
Neat	100	0	0	0	0	0
0	97.5	1267.5	0	0	2.5	32.5
5	92.5	1202.5	5	65	2.5	32.5
10	87.5	1137.0	10	130	2.5	32.5
15	82.5	1072.5	15	195	2.5	32.5
20	77.5	1007.5	20	260	2.5	32.5

Where: 0 T, 5 T, 10 T, 15 T and 20 T represent treated fibre reinforced compositions while 0 U, 5 U, 10 U, 15 U and 20 U represent untreated fibre reinforced compositions.

corresponding weight proportions and were properly blended. Water to be added was measured using a measuring cylinder, and then added to the mixture and thoroughly mixed until a homogenous paste was formed. The mixing proportions for the composites were as shown in Table 1.

2.1.5 Production of Composites

The homogenous paste was poured into the cylindrical mould of 100 x 40 mm length and diameter for the compressive test sample and also to a mould of 100 x 30 x 20 mm for the bending test. Before filling the mould and closing it, cellophane sheet was placed between the mould and the paste so as to facilitate easy removal. After the mould was filled to capacity it was compressed within the mould using hydraulic press with a capacity of 20 kN. Constant force was applied for about an hour using the Mini press compression moulding machine. The sample was removed from the mould and then allowed to cure in air at room temperature which ranged between 24 ±2℃ in the laboratory for a period of 28 days. After curing, compressive, bending and water absorption tests were carried out on the samples.

2.1.6 Property Test

1) *Measurement of Compressive Properties*

Compressive test was carried out in accordance to American Standard Testing and Measurement (ASTM (2015a) - ASTM C873 and using INSTRON 3382 Floor Model Universal Tester at a fixed crosshead speed of 10 mm/min. The developed composite samples and the neat sample of 100 x 40 mm were used. Three identical samples were tested for each weight fraction from where the average values were used as the representative values. The specimen is placed between compressive plates parallel to the surface. The specimen is then compressed at a uniform rate. The maximum load is recorded along with stress-strain data. An extensometer attached to the front of the fixture was used to determine modulus.

2) *Measurement of Bending Properties*

Three point bend tests were performed in accordance to the standard ASTM D 790 M (ASTM 2015b) to measure bending properties using INSTRON 3382 Floor Model Universal Tester at a crosshead speed of 0.3 mm/mm and at a specific strain rate of 10^{-3}/s. The samples were of 100 x 30 x 20 mm. Three samples were tested for each weight fraction used and the average values were taken to represent the actual values.

3) *Water Absorption Test (Swelling Behaviour)*

The dried composite samples and the neat sample were immersed in distilled water and the experiment was carried out at room temperature of 24 ±2℃. The water absorption property of the samples was determined by weighing those samples before immersing them in 700 cm^3 water. This test was done for 7 hours for the various samples. This short time was used to avoid dissolution of the red sand in water if soaked for long time. The samples were examined at an interval of 1 hour by removing, cleaning and then weighing. The weight after a period of 7 hours was taken and the percentage weight gained was used to determine water absorption potential of the materials. The percentage of water content (W_t) was determined using Equation 1:

$$\% W_t = [(W_t - W_o) / W_o] \times 100\% \quad (1)$$

where, W_t is the weight of sample at time t, and W_o is the initial weight of the sample.

3. Results and Discussion

The results of the compressive strength at peak and yield for both treated and untreated palm fruit fibres reinforced cement/red sand based composites and neat were as shown in Figure 1.

Compressive properties describe the behaviour of a material when it is subjected to a compressive load as specified in the standard. Compressive strength and modulus are the two most common values produced. It was observed from the plots that both compressive strength at peak and yield properties increase as the red sand content increases for the treated fibre reinforced composites from 0 – 20% but for the untreated fibre reinforced composites, initial increase from 0 – 10 was followed by a decrease from 15 – 20%. However, sample with 10 % red sand from untreated OPFF gave the best compressive strength at peak with a value of 15.62 N/mm^2 followed by sample from 20 % of red sand with treated OPFF with a value of 14.15 N/mm^2.

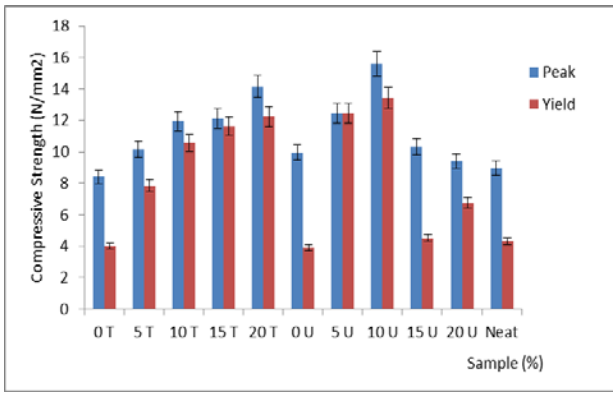

Figure 3. Compressive Strength at Peak and Yield for the Developed Composites and the Neat Sample

Similarly, the yield strength showed that 10 % red sand from untreated OPFF gave the best compressive strength at yield with a value of 13.43 N/mm^2 followed by sample from 5 % of red sand with untreated OPFF with a value of 12.43 N/mm^2. The results showed that, compressive strength of cementitious composites can be improved by blending cement with red sand and OPFF. The best strength was obtained from the blend of the three different materials which revealed that each component has contributed positively to the enhancement of the compressive strength for the developed composites.

The red sand as ceramic material has good compressive strength and, it can be deduced from the results that the compressive strength of the red sand contributes immensely to compressive strength of the developed composites. The fibres on the other hand were noticed to have influence on the interfacial adhesion which was responsible for the trend observed as the red sand content increases for both treated and untreated OPFF reinforced composites. The compressive strength increases as the red sand content increases for the treated OPFF reinforced composites because the treatment aids proper adhesion at the interface.

Due to the presence of lignin, this serves as polymer matrix to the cellulose of the OPFF in an untreated condition (Oladele *et al*., 2010). The initial increase in strength was followed by decrease at 10 % of red sand addition. Optimum properties were obtainable within 10-20% red sand addition for treated OPFF while the optimum were obtainable between 5 and 10 % of red sand with the untreated OPFF addition. The compressive strength of the material can be used for the determination or prediction of the hardness of the materials and their resistance to surface indentation. The neat sample response showed that the compressive strength of cement can be improved by the addition of these additives; red sand and OPFF which are environmental friendly and renewable. The peak and yield values of the neat sample are 8.96 and 4.33 N/mm^2 and these imply about 74% and 210% increase, respectively.

Also, this is a better result compared to the work by del Carmen Camacho *et al*. (2014) in which it was discovered that the addition of CNT to Portland cement mortars does not significantly affect the compressive strength where less than 7% enhancement was achieved at 28 days curing time.

Figure 4 showed compressive modulus of the materials in which it was observed that the moduli of all the untreated OPFF reinforced composites were less than that of the neat sample and that of the treated OPFF reinforced composites. It was noticed that the compressive modulus tends to increase as the red sand content increases while it tends to decrease as the red sand content increases for treated and untreated OPFF reinforced composites, respectively. These responses may be due to the effects of the OPFF fibres as discussed in Figure 3. The results revealed that 15 % red sand based composite from treated OPFF gave the best results with a value of 419.80 N/mm^2 followed by the neat sample with a value of 402.60 N/mm^2.

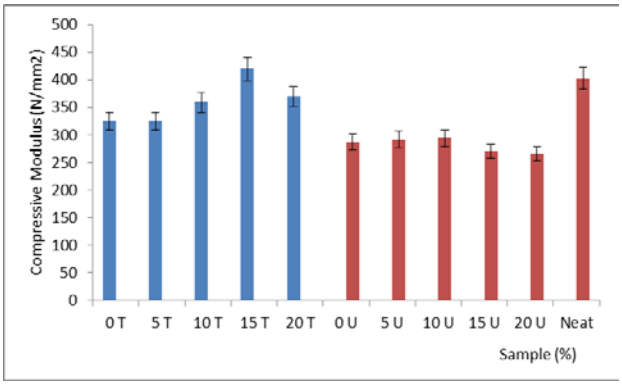

Figure 4. Compressive Modulus for the Developed Composites and the Neat Sample

Figure 5 shows the bending strength at peak and yield. The bending strength of the developed composites was improved compared to the neat sample. Most of the samples did not displayed yield strength and of those with yield strength, only sample without red sand but with treated OPFF showed improved yield strength compared to the neat sample. This performance could be due to treatment of the OPFF that aided strength enhancement and surface modification (Oladele *et al*., 2010). It was observed from the results that sample with 5 % red sand addition from both untreated and treated OPFF reinforced samples gave the best results with values 3.52 and 3.50 N/mm^2, respectively. Compared to the neat sample with a value of 2.50 N/mm^2, this culminated to 40 % enhancement. Also, the bending strength at yield for sample with the best value was 3.25 N/mm^2 from sample without red sand but with treated

OPFF compared to that of the neat sample with a value of 2.11 N/mm^2, which led to about 54 % enhancements. Unlike the work by del Carmen Camacho *et al.* (2014) that revealed that the addition of CNT to Portland cement mortars does not significantly affect the bending strength (less than 6%) at 28 days curing time, the addition of OPFF brought about high enhancement of the bending strength at peak of the developed cementitious composites.

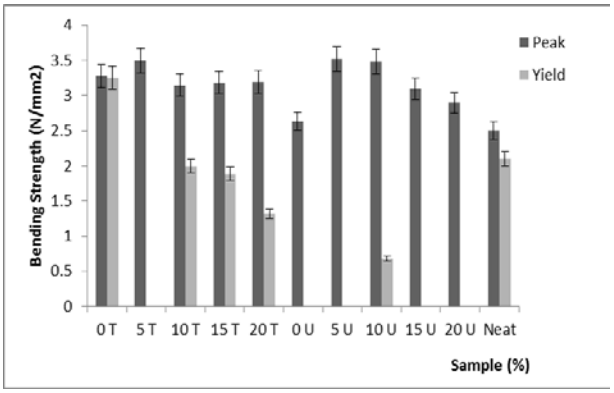

Figure 5. Bending Strength at Peak and Yield for the Developed Composites and the Neat Sample

The bending modulus was as shown in Figure 6. Similar to the results in Figure 4, the moduli of the developed composites were low compared to the neat sample except for the sample developed with 5 % red sand from untreated OPFF with a value of 264.50 N/mm^2. The neat sample followed having marginally exceeded that of 10 % red sand from treated OPFF with values 229.29 and 219.15 N/mm^2, respectively.

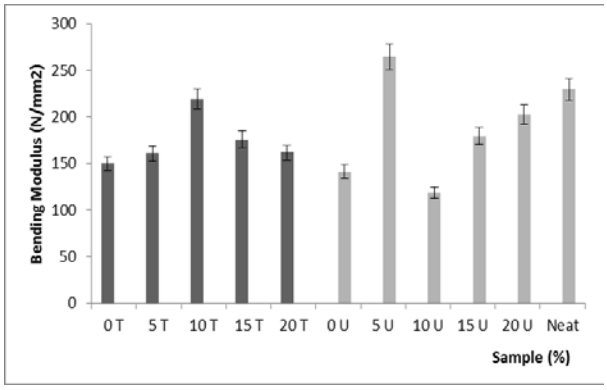

Figure 6. Bending Modulus for the Developed Composites and the Neat Sample

Considering the enhancement by this feat, about 15 % has been achieved. Again, considering the red sand content that aid improved bending strength and modulus, it falls between 5 and 10 % which showed that with less quantity of the red sand, the bending property of cement based material can be improved. This become important as this will reduce the cost of production of high quality building materials thereby allowing the product to be available for consumption at affordable rate.

Rate of water absorption of the materials was as shown in Figure 7. This test was carried on the samples because the target application was building construction (Oladele *et al.*, 2009). This test will help determine the extent at which the formed composites can absorb water in case of water attack in service environment. Since the amount of the fibre used was constant, therefore, the obtained variation will be based on treated and untreated conditions of the fibres in addition to amount of red sand present.

Figure 7. The Rate of Water Absorption for the Developed Composites and the Neat sample after 7 Hours of Immersion

It was observed from the results that the rate of water absorption in both treated and treated conditions of the OPFF increases from 0-15 % of the red sand before reducing which showed that the red sand had similar effect on the developed composite materials. However, it was discovered that the untreated OPFF reinforced samples absorbed more water at the end of 7 hours of immersion than their treated reinforced counterparts. This observed trend may be due to the removal or reduction in the amount of lignin content which is usually responsible for the hydrophilic nature of natural fibres from the OPFF after treatment. The best results were obtained within 0-10 % red sand treated OPFF samples with sample without red sample emerging as the best with a value of 4.55 % followed 4.87 % from 5 % red sand. The neat sample that did not contain OPFF has a value of 6.80 % and this culminated to about 33 % enhancement. It follows that; the addition of these additives can aid the reduction of water absorption tendency of Portland cement in building application. This result depicts a good feat compared to the effect of the addition of CNT to the cement matrix which could

imply the development of higher levels of corrosion in aggressive conditions, such as carbonation and contamination by chloride ions as reported by del Carmen Camacho *et al*. (2014).

4. Conclusion

The results from compressive and bending properties revealed that the strengths and moduli of cement based composite materials for structural application can be improved by red sand and oil palm fruit fibre additives, especially for low technology application. The untreated OPFF gave the best response in terms of the mechanical properties while the treated OPFF gave the best response in terms of water absorption behaviour.

Considering the range of red sand addition that gave the best response with respect to these properties, it can be deduced that low content, 5 % of the red sand within the cement based composites can be adopted in addition to the OPFF in both treated and untreated conditions to improve the bending and water absorption properties of cement based materials while high content, 10-15 % improves the compressive properties. The work reveals the potentials in the use of red sand for building application by working on its limitation.

References:

ASTM (2015a), *ASTM C873 / C873M-15: Standard Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds*, American Standard Testing and Measurement (ASTM International), West Conshohocken, PA.

ASTM (2015b), *ASTM D790-15e2: Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials*, American Standard Testing and Measurement (ASTM International), West Conshohocken, PA.

Baeza, F.J., Galao, O., Zornoza, E. and Garcés, P. (2013), "Effect of aspect ratio on strain sensing capacity of carbon fibre reinforced cement composites", *Material Design*, Vol.51, pp. 1085-1094.

del Carmen Camacho, M., Galao, O., Baeza, F.J., Zornoza, E., and Garcés, P. (2014), "Mechanical properties and durability of CNT cement composites", *Materials*, Vol.7, pp. 1640-1651

Khairiah, B. and Khairul, A.M.A. (2006), "Biocomposites from oil palm resources", *Journal of Oil Palm Research*, Special Issue-April, pp.103-113.

Lee, S.M., Cho, D., Park, W.H., Lee, S.G., Han, S.O. and Drzal, L.T. (2005), "Novel silk/poly(butylene succinate) biocomposites: The effect of short fibre content on their mechanical and thermal properties", *Composites Science and Technology*, Vol.65, pp.647-657.

Muthusamy, S., Wang, S. and Chung, D.D.L. (2010), "Unprecedented vibration damping with high values of loss modulus and loss tangent, exhibited by cement-matrix graphite network composite", *Carbon*, Vol.48, pp.1457-1464.

Myrtha, K., Holia, O., Dawam, A.A.H. and Anung, S. (2008), "Effect of oil palm empty fruit bunch fibre on the physical and mechanical properties of fibre glass reinforced polyester resin", *Journal of Biological Sciences*, Vol.8, No.1, pp.101-106.

Oladele, I.O., Akinwekomi, A.D., Aribo, S. and Aladenika, A. K. (2009). "Development of fibre reinforced cementitious composite for ceiling application", *Journal of Minerals and Materials Characterisation and Engineering*, Vol.8, No.8, pp. 583-590.

Oladele, I.O., Okoro, M.A. and Ajileye, J.O. (2015), "The Effect of natural rubber on the bending properties of coconut coir (*Cocos Nucifera*) reinforced red sand composites", *ACTA Tehnica Corviniensis - Bulletin of Engineering, Fascicule*, Vol.2, pp.87-92

Oladele, I.O., Omotoyinbo, J.A. and Adewara, J.O.T. (2010), "Investigating the effect of chemical treatment on the constituents and tensile properties of sisal fibre", *Journal of Minerals and Materials Characterisation and Engineering*, Vol.9, No.6, pp.569- 582

Rozman, H.D., Saad, M.J. and Mohd Ishak, Z.A. (2003), "Bending and impact properties of oil palm empty fruit bunch (EFB) – polypropylene composites: The effect of maleic anhydride chemical modification of EFB", *Journal of Polymer Testing*, Vol.22, pp.335-348.

Vilaplana, J.L., Baeza, F.J., Galao, O., Zornoza, E. and Garcés, P. (2013), "Self-sensing properties of alkali activated blast furnace slag (BFS) composites reinforced with carbon fibres", *Materials*, Vol.6, pp.4776-4786.

Wen, S. and Chung, D.D.L. (2007), "Partial replacement of carbon fibre by carbon black in multifunctional cement-matrix composites", *Carbon*, Vol.45, pp.505-513.

Zornoza, E., Catalá, G., Jiménez, F., Andión, L.G. and Garcés, P. (2010), "Electromagnetic interference shielding with Portland cement paste containing carbon materials and processed fly ash", *Material Construction*, Vol.60, pp.21-32.

Author's Biographical Notes:

Isiaka Oluwole Oladele *holds a Master's degree and PhD in the area of natural-fibre reinforced polymer composites from the Department of Metallurgical and Materials Engineering, Federal University of Technology, Akure, Ondo State, Nigeria. Dr. Oladele is a Senior Lecturer in the department and former Sub-Dean, School of Engineering and Engineering Technology. He has supervised many undergraduate and postgraduate projects and has published in local and international journals and conference proceedings.*

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Chemical Composition and Characterisation of Skin Gelatins from Two Different Freshwater Fish Species in Osun State of Nigeria: A Comparative Study

Ayoade L. Adejumo [a,Ψ], Fatai A. Aderibigbe[b] and Rasheed U. Owolabi[c]

[a]Department of Chemical Sciences, Osun State University, Osogbo, Nigeria; E-mail: ayoade.adejumo@uniosun.edu.ng;

[b]Department of Chemical Engineering, University of Ilorin, Ilorin, Nigeria; E-mail: aderibigbe_fatai@yahoo.com

[c]Department of Chemical and Petroleum Engineering, University of Lagos, Nigeria; E-mail: uthmanrash642@yahoo.com

[Ψ] *Corresponding Author*

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Abstract: *In this study, a comprehensive extraction of gelatin from the skin of two fresh water fish species from Osun State of Nigeria (7.5876° N, 4.5624° E), namely: tilapia and catfish by acid extraction was carried out. The extraction was carried out through series of steps involving rinsing in water, dipping in sodium hydroxide (0.1 M), and soaking in 0.1 M acetic acid at room temperature of 25 °C, followed by a final extraction with water at 45 °C for 12 h. The results obtained herein showed that the fish gelatins were comparable to the fish gelatins contained in past reports. The proximate analysis showed that the protein content of gelatin extracted from catfish gelatin contains 7.45% and that of tilapia gelatin contains 72.95%. It was found that tilapia fish skin gelatin is more hydrogen bonded than that of catfish skin gelatin. The foaming properties of tilapia fish gelatin (foaming capacity: 28%, foaming stability: 18%) were higher than the foaming properties of catfish gelatin (foaming capacity: 14%, foaming stability: 10%). The gelatins in this study contained all essential amino acids with glutamate being the most prominent ones. The viscosity at 40 °C was low in catfish gelatin (2.49 cP) compared to tilapia fish gelatin (3.58 cP). From this result, it can be concluded that gelatin from tilapia fish can act as better foaming agent as compared to gelatin extracted from its catfish.*

Keywords: *Fish skin, gelatin, tilapia, catfish, viscosity, amino acid composition*

1. Introduction

Gelatin is a clear and tasteless protein. It is a natural hydrocolloidal macromolecular material that is traditionally produced as a result of partial hydrolysis of collagen from the skin, cartilages, tendons or bone of porcine or bovine animals. The increasing demand of gelatin is as a result of its wide use in many industrial fields, such as food, material, pharmacy and photography, especially in the food and pharmaceutical industries. More importantly, gelatin has an increasing number of new applications for instance, gelatin is used as emulsifiers, foaming agents, colloid stabilisers, fining agents, biodegradable packaging materials and microencapsulating agents. These recent applications are strategies to meet the growing demands of green and sustainable chemistry which calls for replacement of synthetic agents with natural ones, in line with the growing trend to replace synthetic agents with more natural ones. Most of the past studies are dedicated to using collagens and gelatins from alternative sources to land-based animals.

However, the development of gelatin alternatives has gained importance in recent years as the demand for non-bovine and non-porcine gelatin has increased due to the bovine spongiform encephalopathy (BSE) crisis and for religious and socio-cultural reasons (Sabon et al., 2013). Since then, there has been much concern about using gelatin derived from possibly infected animal parts. Pig skin gelatin has suffered religious restrictions especially for Judaism and Islam, therefore, only beef gelatinmn is acceptable provided it has been prepared according to the religious rites (Badii and Howell, 2006). The development of gelatin alternatives is therefore highly desirable to food processors (Karim and Bhat, 2009). Due to these religious reasons and health concerns, the study of gelatin from extraction from fish parts, such as skin, bone and scales, is of great interest.

Several works have been carried out on the properties of gelatin from fish skin and bones (Rawdkuen et al., 2013; Chandra et al., 2013; Ketnawa et al., 2016; Bor-Sen et al., 2008; Jan and Asbjorn, 2007; Gómez-Estaca et al., 2009; Irwandi et al., 2009; Liu et al., 2009; Ratnasari et al., 2013; Chandra et al., 2015; Binsi et al., 2009). Go´mez-Guille´n et al. (2001) and Gudmundsson (2002) reported that the properties of gelatin such as the contents of both hydrophobic and hydroxylated amino acids, as well as molecular weight distribution and gelatin viscosity, seem to be species specific. These past findings are corroborated by a number of studies carried out on properties of fish skin gelatins showing that their properties differ from those of mammalian gelatins and vary between species (Choi

and Regenstein, 2000; Ferna´ndez-Diaz et al., 2001; Go`mez-Guille`n and Montero, 2001; Grossman and Bergman, 1992; Gudmundsson, 2002; Gudmundsson and Hafsteinsson, 1997; Holzer, 1996). However, some studies have pointed out that tropical and sub-tropical warm-water fish species (tilapia, nile perch, catfish) might have similar rheological properties and thermostability to that of mammal gelatins, depending on the species, type of raw material and processing conditions (Gilsenan and Ross-Murphy, 2000; Jamilah and Harvinder, 2002; Muyonga et al., 2004; Karim and Bhat, 2009; Gómez-Guillén et al., 2009; Rawdkuen et al., 2010).

As far as fish gelatin is concerned, the huge number of species having very different intrinsic characteristics, has aroused the interest of the scientific community in optimising the extracting conditions as well as characterising the yields, physico-chemical and functional properties of the resulting gelatins, obtained mainly from skin and bone residues (Gómez-Guillén et al., 2009). To reveal such properties, gelatin from each actual species must be studied. But Gómez-Guillén et al. (2009) observed that strict comparisons are difficult since methodologies may differ considerably from one work to another. In this work, gelatin extractions were carried out following the same protocol.

In Nigeria, fish farming especially catfish has become a significant fish resource. The annual production in Nigeria of catfish amounts to15,489 tonnes (Ekunwe and Emokaro, 2009) with projected domestic production to have reached 671,492 tonnes by 2015 (FDF, 2008). In the present investigation, the objective is to determine and compare the properties of tilapia and catfish skins' gelatins and to determine the effect of the species on the nature of gelatin obtained.

2. Materials and Methods

2.1 Materials

All chemicals used in this study were of analytical grade. Two different species of fresh water fishes were obtained from local vendor in Eko-ende, Osun State, Nigeria, namely catfish and tilapia fish. The two fish species caught from Otin River were obtained from local fisherman. Residual meat in the skin was removed manually with a new razor blade and the cleaned fish skin was washed with tap water. The skin fish was packed in polyethylene plastic bags and stored in the freezer at -20℃ until it was used. Before the gelatin extraction, the frozen skins were thawed with running tap water until the core temperature of the skin reached 8-10℃.

2.2 Methods

2.2.1 Extraction of gelatin from catfish and tilapia fish

The method of Kittiphattanabawon et al. (2010) was adapted for gelatin extraction with little modification. In summary, 100 g of tilapia and catfish skins were washed with running tap water and dipped in 0.5 M NaCl for 5 min at 5^0C. A Glass stirrer was used to stir the skin dipped in sodium chloride solution. The Skin was then washed with tap water three times to remove salt solution before treating with 0.1M NaOH. The skin was mixed with 0.1M NaOH at a sample to solution ratio of 1:10 (mass/volume ratio). Acetic acid concentration of 0.1 M was used because Sompie et al. (2015) reported that the higher acetic acid concentration caused decreased viscosity. The mixture was placed on a magnetic stirrer for 2 h at room temperature of 25℃ to remove non collagenous proteins. The alkali solution was changed every 40 min. The pretreated skin was washed with distilled water until the neutral pH of wash water was obtained. The pH of wash water was monitored using a pH paper. The skin was mixed with 0.1 M acetic acid at a sample to solution ratio of 1:10 (mass/volume ratio) and stirred for 40 min at room temperature. The swollen skin was washed thoroughly with tap water until pH of wash water became neutral. The final extraction was carried out in distilled water at 45°C with a skin/water ratio of 1:10 (w/v) in a controlled temperature water bath for 12 hours while the mixture was continuously stirred. Then the mixtures were filtered in two layers of cheese cloth. The resultant filtrate was freeze-dried. All gelatin samples were weighed, calculated for extraction yield and subjected to analyses.

2.2.2. Analyses of Gelatin

1) Yield of gelatin

The yield of gelatin was calculated based on dry weight of fresh skin using the following formula:

$$\%\ \text{Yield of gelatin (wet wt. basis)} = \frac{\textit{weight}\ \text{of freeze-dried gelatin}}{\text{weight of wet skin}} \times 100 \quad \ldots\ldots\ldots\ldots (1)$$

2) Proximate analysis

The moisture, ash and fat content of extracted dried gelatin were determined in triplicate according to the AOAC (2006). The crude protein content was determined by estimating its total nitrogen content by the Kjeldahl method (AOAC, 2006). A factor of 5.55 was used to convert the nitrogen value to gelatin protein. Gelatin (1.0g) was dissolved in 40 g of distilled water and the pH of the solution was then measured with Mettler Delta pH meter.

3) Determination of Viscosity

The viscosity of the gelatin (6.67% concentration at 60°C) was measured using a Brookfield digital viscometer (model DV-E, Brookfield Engineering, Middleboro, MA, USA) equipped with a No. 1 spindle at

30±0.5°C. The measured values were obtained directly in centistokes (cP) from the instrument.

4) Determination of Amino Composition

The amino acid content of the gelatins was determined using Gas chromatography (GC) according to the modified methods (AOAC, 2006; Danka et al., 2012). The dried and pulverised sample was made to be free of water by ensuring constant weight for a period of time in the laboratory. The sample of 10.0g was weighed into the 250 ml conical flask capacity. The sample was defatted by extracting the fat content of the sample with 30ml of the petroleum spirit three times with soxhlet extractor that was equipped with thimble. The sample was hydrolysed three times for complete hydrolysis to be achieved for the totality of amino acid recovery. Both the pulverised sample and defatted sample were soaked with 30ml of the 1.0 M potassium hydroxide solution and incubated for 48 hours at 110℃ hermetically closed borosilicate glass container. After the alkaline hydrolysis, the hydrolysate was neutralised to get the range of 2.5-5.0. The purified solutions were derivatised with ethylchoroformate by the established mechanism.

The derivatising agent was afterwards removed by passing streams of nitrogen. Aliquots of amino acids derivatives dissolved in dichloromethane were analysed by gas chromatography equipped with pulse flame photometric detector (GC-PTFD) -coupled gas chromatography (HP 6890). 1 µl of concentrate was injected into GC-PFPD using HP5 (30 m × 0.25 mm × 0.255 mm ID) column for individual amino acid peaks. The initial temperature of the hydrogen carrier gas and column was 60 ℃. It was ramped at 8 ℃ for 20 min and held constant for 2min and then at 12 ℃/min for 6 min and held for 2 min.

Amino acids standard solutions were repeatedly analysed five (5) times and calibration curves obtained had correlation coefficients between 0.9996 and 0.9999. Limits of detection (LOD) and quantification (LOQ) were evaluated from signal- noise ratio of 3:1 and 10:1, respectively.

5) Colour Measurement

The colour of gelatin solutions (6.67% w/v) was measured by a Hunter lab colour meter (Color Flex, Hunter Lab Inc., Reston, VA, USA). L*, a* and b* parameters, indicating lightness / brightness, redness / greenness and yellowness / blueness, respectively, were recorded. The colorimeter was calibrated with a white standard.

6) Fourier Transform Infrared (FTIR) Spectroscopic Analysis

Gelatin samples were subjected to FTIR analysis using Bruker Model EQUINOX 55 FTIR spectrometer (Bruker, Ettlingen, Germany) equipped with a deuterated L-alanine triglycinesulphate (DLATGS) detector. The horizontal attenuated total reflectance (HATR) accessory was mounted in the sample compartment. The internal reflection crystal (Pike Technologies, Madison, WI, USA), made of zinc selenide, had a 45° angle of incidence of the IR beam. Spectra were acquired in the IR range of 4000-650 cm^{-1} (mid-IR region) at 25°C. Automatic signals were collected in 32 scans at a resolution of 4 cm^{-1}. These signals were recorded against a background spectrum from the clean and empty cell at 25°C. Analysis of spectral data was carried out using the OPUS 3.0 data collection software program (Bruker, Ettlingen, Germany). Prior to data analysis, the spectra were baseline corrected and normalised.

7) Foaming Properties

Foam formation ability (FA) and foam stability (FS) of gelatin were determined by the procedure of (Cho et al., 2004). Gelatin solution, 1g/100 ml was put in a beaker and swollen at 60℃. The foam was prepared by homogenising at 10,000rpm for 5 min in a homogeniser (Euro turrax t20b.ika Labortechnik, Staufen Germany). The homogenised solution was then poured into a 250ml measuring cylinder. The foam formation ability was calculated according to the following equation:

$$FA\ (\%) = \frac{V_1 - V_0}{V_0} x100 \quad \text{..... (2)}$$

The foam stability was calculated by allowing the homogenised sample to stand at room temperature for 30 min and the volume of the homogenised sample was then recorded. Foam stability was calculated as follows:

$$FS\ (\%) = \frac{V_2 - V_0}{V_0} \text{x}\,100 \quad \text{..... (3)}$$

8) Statistical analysis

All experiments were performed in triplicate. Data were presented as means ± standard deviation and the probability value of $P < 0.05$ was considered significant. Analysis of variance (ANOVA) was performed, and mean comparisons were done by Duncan's multiple range test (Steel and Torrie, 1980). Analysis was performed using an SPSS package (SPSS for windows, SPSS Inc, Chicago, IL, USA).

3. Result and discussion

3.1. Yield of gelatin

The degree of conversion of collagen into gelatin depends on the processing parameters (temperature, extraction time and pH), the pretreatment conditions, the properties and the preservation method of the starting raw material (Karim and Bhat, 2009). In this work, the same condition was used. The yield of tilapia skin gelatin (TSG) and catfish skins gelatin (CSG) are 17.9% and 18.24% respectively. It was observed that tilapia

skin swelled more in alkaline and acidic solution compared to the skin of catfish. Therefore, we could say that tilapia skin gave a higher yield, possibly due to increase in opening of cross-links during swelling as evidenced in higher level of swelling. Jamilah and Harvinder (2002) stated that the difference in gelatin recovery from different species could be attributed to the intrinsic characteristics of the skin and collagen molecules, the collagen content, the amount of soluble components in the skins, the loss of extracted collagen through leaching during the series of washing steps or to an incomplete collagen hydrolysis. The yield of gelatins for both tilapia and catfish in the present study was higher than the reported values. Grossman and Bergman (1992) reported gelatin yield of about 15% for tilapia, while the gelatin yields obtained for the black and the red tilapias were 5.39 and 7.81%, respectively (Jamilah and Harvinder, 2002). Samart et al. (2012) reported gelatin yield of 10.14% for giant cat fish.

3.2. Proximate Composition of Gelatin

The proximate composition of fish gelatin extracted from fish skins is summarised in Table 1. The proximate analysis of the catfish gelatin showed 4.54% moisture, 7.54% protein, 20% fat and 1.61%, while that of tilapia fish gelatin showed 4.12% moisture, 72.95% protein, 18% fat and 1.96% ash. Moisture and ash contents of both fish sources are not significantly ($p > 0.05$) different. The moisture content of both samples was well below the prescribed limit of 15% (GME, 2005) for edible gelatin. Protein and fat contents of tilapia gelatin were significantly ($p < 0.05$) higher than that of catfish. At 6-8% moisture, gelatin is very hygroscopic and it becomes difficult to determine the physico-chemical attributes with accuracy . The gelatins were found to be low in ash content, well below the recommended maximum of 2.6% (Jones, 1997).

Table 1. Proximate analysis of two samples

Composition	Catfish gelatin	Tilapia fish gelatin
Moisture (%)	4.54±1.43[a]	4.12±0.76[a]
Protein(%)	7.45±2.43[a]	72.95±3.25[b]
Fat (%)	20±1.43[a]	18±0.21[b]
Ash(%)	1.61±0.53[c]	1.96±2.63[c]

Different letters in the same row indicate significant differences ($p<0.05$).

Values are given as mean ± SD from triplicate determinations.

It was shown that the protein content of gelatin extracted from catfish gelatin contains 7.45% and that of tilapia gelatin contains 72.95%. The protein content of tilapia fish gelatin is far higher than that of catfish gelatin (7.45%) which is surprisingly low. The 7.45% of protein content of catfish gelatin is lower than the reported values. Gelatin from splendid squid skin had protein content of 90% (Nagarajan et al., 2012), cuttlefish skin gelatin had 91.35% protein (Balti et al., 2011), giant squid skin gelatin had 88% protein (Uriarte-Montoya et al., 2011), skate skin gelatin had 92.31% protein. Jongjareonrak et al. (2006) reported a protein content of 87.9% and 88.6% in gelatin extracted from the skins of bigeye snapper and brown eye snapper, respectively. The gelatin from the skins of adult Nile perch also contained 88% protein (Muyonga et al., 2004).

3.3 Viscosity

The second important physical property is the viscosity of a gelatin (Jamilah *et al*., 2002). The viscosity of gelatin extracted from catfish at 40°C and 100°C are 2.49 and 1.38cP, whereas, those extracted from tilapia skin at 40°C and 100°C ranges from 3.58 and 1.38cP (see Table 2). Generally, viscosities of gelatin at 100 ^{o}C were significantly ($p < 0.05$) lower than at 40 ^{o}C while no significant ($p > 0.05$) difference exists between viscosities of both samples at both temperatures. The viscosity at 40°C was lower in catfish gelatin compared to tilapia fish gelatin. The viscosity is the measuring resistance force of the solution. The value is closely related to the molecular weight of the component that resulted in cohesion force between molecules.

Johnston-Banks (1990) reported that the viscosities of most of the commercial gelatins are up to 13.0 cP. The results obtained in this work are far below that of commercial values, however, they fall within the ranges reported in the literature. For instance, Jamilah and Harvinder, (2002) reported the viscosity values of 3.2 cP and 7.12 cP for red and black tilapia, respectively, and for channel catfish, it was 3.23 cP (Yang et al., 2007). From the above results, it is thus shown that natural variation in the viscosity can be expected from different fish species tested at the same condition. The difference in viscosity between gelatins could be due mainly to the molecular weight distribution of protein components in gelatins (Jongjareonrak et al., 2010).

Table 2. Viscosity of catfish and tilapia fish gelatin

Samples	Viscosity (cP) at 40 °C	Viscosity (cP) at 100°C
Tilapia gelatin	3.58±0.11[a]	1.38±0.34[a,b]
Catfish gelatin	2.49±1.01[a]	1.50±0.81[a,b]

Different letters indicate significant differences ($p<0.05$).

[a] significantly different across the column and

[b] significantly different across the row.

Values are given as mean ± SD from triplicate determinations.

3.3.1 Amino Acid Composition

The amino acid composition of different gelatins may vary depending mainly on the source, and the major variation between gelatins would be the amount of the amino acids (Zhou et al., 2006). Table 3 shows the

amino acid composition of the gelatins from skins of both tilapia and catfish.

Table 3. The amino acid composition of gelatins from the skins of catfish and tilapia fishes (as g amino acid/100g gelatin).

Amino acids	Tilapia skin gelatin (%)	Catfish skin gelatin (%)
Glycine	3.81	6.02
Alanine	3.98	4.98
Serine	4.48	4.99
Proline	4.01	4.19
Valine	4.17	3.93
Threonine	3.45	3.08
Isoleucine	5.17	3.72
Leucine	8.06	6.84
Aspartate	8.66	9.61
Lysine	5.32	3.55
Methionine	1.85	1.84
Glutamate	14.54	17.74
Phenylalanine	6.58	4.97
Histidine	3.41	2.35
Arginine	5.91	12.26
Tyrosine	3.62	3.08
Tryptophan	4.77	1.05
Cystine	1.86	1.24
Total	**93.65**	**95.44**

The amino acid content of the gelatin of catfish is higher than that of the tilapia. Both have very high contents of glutamate, followed by arginine in catfish and aspartate in tilapia. The two are essentially low in methionine when the value of methionine in both is almost the same value, while tryptophan is the lowest amino acid in cat fish. This composition is different from those reported for red and black tilapias by Jamilah and Harvinder (2002), tilapia by Zhou et al. (2006) and catfish by Jongjareonrak et al. (2010).

From this work, the amino acid content in skin gelatin from tilapia fish was higher than that reported in red tilapia and black tilapia (76.4 and 86.5 residues per 100 residues, respectively) (Jamilah and Harvinder, 2002). Ledward (1986) reported that the stability of the triple helical structure in renatured gelatins was associated with the total content of pyrrolidine amino acids, and hydroxyproline plays an essential role in the stabilisation of the triple-helix strands of collagen via its hydrogen bonding ability through its –OH group. Gelatin with higher content of hydroxyproline is believed to have higher visco-elastic properties and its ability to develop triple helix structures, which are important for stabilising the gelatin gel structure (Go` mez-Guille`n et al., 2009). In addition, the size of the proteinchains also determines the gelatin properties. From the result, cysteine, tryptophan, asparagine and glutamine were not found in gelatin from both sources. In this work, cysteine and tryptophan are present contrary to Foegeding et al. (1996) who reported that cysteine and tryptophan are not commonly present in gelatin.

3.4. Colour

The colour of a gelatin gel is important aesthetic properties, depending on the application for which the gelatin is intended. In general, light colour is preferred because it is easier to incorporate gelatins into any food system without imparting any strong colour attribute to the product. The colours of gelatin solution from tilapia and catfish skins at the concentration of 6.67% are shown in Table 4. The L* values of gelatin gel from catfish skin, 41.46 was significantly ($p < 0.05$) higher than that of tillapia skin, 37.51, even though, gelatin gel from tilapia skin gave significantly ($p < 0.05$) higher a* and b* values than catfish skin. These results suggested that gelatin gels from catfish skin had a lighter colour but lower yellowness and greenness than that of tilapia skin. From the previous work, L^*, a^* and b^*, the values of gelatin from the skin of giant catfish are 63.07, -0.08 and 9.35 (Sai-Ut et al., 2012), while Jongjareonrak et al. (2010) also reported the values of 20.43, -0.61 and 1.36 for L^*, a^* and b^* respectively for giant catfish. The colour of gelatin is generally dependant on the raw materials extracted and whether it is the first, second or later extraction.

According to the instrumental colour measurement, catfish gelatin was significantly lighter/whiter than the tilapia fish gelatin. By visual observation catfish gelatin appeared pearly white while tilapia gelatin was light brown in colour.

3.4.1 FTIR Spectroscopy

FTIR spectroscopy has been used to monitor the functional groups and secondary structure of gelatin (Muyonga et al., 2004), as well as studying collagen cross-linking, gelatin denaturation, and melting. The FTIR spectra of gelatin extracted from catfish and tilapia are depicted in Figures 1 and 2, respectively. It was showed that the characteristic absorption of amide I peaks at 1635.64 cm^{-1}, represents C=O stretching and gives most useful information about secondary structure protein (Thiansilakul and Roytrakul, 2009). The values of C=O obtained in this study are similar to values reported by Nagarajan et al. (2012) and Sai-Ut et al. (2012).

Table 4. The values of instrumental colour and visual observation of gelatins from tilapia and catfish

	Colour attribute			
Source of gelatin	L^*	a^*	b^*	Observed colour
Catfish	41.46 ± 0.63^a	-1.02 ± 1.35^a	0.53 ± 0.33^a	pearly white
Tilapia	37.51 ± 2.51^b	4.21 ± 2.11^b	1.20 ± 0.12^b	light brownish

Different letters in the same column indicate significant differences ($p<0.05$). Values are given as mean ± SD from triplicate determinations.

Characteristic absorptions of amide A occurred at 3305.99 cm-1 for gelatin from cat fish skin and 3286.70 cm for gelatin from tilapia fish skin. These represent hydrogen bonded N-H stretching vibrations. The result shows that tilapia fish skin gelatin is more hydrogen bonded and is similar to report of Nagarajan et al. (2012) while that of catfish skin gelatin shows a value similar to report of Sai-Ut et al. (2012). The lower peak value of figure with catfish gelatin indicates the lower protein secondary structure (α – helix) that was due to the degradation of the gelatin molecules, providing greater free amino acids (Muyongaal. 2004).

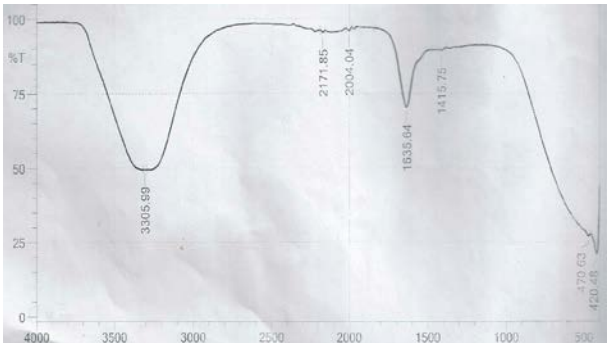

Figure 1. FTIR spectra of gelatin from catfish

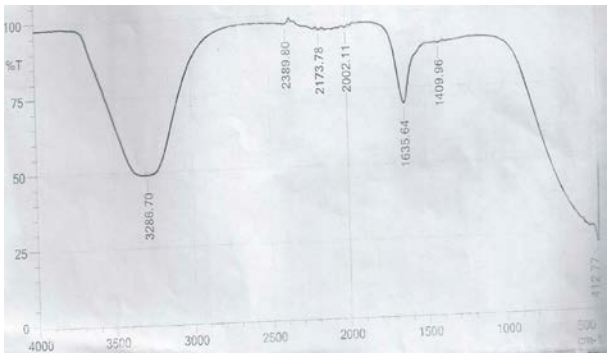

Figure 2. FTIR spectra of gelatin tilapia fish

3.5. Foaming Properties

Foaming capacity and foaming stability become important parameters to characterise the functional properties of proteins. Gelatin is one of the most widely used protein foaming agent. The good protein foaming agent should stabilise foams rapidly and effectively at low concentration and become an effective foaming agent over the pH range that exists in various foods. The foaming properties of both gelatins were tabulated in Table 5. Both foaming capacity and foaming stability of the tilapia fish gelatin were significantly ($p < 0.05$) higher than that of catfish gelatin. From the result obtained, it showed that the foaming properties of tilapia fish gelatin were higher than the foaming properties of catfish gelatin.

Nagarajan et al. (2012) reported that gelatin with the less degradation and longer chain length more likely formed the stronger films surrounding the air bubbles, especially when the sufficient concentration was used. The results obtained in this work is not in agreement with Jongjareonrak et al. (2010) who obtained values of 130% and 35 % for foam capacity and foam stability respectively for giant catfish. However, it is well comparable with Shyni et al. (2014) who reported values of 21.5 %, 17.4 % and 19.2 % for foam capacity, and 17.6 %, 10.5 % and 14.4 % for tuna, dog shark and rohu fish skins, respectively.

From this result, it can be concluded that gelatin from tilapia fish can act as better foaming agent as compared to gelatin extracted from catfish.

Table 5. The foaming properties of gelatins from the skins of catfish and tilapia fishes

Sample	Foaming Capacity %	Foaming Stability%
Tilapia gelatin	28±2.34[a]	18±3.54[a]
Catfish gelatin	14 ± 2.34[b]	10 ± 6.43[b]

Different letters in the same column indicate significant differences ($p<0.05$).
Values are given as mean ± SD from triplicate determinations.

4. Conclusion

This study has investigated chemical compositions and characterization of gelatin from catfish and tilapia fish. The functional properties such as viscosity, foaming capacity and stability of gelatin from tilapia skin were greater than that of the catfish skin indicating that tilapia fish gelatin has a higher application in food industries.

Nonetheless, the physicochemical properties of the two fish gelatins showed the potential of high quality of gelatins that could be used in food applications. The potential is higher for catfish skins than tilapia skin because catfish skin gives higher gelatin yield. Catfish skin gelatin had a slightly higher amino acid composition compared with that of tilapia skin gelatin.

References:

AOAC (2006), *Official Methods of Analysis of AOAC International*, 18th edition, Association of Official and Analytical Chemists International, Virginia, USA

Badii, F. and Howell, N. K. (2006), "Fish gelatin: structure, gelling properties and interaction with egg albumen proteins", *Food Hydrocolloids*, Vol.20, pp.630-640.

Balti, R., Jridi, M., Sila, A., Souissi, N., Nedjar-Arroume, N., and Guillochorn, D. (2011), "Extraction and functional properties of gelatin from the skin of cuttlefish (Sepia officinalis) using smooth hound crude acid protease-aided process", *Food Hydrocolloids*, Vol.25, pp.943-950.

Binsi, P.K., Shamasundar, B.A., Dileep, A.O., Badii, F. and Howell, N.K. (2009), "Rheological and functional properties of gelatin from the skin of bigeye snapper (Priacanthushamrur) fish:

influence of gelatin on the gel-forming ability of fish mince", *Food Hydrocolloids*, Vol.23, pp.132-145.

Bor-Sen, C., Roberto, J.A, Peter, J.B, Haani, J., Rajnesh, N., Syed, H.I., Greg, M.G., and William, J.O. (2008), "Cold water fish gelatin films: Effects of cross-linking on thermal, mechanical, barrier, and biodegradation properties", *European Polymer Journal*, Vol.44, pp.3748-3753

Chandra, M.V. and Shamasundar, B.A. (2015), "Rheological properties of gelatin prepared from the swim bladders of freshwater fish Catlacatla", *Food Hydrocolloids*, Vol.40, pp.340-346.

Chandra, M.V., Shamasundar, B.A., and Ramesh Kumar, P. (2013), "Visco-elastic andflow properties of gelatin from the bone of fresh water fish (Cirrhinusmrigala)", *Journal of Food Science*, Vol.78, pp.1009-1016

Choi, S.S., and Regenstein, J.M. (2000), "Physicochemical and sensory characteristics of fish gelatin", *Journal of Food Science*, Vol.65, pp.194-199.

Cho, S.M., Kwak, K.S., Park, D.C., Gu, Y.S., Ji, C.I. and Jang, D.H. (2004), "Processing optimisation and functional properties of gelatin from shark (Isurusoxyrinchus) cartilage", *Food Hydrocolloids*, Vol.18, pp.573-579.

Danka, P.O., Dobrina, D.T. and Kalin, V.I. (2012), "Simultaneous identification and determination of total content of amino acids in food supplements – Tablets by gas chromatography", *Asian Journal of Pharmaceutical and Clinical Research*, Vol.5, pp.57-68.

Ekunwe, P.A. and Emokaro, C.O. (2009), "Technical efficiency of catfish farmers in Kaduna, Nigeria", *Journal of Applied Sciences Research*, Vol.5, pp.802-805.

FDF (2008), *Fisheries Statistics of Nigeria Projected Human Population: Fish Demand and Supply in Nigeria from 2000 – 2015*, Federal Department of Fisheries, p.56.

Ferna´ndez-Diaz, M.D., Montero, P. and Go`mez-Guille`n, M.C. (2001), "Gel properties of collagens from skins of cod (Gadusmorhua) and hake (Merlucciusmerluccius) and their modification by coenhancers magnesium sulphate, glycerol and transglutaminase", *Food Chemistry*, Vol.74, pp.161-167.

Foegeding, E., Lanier, T.C., andHultin, H.O. (1996), "Characteristics of edible muscle tissue", In: Fennema, O.R. (Ed.), *Food Chemistry*, MarcelDekker, New York, p.879-942

GME (2005), "Standardised methods for the testing of edible gelatin", In: *Gelatine Monograph* (p.104). 4, Avenue E. Van Nieuwenhuyse, Be 1160 Bruxelles: Gelatin Manufacturers of Europe.

Gilsenan, P.M. and Ross-Murphy, S.B. (2000), "Rheological characterisation of gelatins from mammalian and marine sources", *Food Hydrocolloids*, Vol.14, pp.191-195.

Go`mez-Guille`n, M.C., and Montero, P. (2001), "Extraction of gelatin from megrim (Lepidorhombusboscii) skins with several organic acids", *Journal of Food Science*, Vol.66, pp.213-216.

Gómez-Estaca, J., Montero, P., Fernández-Martín, F., and Gómez-Guillén, M.C. (2009), "Physico-chemical and film-forming properties of bovine-hide and tuna-skin gelatin: A comparative study", *Journal of Food Engineering*, Vol.90, pp.480-486.

Gómez-Guillén, M.C., Giménez, B., López-Caballero, M.E., Montero, M.P., Binsia, P.K., Shamasundara, B.A., Dileepa, A.O., Badiib, F. and Howell, N.K. (2009), "Rheological and functional properties of gelatin from the skin of Bigeye snapper (Priacanthushamrur) fish: Influence of gelatin on the gel-forming ability of fish mince", *Food Hydrocolloids*, Vol.23, pp.132-145.

Grossman, S. and Bergman, M. (1992), *Process for the Production of Gelatin from Fish Skins*. US Patent 5,093,474.

Gudmundsson, M. (2002), "Rheological properties of fish gelatins", *Journal of Food Science*, Vol.67, pp.2172-2175.

Gudmundsson, M., and Hafsteinsson, H. (1997), "Gelatin from cod skins as affected by chemical treatments", *Journal of Food Science*, Vol.62, pp.37-39.

Holzer, D. (1996), *Gelatin Production*, US Patent 5,484,888.

Irwandi, J., Faridayanti, S., Mohamed, E.S.M., Hamzah, M.S., Torla, H.H. and Che Man, Y.B. (2009), "Extraction and characterisation of gelatin from different marine fish species in Malaysia", *International Food Research Journal*, Vol.16, pp.381-389.

Jamilah, B. and Harvinder K.G. (2002), "Properties of gelatins from skins of fish - Black tilapia (Oreochromismossambicus) and Red tilapia (Oreochromisnilotica)", *Food Chemistry*, Vol.77, pp.81-84

Jan, A.A. and Asbjorn, G. (2007), "Extraction and characterisation of gelatin from Atlantic salmon (Salmosalar) skin", B*ioresource Technology*, Vol.98, pp.53-57

Johnston-Banks, F.A. (1990), "Gelatin", In: Harris, P. (Ed.), *Food Gels*, Elsevier Applied Science Publishers, London, p.233-289

Jones, N.R. (1997), "Uses of gelatine in edible products", In: Ward, A. and Courts, A. (Eds), *The Science and Technology of Gelatin*, Academic Press, London, p.366-394

Jongjareonrak, A., Benjakul, S., Visessanguan, W., Prodpran, T., and Tanaka, M. (2006), "Characterisation of edible films from skin gelatin of brownstripe red snapper and bigeye snapper", *Food Hydrocolloids*, Vol.20, pp.492-501.

Jongjareonrak, A., Rawdkuen, S., Chaijan, M., Benjakul, S. Osako, K. and Tanaka, M. (2010), "Chemical compositions and characterisation of skin gelatin from farmed giantcatfish (Pangasianodon gigas)", *Food Science and Technology*, Vol.43, pp.161-165.

Karim, A.A. and Bhat, R. (2009), "Fish gelatin: Properties, challenges, and prospects as an alternative to mammalian gelatin", *Food Hydrocolloids*, Vol.23, pp.563-576.

Ketnawa, S., Benjakul, S., Martinez-Alvarez, O., Rawdkuen, S., (2016), "Fish skin gelatin hydrolysates produced by visceral peptidase and bovine trypsin: bioactivity and stability", *Food Chemistry*, Vol.56, pp.650-658.

Kittiphattanabawon, P., Benjakul, S., Visessanguan, W., and Shahidi, F. (2010), "Comparative study on characteristics of gelatin from the skins of brown banded bamboo shark and blacktip shark as affected by extraction conditions", *Food Hydrocolloids*, Vol.24, pp.164-171.

Ledward, D.A. (1986), "Gelation of gelatin", In: Mitchell, J.R. and Ledward, D.A. (Eds.), *Functional Properties of Food Macromolecules*, Elsevier Applied Science Publishers, London, p.233-289

Liu, H.Y., Han, J., and Guo, S.D. (2009), "Characteristics of the gelatin extracted from Channel Catfish (IctalurusPunctatus) head bones", *Food Science and Technology*, Vol.42, pp.540-544

Muyonga, J.H., Cole, C.G.B., and Duodu, K.G. (2004), "Fourier transform infrared (FTIR) spectroscopic study of acid soluble collagen and gelatin from skins and bones of young and adult Nile perch (Latesniloticus)", *Food Chemistry*, Vol.86, pp.325-333.

Nagarajan, M., Benjakul, S., Prodpran, T., Songtipya, P., andKishimura, H. (2012), "Characteristics and functional properties of gelatin from splendid squid (Loligoformosana) skin as affected by extraction temperatures", *Food Hydrocolloids*, Vol.29, pp.389-397.

Ratnasari, I., Yuwono, S.S., Nusyam, H. and Widjanarko, S.B. (2013), "Extraction and characterisation of gelatin from different fresh water fishes as alternative sources of gelatin", *International Food Research Journal*, Vol.20, pp.3085-3091.

Rawdkuen, S., Sai-Ut, S., Ketnawa, S., Thitipramote, N., and Benjakul, S. (2010), "Fish skin gelatin: Extraction and some functional properties", *Proceedings of the 3rd Technology and*

Innovation for Sustainable Development International Conference, Nong-Khai, Thailand, March, pp.384-388.

Rawdkuen, S., Thitipramote, N., and Benjakul, S. (2013), "Preparation and functional characterisation of fish skin gelatin and comparison with commercial gelatin", *International Journal of Food Science and Technology*, Vol.48, pp.1093-1102.

Sabon, N.M., Badii, F. and Howell, N.K. (2013), "Preparation and characterisation of chicken skin gelatin as an alternative to mammalian gelatin". *Food Hydrocolloids*, Vol.30, pp.143-151

Sai-Ut, S., Jongjareonrak, A., and Rawdkuen, S. (2012), "Re-extraction, recovery, and characteristics of skin gelatin from farmed giant catfish", *Food and Bioprocess Technology*, Vol.5, pp.1197-1205.

Samart S., Akkasit, J. and Saroat, R. (2012), "Re-extraction, recovery, and characteristics of skin gelatin from farmed giant catfish", *Food Bioprocess Technology*, Vol.5, pp.1197-1205

Shyni, K., Hema, G.S., Ninan, G., Mathew, S., Joshy, C.G. and Lakshmanan, P.T. (2014), "Isolation and characterisation of gelatin from the skins of skipjack tuna (Katsuwonus pelamis), dog shark (Scoliodon sorrakowah), and rohu (Labeo rohita)", *Food Hydrocolloids*, Vol.39, pp.68-76.

Steel, R.G.D. and Torrie, J.H. (1980), *Principles and Procedures of Statistics: A Biometrical Approach*, McGraw-Hill, New York

Thiansilakl, Y., Benjakul, S. and Shahidi, F. (2009), "Compositions, functional properties and antioxidative activity of protein hydrolysates prepared from round scad (Decapterusmaruadsi)", *Food Chemistry*, Vol.103, pp.1385-1394.

Uriarte-Montoya, M.H., Santacruz-Ortega, H., Cinco-Moroyoqui, F.J., Rouzaud-Sández, O., Plascencia-Jatomea, M., and Ezquerra-Brauer, J.M. (2011), "Giant squid skin gelatin: chemical composition and biophysical characterisation", *Food Research International*, Vol.44, pp.3243-3249.

Yang, H., Wang, Y., Jiang, M., Oh, J. H., Herring, J., and Zhou, P. (2007), "2-Step optimisation of the extraction and subsequent physical properties of channel catfish(Ictalurus punctatus) skin gelatin", *Journal of Food Science*, Vol.72, pp.188-195.

Zhou, P., Mulvaney, S.J. and Regenstein, J.M. (2006), "Properties of Alaska pollock skin gelatin: A comparison with tilapia and pork skin gelatins", *Journal of Food Science*, Vol.71, pp.313-321.

Authors' Biographical Notes:

Ayoade L. Adejumo *is currently the Head of Chemical Sciences Department, Osun State University, Osogbo, Nigeria. He started his academic career at Crescent University, Abeokuta, Nigeria in 2008 as an Assistant Nigeria. He later left for Fountain University, Osogbo, Nigeria in 2009, also, as an assistant lecturer. In 2011, Dr. Adejumo was appointed as lecturer II officer at Osun State University, where he rose to the position of Senior Lecturer. Adejumo graduated from Ladoke Akintola University of Technology, Ogbomoso, Nigeria and Obafemi Awolowo University, Ile-Ife, Nigeria for his Bachelor's, Master's and PhD degrees, all in Chemical Engineering. He is a member of the Nigerian Society of Engineers (NSE), a Registered Engineer with the Council of the Regulation of Engineering in Nigeria (COREN). Areas of his research interests include industrial enzymes application, biomass conversion into biofuel and chemical kinetics.*

Fatai A. Aderibigbe *is currently the Head of Chemical Engineering Department, University of Ilorin, Ilorin, Nigeria. He started his academic career at Osun State College of Technology, Esa-Oke, as Lecturer III officer. He later left for Ondo State University of Science and Technology, Okiti-Pupa, Nigeria in 2012 as a lecturer I officer. In 2014, he was appointed as Senior lecturer at University of Ilorin. Dr. Aderibigbe graduated from Obafemi Awolowo University, Ile-Ife, Nigeria for his Bachelor's, Master's and PhD degrees, all in Chemical Engineering. He is a member of the Nigerian Society of Engineers (NSE), a Registered Engineer with the Council of the Regulation of Engineering in Nigeria (COREN). Areas of his research interests include industrial enzymes application, biomass conversion into biofuel and chemical kinetics.*

Rasheed U. Owolabi *was formerly a Lecturer at the Industrial and Environmental Chemistry Department of Fountain University, Osogbo, Osun State, Nigeria where he started as an Assistant Lecturer and rose to the position of a Lecturer II from 2008 to 2012. He is presently a Lecturer I at the Chemical and Petroleum Engineering department of the University of Lagos. Owolabi graduated from LAUTECH, Ogbomoso and University of Lagos for his Bachelor's and Master's degrees both in Chemical Engineering. He obtained his Ph.D in Chemical Engineering at the University of Lagos, and is a member of the Nigerian Society of Engineers (NSE), a Registered Engineer with the Council of the Regulation of Engineering in Nigeria (COREN) and an affiliate member of the institute of Chemical Engineers, UK. Areas of his research interests include lube and plant oil chemistry, green chemistry, biomass conversion into biofuel, biodiesel or bio-energy, polymerisation processes, polymer synthesis (addition polymers), chemical kinetics and polymer reaction engineering.*

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Design and Fabrication of a Moist Heat Therapy Device for Treating Non-specific Low Back Pain

Olawale O.E. Ajibola [a,Ψ], Kehinde O. Fagbolagun[b], and Olayide P. Folorunso[c]

[a]Department of Systems Engineering, Faculty of Engineering; University of Lagos, Akoka, Yaba, Lagos, Nigeria; E-mail: waleisiro@yahoo.com

[e]Department of Biomedical Engineering, Faculty of Basic Medical Sciences, College of Medicine of University of Lagos, Akoka, Yaba, Lagos, Nigeria Email: kennygbl@yahoo.com

[c]Department of Systems Engineering, Faculty of Engineering; University of Lagos, Akoka, Yaba, Lagos, Nigeria; E-mail: folos_ola@yahoo.com

[Ψ] *Corresponding Author*

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Abstract: *In this paper, the design and fabrication of an electronic moist heat therapy device is described for administering heat therapy treatment for non-specific low back pain (LBP). The device which is handy and low weight, incorporates low cost components such as a PIC16F microcontroller, a potentiometer to manually adjust voltage supply to the heater, a temperature sensor, a seven-segment display, a 12VDC power supply, and a heater component made up of a number of serially connected ceramic sealed resistors. In addition to these components, the device also incorporates a Bluetooth feedback system for temperature management through a third party electronic device like a mobile phone. Initial results obtained from the device show its advantages over the use of traditional hot water bottles which temperature cannot be regulated. The device is capable of maintaining target temperature required for effective heat therapy for non-specific LPB, without any concerns of heat loss or subsequent fall in temperature.*

Keywords: *Non-specific low back pain, moist heat therapy, Microcontroller, potentiometer, Bluetooth, and ceramic sealed resistors*

1. Introduction

Low Back Pain (LBP) is a common musculoskeletal disorder causing huge humanitarian and economical costs (van Middelkoop et al., 2011). It refers to spinal and para spinal symptoms in the lumbosacral region (Koes et al, 2010; Andreisek et al., 2013) and is often classified as acute (short term), sub-acute (intermediate) and chronic (long-term) according to duration of pain. Low back pain is typically described as specific or non-specific. Non-specific LBP is described as a "mechanical" back pain of musculoskeletal origin in which symptoms vary with physical activities. A wide range of terms are used for nonspecific mechanical induced pains, these include: low back pain/strain/sprain, lumbago, facet joint syndrome, sacroiliac syndromes, segmental dysfunction, somatic dysfunction, ligamentous strain, and myofascial syndrome. These typically involve processes in the muscles and/or ligaments that are difficult to be reliably identified by physical examination or diagnostic testing (Emch and Modic, 2011).

When injury occurs to soft tissues, inflammation occurs in which chemical mediators are released that not only induce an inflammatory response, but also sensitise nociceptors (pain receptors) and other somatosensory components of the nervous system. Some of these inflammatory mediators include: serotonin, cytokines, bradykinine and prostaglandins. Nociceptors transmit nerve signals that travel through the spinal cord to the brain, where the sensation of pain is recognised. At the same time, neurotransmitters initiate a spinal reflex that increases muscle motor activity and tonicity at the site of injury, leading to a reflexive muscle contraction. If persistent, the increase in muscle tone can cause painful muscle spasms, which can lead to further tissue damage due to decreased blood flow and oxygen (hypoxia) to the surrounding tissues. Pain in turn increases. This injury process is called the pain-spasm-pain cycle (Nadler et al., 2004). This cycle must be interrupted to prevent further tissue injury and to reduce the sensation of pain. Body weight also contributes to back pain due to the muscles being overworked, since approximately 50% of the body weight acts to compress the lumbar spine in upright postures, it adds strain to the muscles and ligaments in the back. Much greater force arises from tension in the Para spinal muscles which stabilise the spine. In order to compensate for extra weight, the spine can become tilted and stressed unevenly, extra stomach weight also pulls the pelvis forward and strains the lower back, thereby creating pain.

Superficial heat has been used for centuries to manage such pain occurring in the lower back region with specific goal of relieving pain, altering the physiologic processes underlying tissue healing, and

affecting the plasticity of connective tissue, including muscle, tendon, ligament, and joint capsule. Traditionally, such modalities include; hot water bottles, heated stones, soft heated packs filled with grain, poultices, hot towels, hot baths, saunas, steam, heat wraps, heat pads, electric heat pads and infra-red heat lamps (Qaseem et al., 2017, Ajibola and Folorunso, 2017). Thermo receptors (special temperature-sensitive nerve endings) are activated by changes in skin temperature, these receptors initiate nerve signals that block nociception (the pain signal processing that results from a noxious stimulus) within the spinal cord.

Topical modalities applied with physical support activate another type of specialised nerve endings called proprioceptors. Proprioceptors detect physical changes in tissue pressure and movement. Proprioceptor activity also inhibits the transmission of nociceptive signals to the brain. The activation of these receptors within the spinal cord reduces muscle tone, relaxes painful muscles, and enhances tissue blood flow. The primary goal of heat therapy is therefore to alter the tissue temperature in a targeted region over time for the purpose of inducing a desired biological response such as pain relief (analgesia) and increase in tissue metabolism (Nadler et al., 2004).

2. Literature Review

2.1 The Physiological Effect of Heat Therapy

Heat therapy, also known as thermotherapy is the use of heat in the treatment of pain and other similar health conditions. Thermotherapy consists of application of heat or coldness for the purpose of changing the cutaneous, intra-articular and core temperature of soft tissue with the intention of improving the symptoms of certain conditions (Brosseau et al., 2003, Nadler et al., 2004). It is useful for the treatment of musculoskeletal injuries and soft tissue injuries. Using heat as a therapeutic intervention decreases pain in joint and muscle as well as soft tissues (Petrofsky et al., 2013, Nadler et al., 2004). The primary objective of heat therapy is the expansion of blood capillaries, increased blood flow to the affected area that provides nutrients and oxygen for better healing.

The application of thermotherapy leads to increasing the extensibility of collagen tissues, decreasing joint stiffness, reducing inflammation, edema (swelling), and aids in the post-acute phase of healing, and increasing blood flow. The increased blood flow to the affected area provides proteins, nutrients, and oxygen for better healing (William, 2008). It also results in increase in soft tissue flexibility, muscle resistance, easier and better contraction of smooth muscles, and improvement in the muscles motor function (Szymanski, 2001). Besides, thermotherapy triggers decline in pain especially low back pain through inhibiting pain signal and pressure exerted on the back muscles (Nadler et al., 2003).

In addition, when hot water bottle (especially in case of providing deep heat) is used, it leads to distraction of a person's focus from his/her pain, muscle relaxation, and hence pain relief. Continued thermotherapy leads to alleviating pain in people with acute low back pain, which decreases muscle seizure or spasm and resolves inability (Nadler et al., 2003; Kent, 2006).

The application of moist heat is a routinely prescribed therapy in today's medical field. The body's physiological response to moist heat is dilation of the blood vessels, causing an increase in the blood flow to the area under treatment. Increased local circulation enhances recovery by flushing away the waste products and bringing in fresh blood cells to the treatment area. Moist heat is exceptionally useful in treating back pain caused by muscle spasms from strain and tension. It can also temporarily alleviate pain associated with arthritic and musculoskeletal conditions. The increased blood flow can help relax muscles in spasm and help maintain joint and muscle flexibility.

Heat stimulates the cutaneous thermoreceptors that are connected to the cutaneous blood vessels, causing the release of bradykinin which relaxes the smooth muscle walls resulting in vasodilation. Muscle relaxation occurs as a result of a decreased firing rate of the gamma efferent, thus lowering the threshold of the muscle spindle fibres and increasing afferent activity. There is also a decrease in firing of the alpha motor neuron to the extrafusal muscle fibre, resulting in muscle relaxation and decrease in muscle tone (Sands et al., 2013; Steven et al., 2003).

For therapeutic modalities to be effective, it must have the capacity to produce desirable effects at the intended tissue depth (Ajibola and Folorunso, 2017). The maximal effect of energy occurs when its rays strike the body at a right angle since some of the rays are reflected away from the target site as the angle deviates from right angle, thereby reducing the level of absorption. According to Filip Struyf et al 2014, this phenomenon is guided by two basic laws; the Cosine law for conduction and the Inverse square law for radiation;

The Cosine law states that as the angle deviates from 90 degree, the energy varies with the cosine of the angle.

$$\textit{Effective energy} = \textit{Energy} \times \textit{cosine of the angle of incidence} \quad (1)$$

The inverse-square law states that if the rays strike the tissues at a right angle, the power intensity per unit area from a point source varies inversely according to the square of the distance from the source. According to the inverse square law, the intensity of radiant energy striking the tissues is directly proportional to the square of the distance between the source of the energy and the tissues:

$$\textit{Intensity of radiant energy, } E = E_s/D^2 \quad (2)$$

Where,

E_S amount of energy produced by the source,

D^2 square of the distance between the target and the source,

E resulting energy absorbed by the tissue.

However, for radiant energy, a difference of $\pm 10^oC$ from the right angle is considered to be within acceptable limits. This means that each time the distance between the energy and the tissue is doubled, the intensity of the energy received by the tissue is reduced by a factor of four.

Superficial heat modalities convey heat mainly by conduction or convection, it elevates the temperature of the tissues and provides the greatest effect at 0.5cm or less from the surface of the skin. As a vasodilator, heat should be avoided in tissues with inadequate vascular supply, in case of acute injury, in bleeding disorders (because heat would increase bleeding), in tissues with a severe lack of sensitivity, and in scars (Benzon et al., 2013).

The amount of heat flow through tissue varies with the type of tissue, and is called thermal conductivity. Changes in surface tissue temperature caused by superficial heating agents depend on the intensity of heat applied, time of heat exposure, thermal medium for surface heat. Heat therapy is delivered by three mechanisms: conduction, convection, and conversion. Superficial heat is usually conductive heat (e.g., hot water baths, electric heating pads, warm compresses), methods for providing convective superficial heat include; fluidotherapy, whirlpool, moist air baths, and hot air baths. Conversion heating involves the conversion of one energy form (e.g. light, sound) into another (heat). Superficial heat is produced by heat lamps or radiant light bakers, with heat being transferred when the conveying medium (light energy) is converted to heat energy at the skin surface. Some of the factors that determine the extent of the physiologic response to heat are; level of tissue temperature (usually 40-45 ^oC), duration of the tissue temperature increase, the rate of increase in the tissue temperature, and size of the area being treated.

Generally accepted evidence dictates that the duration and temperature range of heat therapy should be dependent on the level of injury, and clinical rationale (Hartzell et al., 2012; Prentice, 2002; Starkey, 2004). In low back pain, tissue heat transfer is dependent on body weight (Savastano et al., 2009; Petrofsky et al., 2009; Stephen et al., 2014). It is therefore necessary to be able to regulate and monitor the rate of temperature increase so as to tailor the application of the heat therapy device to individuals, to ensure patient safety, ease of application, control of heating and maintenance of target temperature.

This paper focuses on an electronic moist heat therapy device intended for treating non-specific LBP, it uses a manually adjusted potentiometer to set the desired temperature, allowing for a more effective user control of the device as the temperature will not exceed the limit set by the user. Controlled increase in thermal temperature is important in the case of injured muscles to increase tissue elasticity, thereby allowing the muscle to elongate and resist further injury (Lund et al., 2017; Angilletta et al., 2010; Arnason et al., 2008; Bazett-Jones et al., 2008), and also to prevent burn as a result of overheating. This (controlled increase) is important to limit the risk of tissue damage and is dependent on the use of a controller which is designed to force the temperature treatment progression at the desired temperature and minimise the treatment time required (Robert et al., 2005). Other heat modalities have no means of regulating or monitoring the tissue temperature through a third-party device and are therefore not effective as there is a constant need to interrupt the process of therapy to adjust for a rapidly decreasing temperature since the desired temperature cannot be maintained.

2.2 Benefits of Topical Heat Therapy

Some of the benefits provided by topical heat therapy may be mediated directly in the brain. Functional brain imaging research (Kang et al, 2011) has revealed central effects of non-noxious skin warming with increased activation of the thalamus and posterior insula of the brain. In addition, innocuous tactile stimulation of the skin activates the thalamus and S2 region of the cerebral cortex. These direct effects on the brain may mitigate the sensation of pain in the brain, thereby providing pain relief. A 1^oC increase in tissue temperature is associated with a 10% to 15% increase in local tissue metabolism (Tristan et al., 2012). This increase in metabolism aids the healing process by increasing both catabolic and anabolic reactions needed to degrade and remove metabolic by-products of tissue damage and provides the milieu for tissue repair.

Topical heat treatment applied directly on the skin increases both deep tissue temperature and blood flow. Mahajan et al. (2010) informed that heating pad treatment on the skin of the lower back region at 40^oC increases deep muscle tissue temperature by 5^oC, 3.5^oC, and 2^oC at muscle tissue depths of 19mm, 28mm, and 38mm below the surface of the skin, respectively. Conductive topical heat treatment of the knees of healthy subjects increased popliteal artery blood flow by 29%, 94%, and 200% after 35 minutes of treatment with heating pad temperatures of 38^oC, 40^oC, and 43^oC, respectively (Struyf et al., 2014; Erasala et al., 2001; Mendiguchia et al., 2013) demonstrated that deep tissue blood flow was found to increase 27%, 77% and 144% in the trapezius muscle of healthy volunteers with heating pad treatments, resulting in skin temperature increases of 38^oC, 40^oC and 42^oC, respectively.

The latter two studies show a two to threefold increase in deep tissue blood flow with moderate levels of conductive topical heat treatment applied directly to the skin. In addition, it was reported that a significant

increase in trapezius muscle conduction velocity, most likely due to increased tissue blood flow, occurred with hot pack treatment at moderate temperatures (Cramer, et al., 2012).

Continuous application of low-level heat therapy (LLHT) directly on the skin has been shown to be safe and therapeutically effective in treating musculoskeletal disorders. According to Paul Kennedy et al. (2017), a randomised controlled clinical trial evaluating the effects of a wearable medical device that provided eight hours of continuous LLHT for the treatment of delayed onset muscle soreness of the quadriceps muscles showed significant increases in pain relief after eight hours of heated knee wrap wear at temperatures of 38ºC and 40ºC compared with a control group that wore unheated control wraps on both knees.

The same procedure has also been found to be effective for treating acute muscular low back pain especially those associated with menstrual pain. Using the same approach, Steiner et al. (2000) showed that if continuous LLHT is applied for eight hours per day over three consecutive days significant increase in pain relief persisted in the heat-treated group twenty-four hours after all treatments were stopped compared to an unheated control treatment. Akin et al. (2001) demonstrated that continuous low-level heat therapy with a wearable medical device applied directly on the skin of the lower abdomen for 12 hours per day for two days, provided significant pain relief in patients with dysmenorrhea when compared to a control group wearing an unheated device.

Continuous LLHT is also effective for the treatment of wrist pain associated with strains, sprains, and osteoarthritis. In their work, Michlovitz et al. (2002) showed incremental pain relief with eight continuous hours of topical heat treatment for three consecutive days compared with placebo treatment. Pain relief progressively increased with each successive day of therapy and persisted in the heat-treated group on the fourth and fifth day after all treatments were stopped. The therapeutic benefit of heat therapy in subjects with wrist pain included a significant increase in grip strength after three consecutive days of LLHT, which remained two days after all treatment had stopped. Similar therapeutic benefits were observed in subjects with carpal tunnel syndrome.

2.3 Safety of Heat Therapy

Heat therapy is safe when used within the treatment time recommended. Heat can be used to alleviate pain, muscle spasm caused by ischemia that may be relieved by heat, which increases blood flow to the area of injury. Inflammation and swelling are decreased through some of the direct effects of heat application such as increasing metabolism, reducing oxygen tension, lowering pH level, increasing capillary permeability, and releasing histamine and bradykinin thereby causing vasodilation.

Thermotherapy should be used with caution in patients with diabetes mellitus, multiple sclerosis, poor circulation, spinal cord injuries, and rheumatoid arthritis because it may cause disease progression, burns, skin ulceration, and increased inflammation (Nadler et al., 2004, Hurley et al., 2008).

When using thermotherapy, the skin should be protected in heat-sensitive or high-risk patients, especially over regions with sensory deficits. Caution should be used with products generating high intensity heat (greater than 45ºC), such as with Hydro collator packs or electric heating pads. Application time should be restricted for modalities that heat to high intensity levels. Other contraindications include application of heat immediately after an injury, over the eyes or genitals, over the abdomen during pregnancy, and over active infections.

2.4 Heat Therapy in Combination with Modified Physical Activity

Heat should be applied as prescribed on the sore area for a short duration in a position of comfort to assist with pain management. Modified activity should be encouraged as bed rest is not recommended, such activities should be carefully introduced as the patient begins to recover from the worst of the back-pain episode but cold therapy is not recommended (Norris, and Matthews, 2008). As bed rest has been de-emphasised, a more active approach to physical activity has been recommended. These recommendations are similar to those at the turn of the past century when the "disuse syndrome" was viewed as a prominent cause of low back pain (Henschke et al., 2009). The most common situations to avoid are prolonged sitting or standing, to avoid prolonged sitting at work or in a vehicle, patients should be instructed to get up at regular intervals (every 30 minutes) to walk and move their backs, because changing positions can increase pain, attention while getting up or sitting down and doing it slowly may avoid recurrent back spasm.

Low-stress aerobic activities, especially walking, is the best early activity. Patients should generally avoid strenuous activity, such as heavy lifting, climbing, or jogging until symptoms are improving over a period of a few days. Patients with acute low back pain may experience small benefits in pain relief and functional benefits from advice to stay active. The fear that activity will increase the pain is common in acute low back pain sufferers, in most people this will recede as the individual finds that he or she can maintain at least some level of activity. Fear-avoidance beliefs can be defined as a dysfunctional interpretation that physical or social activity will worsen the pain and/or cause harm. Individuals with these beliefs may be identified early in the course of their low back pain episode as those who

state these fears about continued activity. They frequently believe that complete avoidance of activity or even bed rest is necessary to heal, individuals who demonstrate fear-avoidance should be informed of the potential harm of no activity and the dangers of deconditioning and should be urged to return to modified work (Damian Hoy et al., 2014; Henschke et al., 2009).

3. Materials and method

The individual components that make up the device and their principles of operation are briefly discussed. The circuit is powered by a 12V dc battery supply. The microcontroller is the core of device's processing unit, it gives command to all other components of the device based on its programming. The temperature sensor reads the temperature and displays it on a screen, while a second screen displays the time. This device is programmed to self-regulate and shut down once it completes the duration of therapy imputed through the timer potentiometer, this serves as a safety mechanism to prevent overheating or burns.

The temperature potentiometer is manually adjusted to set the desired temperature, this allows for a more effective control of the device as the temperature will not exceed the limit set by the user. There is also a Bluetooth feedback system option for controlling and monitoring through a third-party device like a smart phone. The heater is made up of a number of ceramic sealed resistors which are serially connected, they are small and arranged in such a way as to provide heat to a targeted region of the body without the burn hazard associated with typical heaters. The heater heats up the water contained in the rubber pouch, this water medium transfers heat to a concentrated area of the lower back tissues through an insulated cotton cloth material. The complete block diagram and circuit diagram of the device are illustrated in Figures 1 and 2, respectively.

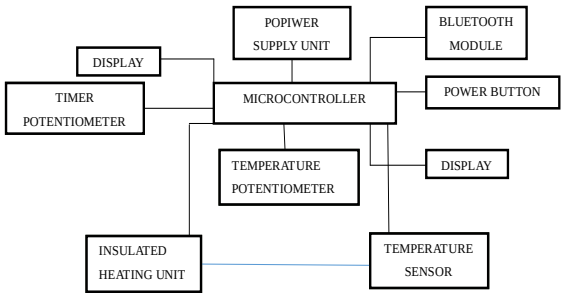

Figure 1. Schematic Block diagram of the device

3.1 Wire-Wound Ceramic Composition Resistors

This type of resistor is made up of resistance wire which is intended for making electrical resistors. In many situations, the stability of the resistor is of primary importance, and thus the alloy temperature coefficient of resistivity and corrosion resistance that play a large part in material selection. When resistance wire is used for heating elements, high resistivity and oxidation resistance is important. Sometimes, resistance wire is insulated by ceramic powder. Ceramic powder helps to control the resistive value of resistors.

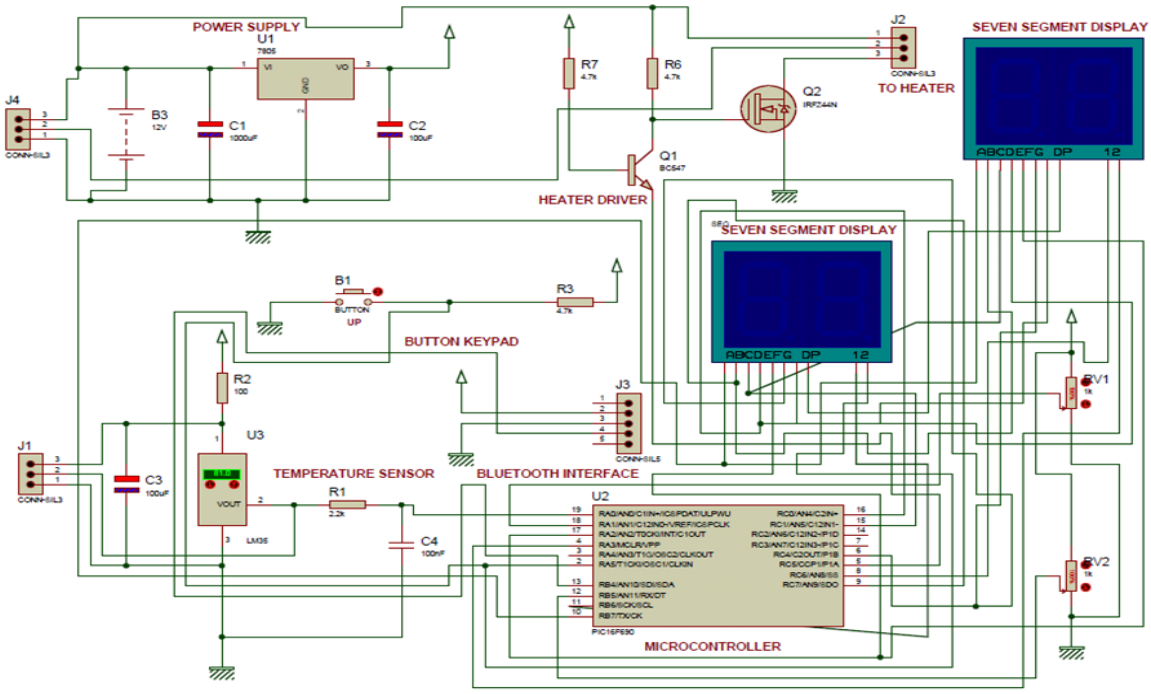

Figure 2. Circuit diagram of the device

Ceramic is also an excellent heat conductor, this property of ceramic allows the cores of the resistor to endure low to moderate power electrical current without overheating and becoming damaged, because of its insulation and thermal properties, ceramic is used to externally insulate and provide greater thermal endurance to some types of resistors. The most common of these resistors are made of resistive wire spun around a ceramic core and then encased in a block or cylinder of ceramic material. The higher the ratio of carbon in the mix, the lower the resistive value the ceramic resistor will have. A higher ratio of ceramic on the other hand will mean a higher resistive value of the resistor.

3.2 Microcontroller (PIC16F689)

The control of the circuit is accomplished through the use of a microcontroller, the PIC16F689, which can be programmed from a PC using the C programming language. The microcontroller delivers commands to the heat therapy device circuitry. The PIC is a family of modified Harvard architecture microcontrollers derived from the PIC1650, the name PIC initially referred to Peripheral Interface Controller. PIC devices generally feature: Flash memory (program memory, programmed using MPLAB devices), SRAM (data memory), EEPROM memory (programmable at run-time), Sleep mode (power savings), Watchdog timer.

3.3 LM-35 Precision Centigrade Temperature Sensor

The LM- 35 precision centigrade temperature sensor is used to measure tissue temperature during the application of heat therapy. It is a precision integrated circuit temperature sensor with an output voltage linearly proportional to the centigrade temperature. The LM-35 sensor has an advantage over linear temperature sensors calibrated in degree kelvin as the user isn't required to subtract a large constant voltage from the output to obtain a convenient centigrade scale. The sensor doesn't require any external calibration or trimming to provide typical accuracies of ±¼ºC at room temperature and ±¾ºC over a full -55ºC to +150ºC temperature range. The low output impedance, linear output, and precise inherent calibration of the LM 35 make the interfacing to the readout control circuitry especially easy. The LM-35 is rated to operate over a temperature range of -55 ºC to +150 ºC; it is therefore suitable for this work.

3.4 Potentiometer

A potentiometer is a three-terminal resistor with a sliding or rotating contact that forms an adjustable voltage divider, it is essentially a voltage divider used for measuring electric potential (voltage); the component is an implementation of the same principle, hence its name. Potentiometers are rarely used to directly control significant amounts of power (more than a watt or so), instead they are used to adjust the level of analog signals (for example volume controls on audio equipment), and as control inputs for electronic circuits. User-actuated potentiometers are widely used as user controls, and may control a very wide variety of equipment functions.

3.5 Heater Driver (MOSFET – IRFZ44N)

The heater driver / actuator is designed to limit the amount of current delivered to the heater and control the consequent working rate of the heater. The heater temperature control provides a periodic control signal having a substantially constant peak to peak magnitude and an average value dependent on a sensed temperature to be regulated. The rate of heating is proportional to the applied current. The power dissipated by joule heating in the heater is proportional to the square of the current. Thus, an increase in current above a certain value will result in overheating of the device. It is therefore important to carefully control the current that is applied to the heater. It would be advantageous to provide a temperature control circuit for the heater that operates in a nonlinear fashion. A further advantage to using such a circuit is that it operates using the same voltages already present in the circuitry for the device being protected. This design provides a power MOSFET–IRFZ44N control circuit for driving the heater.

3.6 HC-05 Bluetooth Module

Signal transmission from the heat pad to a third-party device for monitoring and management during thermotherapy is accomplished through the use of an HC-05 Bluetooth module. Bluetooth transmission is chosen over radio frequency transmission due to frequent interference which occurs when using RF transmission. The HC-05 module is an easy to use Bluetooth SPP (Serial Port Protocol) module designed for transparent wireless serial connection set-up, it is used to transmit data from the heat therapy device to a third-party feedback device for temperature monitoring and management.

3.7 Seven-Segment Display

Temperature display on the heat wrap is accomplished through the use of a seven-segment display. A seven-segment display (SSD) or indicator is a form of electronic display device for displaying decimal numerals that is an alternative to the more complex dot matrix display. It is widely used in digital clocks, electronic meters, basic calculators, and other electronic devices that display numerical information.

4. Results and Discussion

A heat therapy device using moist heat for providing analgesia through the use of an electrical resistive heating material was developed. The modality can be strapped to the lower waist of the patient in the manner as a waist bag. Figure 3 shows pictures of the control

unit and also that of the insulated heating unit detached from the control unit.

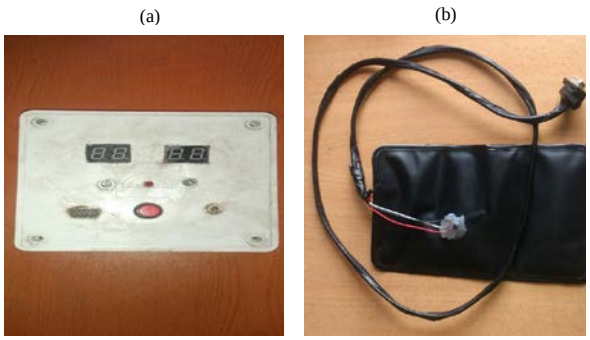

Figure 3: (a) Device control and monitoring unit and (b) Device heater section detached from the control unit

4.1 Results Analysis

Ten young adults participated in the research after agreeing to sign the informed consent forms, and participation in this research was entirely voluntary. The device was placed on the lower back region of selected participants and the duration of exposure ranged between 30 to 45 minutes per therapy session. The heating element of the device was not in direct contact with the surrounding tissues at any time as it was sealed within the water containing pouch through which heat was conducted to the lower back. The study population was fairly selected across age groups without sexual preferences, but subject with increased risk of complications such as people who suffer with ailing cardiovascular systems, spinal cord injuries and rheumatoid arthritis to avoid disease progression, burns, skin ulceration, and increased inflammation. The risks attached with use of the device were minimal as measures were taken to greatly reduce such risks. Some of these measures include:

1. An insulated heat wrap containing the heating unit which is placed on the lower back.
2. A temperature controller which controls the treatment progression at the desired temperature and minimises treatment time.
3. A Bluetooth monitoring and feedback system which constantly monitors the temperature of the device.
4. A power safety system that automatically switches off the device once the treatment time is complete.

Initial results from the device are shown in Figure 4. The results obtained from the moist heat therapy device reveal that from an ambient temperature of 34 ºC, temperature increases steadily to its peak temperature at point A, which is the desired temperature for applying therapy during the first five minutes of therapy, it then remains steady from that point A to point B and beyond throughout the rest of the therapy application.

A plateau effect occurs after peak temperatures are reached; this plateau effect is seen over the rest of the heat application. The heat therapy device is able to maintain its peak value temperature beyond 15 minutes after point A as the device is regulated, the heater shuts off automatically when it reaches its peak / pre-set temperature of 45 ºC and switches back on as it falls below this temperature to ensure that the temperature required to elevate the core muscle temperature is constant and maintained to aid in relieving pain and muscle spasm. The rate of heat loss is slower as device monitors and regulates fall in temperature so that the heat lost to the tissue and environment is replaced continually by the heater.

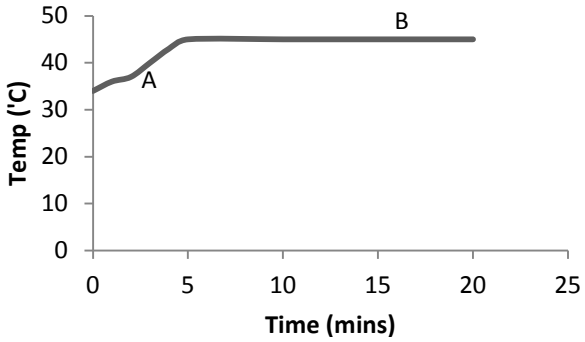

Figure 4: Heating rate for moist heat therapy device

Figure 5 shows experimental results from the traditional method of hot water bottle. An initial temperature of warm water at 60 ºC is used as a starting value at point A as it is considered adequate for therapy, temperature falls rapidly to a temperature of 32 ºC at point B over a period of one hour as seen on the graph and continues to fall towards room temperature, it then remains constant as the modality loses heat rapidly to the immediate environment considering that the rate of heat loss is not regulated.

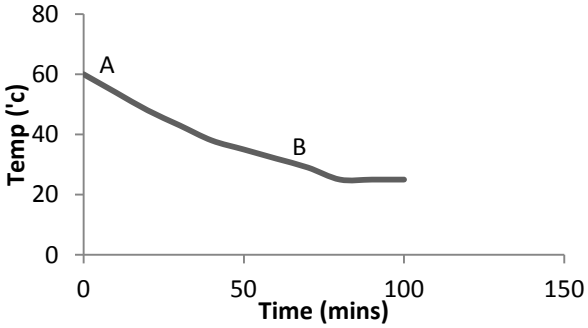

Figure 5: Heating rate for hot water bottle

During heat transfer to the body, the greatest degree of elevated temperature occurs in the skin and subcutaneous tissues within 0.5 cm of the skin surface.

In areas with adequate circulation, temperature increases to its maximum within 6 to 8 minutes of exposure. Muscle temperature at depths of 1 to 2 cm increases to a lesser degree and requires a longer duration of exposure (15 to 30 minutes) to reach peak values (Everett B. Lohman et al, 2012). Intense heat must therefore be applied for a duration of 15-30 minutes for effectiveness. Results show that this modality is not effective in the resolution of low back pain as the rate at which heat is lost fast to the immediate environment, and the thermal conductivity of body is not being replaced in any way. This leads to a reduction in the intensity of the heat applied over time and prevents effective penetration of the tissues to aid in pain relief. The efficacy of heat therapy in low back pain depends on the modality through which heat is applied, as a modality with unregulated rate of heat loss and fall in temperature will prove ineffective in relieving low back pain. A regulated moist heat therapy device in relieving low back pain is effective as the rate of heat loss and subsequent fall in temperature are addressed by constant monitoring and regulation by the device. Figure 6 shows the temperature gradient of electronic heat therapy device versus hot water bottle.

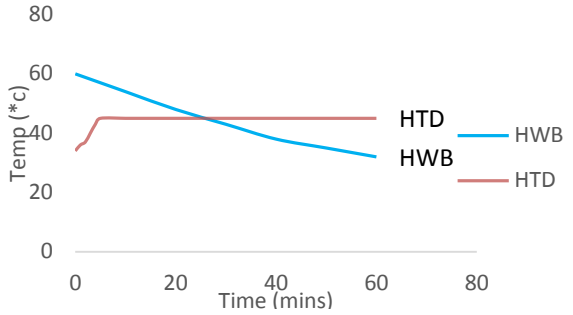

Figure 6: Temperature gradient of an electronic heat therapy device versus hot water bottle

4.2 Market Potential and Cost Analysis

The market potential is quite high for this innovative device particularly in low resource countries. According to a systematic review (Louw et al., 2007), the average lifetime prevalence of LBP in Africa among adolescents was 36%, and 62% among adults. In an urban population in southwestern Nigeria, a prevalence level of between 32-85% was reported (Omokhodion, 2004). A similar study in a teaching hospital in eastern Nigeria showed that out of every 10% of orthopedic patients, 82.1% of adult patients with LBP had LBP of mechanical or non-specific origin (Omoke and Amaraegbulam, 2016), and is within the range of 80% - 90% documented for developed or high-income nations. This shows that LBP of mechanical origin is predominant in Nigeria which has an estimated population of about 186 million (according to the 2017 revision of the World Population Prospects). Approximately 50% of Nigerians are urban dwellers, with the proportion of people between the ages of 15 and 65 years comprising 53.2% of the total population (United Nations, 2012).

The market potential of the device = No. of buyers × qty. purchased by the average buyer × price of 1 unit of the product.
The number of buyers was calculated using an estimated prevalence level of 80% of the adult urban population (53.2%) of a total population of 186 million.
Number of buyers = 0.8 × 0.532 × 186,000,000 = 7,916,160.

The design for this device incorporates low cost components which makes it easily affordable in poor resource countries where access to sophisticated medical equipment is rare. The total cost of the prototype amounts to about $105. However, the final prototype did not benefit from the cheapest industrial prices. The cost summary was done for an estimated 1000 units at $20,000, excluding the extrinsic expenses and chances for discounts, and reductions due to better market experience. The price values were taken from several component distributors. Shipping and handling were not included. Similar products in western markets would cost an upward of $500, making it rather difficult for an average person in a poor resource country to be able to afford such a device.

5. Conclusion

Findings have shown that relief from low back pain depends on the duration (time) and intensity at which heat is applied. The ability to provide improved heat therapy device for the application of thermotherapy is emerging as a preferred option for pain management among sufferers of mechanical low back pain, as physicians and physiotherapists are opposed to complete dependence on prescription drugs/opioids. The development of an electronic heat therapy device is coming at a time when we need a means of monitoring and quantifying the long term physiological response of individuals, and also overcome some limitations of the traditional methods of administering thermotherapy. The developed moist heat therapy device certainly has numerous advantages over traditional methods of heat therapy using hot water bottles particularly in areas of effective heating control and accuracy in maintaining the target temperature, real-time monitoring of tissue temperature during therapy, and over all patience safety.

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References:

Ajibola, O.O.E. and Folorunso, P.O. (2017), "Analysis, design and construction of electronics ice cuff for athletes", *International Journal of Medical Engineering and Informatics*, Vol.9, No.3, pp. 220-236.

Akin, M.D., Weingand, K.W., Hengehold, D.A. Goodale, M.B., Hinkle. R.T. and Smith, R.P. (2001), "Continuous low-level topical heat in the treatment of dysmenorrhea", *Obstetrics and Gynaecology*. Vol.97, pp.343-349.

Andreisek, G., Imhof, M., Wertli, M., Winklhofer, S., Pfirrmann, C.W.A., Hodler, J. and Steurer, J. (2013), "A systematic review of semiquantitative and qualitative radiologic criteria for the diagnosis of lumbar spinal stenosis", *American Journal of Roentgenology*, Vol.201, No.5, pp.W735-W746

Angilletta, M.J.Jr., Cooper, B.S., Schuler, M.S. and Boyles, J.G. (2010), "The evolution of thermal physiology in endotherms", *Frontiers in Bioscience*, Vol.E2, pp.861-881.

Arnason, A., Anersen, T.E., Holme, I., Engebretsen, L. and Bahr, R. (2008), "Prevention of hamstring strains in elite soccer: an intervention study", *Scandinavian Journal of Medicine and Science in Sports*, Vol.18, No.1, pp.40-48

Bazett-Jones, D.M., Gibson, M.H. and McBride, J.M. (2008), "Sprint and vertical jump performances are not affected by six weeks of static hamstring stretching", *The Journal of Strength and Conditioning Research*, Vol.22, No.1, pp.25-31

Benzon, H., Rathmell, J., Wu, C., Turk, D. and Argoff, C. (2013)(Ed), *Raj's Practical Management of Pain*, Elsevier, Philadelphia, USA. pp. 1319.

Brosseau, L., Yonge, K.A., Welch, V., Marchand, S., Judd, M., Wells, G.A. and Tugwell, P. (2003), "Thermotherapy for treatment of osteoarthritis", *Cochrane Database of Systematic Reviews*, Issue 4. CD004522.

Cramer, H., Baumgarten, C., Choi, K-E., Lauche, R., Joyonto, F., Frauke, S. and Gustav Dobos, M. (2012), "Thermotherapy self-treatment for neck pain relief: A randomised controlled trial", *European Journal of Integrative Medicine*, Vol.4, No.4, pp.e371-e378.

Damian Hoy, D., March, L., Brooks, P., Blyth, F., Woolf, A., Bain, C., Williams, G., Smith, E., Vos, T., Barendregt, J., Murray, C., Burstein, R. and Buchbinder, R. (2014), "The global burden of low back pain: Estimates from the Global Burden of Disease 2010 study", *Annals of the Rheumatic Diseases*, Vol.73, pp.968-974.

Emch, T.M. and Modic, M.T. (2011), "Imaging of lumbar degenerative disk disease: History and current state", *Skeletal Radiology*, , Vol.40, pp.1175-1189

Erasala, G.N., Rubin, J.M. and Tuthill, T.A. (2001), "The effect of topical heat treatment on trapezius muscle blood flow using power Doppler ultrasound", *Physical Therapy*, Vol.81, pp.5.

Henschke, N., Maher, C.G., Refshauge, K.M., Herbert, R.D., Cumming, R.G., Bleasel, J., York, J., Das, A. and McAuley, J.H. (2009), "Prevalence of and screening for serious spinal pathology in patients presenting to primary care settings with acute low back pain", *Arthritis Rheum*, Vol.60, No.10, pp.3072-3080

Hurley, D.A., Casserly-Feeney, S.N., Bury, G. and Daly, L. (2008), "Physiology for low back pain: Differences between public and private healthcare sectors in Ireland – a retrospective survey", *Manual Therapy*, Vol.13, No.5, pp.441-449.

Kent, P. (2006), "Heat wrap therapy reduces pain and disability in early stage low back pain", *Australian Journal of Physiotherapy*, Vol.52, No.3, pp.227

Koes, B.W., van Tulder, M., Lin, C-W.C., Macedo, L.G., McAuley, J., and Maher, C. (2010), "An updated overview of clinical guidelines for the management of non-specific low back pain in primary care", *European Spine Journal*, Vol.19, No.12, pp.2075–2094

Lohman, E.B., Sackiriyas, K.S.B., Bains, G.S., Calandra, G., Lobo, C., Nakhro, D., Malthankar, G. and Paul, S. (2012), "A comparison of whole body vibration and moist heat on lower extremity skin temperature and skin blood flow in healthy older individuals", *Medical Science Monitor*, Vol.18, No.7, CR415–CR424.

Louw, Q.A., Morris, L.D. and Grimmer-Somers, K. (2007), "The prevalence of LBP in Africa: A systematic review", *BioMed Central Musculoskeletal Disorders*, Vol.8, pp.105-119.

Lund, J., Rustan, A.C., Løvsletten, N.G., Mudry, J.M., Langleite, T.M., Feng, Y.Z., Stensrud, C., Brubak, M.G., Drevon, C.A., Birkeland, K.I., Kolnes, K.J., Johansen, E.I., Tangen, D.S., Stadheim, H.K., Gulseth, H.L., Krook, A., Kase, E.T., Jensen, J. and Thoresen, G.H. (2017), "Exercise in vivo marks human myotubes in vitro: Training-induced increase in lipid metabolism", *PLOS One*, Vol.12, No.4, pp.e0175441

Mahajan, C., Rath, G.P., Bithal, P.K., Prabhakar, H., Yadav, R. and Dube, S.K. (2010), "Local warming at injection site helps alleviate pain after rocuronium administration", *Journal of Anesthesia*, Vol. 24, No.6, pp.845-848.

Mendiguchia, J., Garrues, M.A., Cronin, J.B., Contreras, B., Los Arcos, A., Malliaropoulos, N., Maffulli, N. and Idoate, F. (2013), "Nonuniform changes in MRI measurements of the thigh muscles after two hamstring strengthening exercises", *The Journal of Strength and Conditioning Research*, Vol.27, No.3, pp.574-581.

Michlovitz, S.L., Erasala, G.N., Hengehold, D.A. and Weingand K.W. (2002), "Continuous low-level heat therapy for wrist pain", *Orthopedics*, Vol.25, pp.S1467

Nadler, S.F., Steiner, D.J., Erasala, G.N., Hengehold, D.A., Abeln, S.B. and Weingand, K.W. (2003), "Continuous low-level heat wrap therapy for treating acute nonspecific low back pain", *Archives of Physical Medical Rehabilitation*, Vol.84, No.3, pp.329-334.

Nadler, S.F., Weingand, K. and Roger, J.K. (2004), "The physiologic basis and clinical applications of Cryotherapy and Thermotherapy for the Pain Practitioner", *Pain Physician*, Vol.7, pp.395-399.

Norris, C. and Matthews, M. (2008), "The role of an integrated back stability program in patients with chronic low back pain", *Complementary Therapies in Clinical Practice*, Vol.14, No.4, pp.255-263

Omoke, N.I. and Amaraegbulam, P.I. (2016), "Low back pain as seen in orthopaedic clinic of a Nigerian teaching hospital", *Nigerian Journal of Clinical Practice*, Vol.19, No.2. pp.12-17.

Omokhodion, F.O. (2004), "Low back pain in an urban population in southwest Nigeria", *Tropical Doctor*, Vol.34, No.1, pp.17-20.

Paul Kennedy, P., Macgregor, L.J., Barnhill, E., Johnson, C.L., Perrins, M., Hunter, A., Brown, C., van Beek, E.J.R. and Roberts, N. (2017), "MR elastography measurement of the effect of passive warmup prior to eccentric exercise on thigh muscle mechanical properties", *Journal of Magnetic Resonance Imaging*, Vol.46, pp.1115-1127

Petrofsky, J., Berk, L., Bains, G., Khowailed, I.A., Hui, T, Granado, M, Laymon, M., and Lee, H. (2013), "Moist heat or dry heat delayed onset muscle soreness", *Journal of Clinical Medicine Research*, Vol.5, No.6, pp.416-425.

Petrofsky, J.S. and Laymon, M. (2009), "Heat transfer to deep tissue: the effect of body fat and heat modality", *Journal of Medical Engineering Technology*, Vol.33, No.5, pp.337-348.

Prentice, W.E. (2002), *Therapeutic Modalities for Allied Healthcare Professionals*, McGraw-Hill. New York.

Qaseem, A. Wilt, T.J., McLean, R.M. and Forciea, M.A. (2017), "Noninvasive Treatments for Acute, Subacute, and Chronic Low Back Pain: A Clinical Practice Guideline from the American College of Physicians. Annals of Internal Medicine. 166(7):514-530

Robert, B.R., Mikhail, S. and Dhiraj, A. (2005), "Minimum time-dose control of thermal therapies", *IEEE Translations in Biomedical Engineering*, Vol.52, No.2, pp.191-200.

Sands, W.A., McNeal, J.R., Murray, S.R., Ramsey, M.W., Sato, K., Mizuguchi, S. and Stone, M.H. (2013), "Stretching and its effects on recovery: A review", *Strength and Conditioning Journal*, Vol. 35, No.5, pp.30-36.

Savastano, D.M., Gorbach, A.M., Eden, H.S., Brady, S.M., Reynolds, J.C. and Yanovski, J.A. (2009), "Adiposity and human regional body temperature", *The American Journal of Clinical Nutrition*, Vol.90, No.5, pp.1124-1131

Starkey C. (2004), *Therapeutic Modalities*, F.A Davis Company, Philadelphia, USA.

Steiner, D., Erasala, G., Hengehold, D. and Abeln S.B. (2000) "Continuous low-level heat therapy for acute muscular low back pain", *Proceedings of the 19th Annual Scientific Meeting of the American Pain Society*, Atlanta, GA. November, pp.*112*

Stephen, J.M., Argus, C. and Driller, M.W. (2014), "The relationship between body composition and thermal responses to hot and cold water immersion", *Journal of Human performance in Extreme Environments*, Vol.2, No.2 (Article 1), pp.1-9

Steven, E.P., David, O.D., Kenneth, L.K. and Mark, D.R. (2003), "Pulsed shortwave diathermy and prolonged long-duration stretching increase dorsiflexion range of motion more than identical stretching without diathermy", *Journal of Athletic Training*, Vol.2, pp.43-50.

Struyf, F., Cagnie, B., Cools, A., Baert, I., Van Brempt, J., Struyf, P. and Meeus, M. (2014), "Scapulothoracic muscle activity and recruitment timing in patients with shoulder impingement symptoms and glenohumeral instability", *Journal of Electromyography And Kinesiology*. Vol.24, No.2, pp 277-284

Szymanski, D.J. (2001), "Recommendations for the avoidance of delayed-onset muscle soreness", *Strength Conditioning Journal*, Vol.23, No.4, pp.7-13.

Tristan, L., Hartzell, R.R. and Mojca, H. (2012), "Therapeutic modalities: An updated review for the hand surgeon", *The Journal of Hand Surgery*, Vol.37, No.3, pp.597-621.

United Nations (2012), *World Population Prospect: The 2012 Revision*, Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat.

United Nations (2017), *World Population Prospect: The 2017 Revision*, United Nations Department of Economic and social affairs (ESA.UN).

van Middelkoop, M., Rubinstein, S.M., Kuijpers, T., Verhagen, A.P., Ostelo, R., Koes, B.W. and van Tulder, M.W. (2011), "A systematic review on the effectiveness of physical and rehabilitation interventions for chronic non-specific low back pain", *European Spine Journal*, Vol. 20, No.1, pp.19-39.

William, E.P. (2008), *Arnheims Principles of Athletic Training: A Competency Based Approach*, McGraw-Hill, New York.

Yoona Kang, Y., Williams, L.E., Clark, M.S., Gray, J.R. and Bargh, J.A. (2011), "Physical temperature effects on trust behavior: The role of insula", *Social Cognitive and Affective Neuroscience*, Vol.6, No.4, pp.507-515.

Authors' Biographical Notes:

Olawale O.E. Ajibola *obtained his BSc (Hons) degree in Mathematics from the University of Ibadan, Ibadan, MSc degree in Engineering Analysis and PhD in Systems Engineering both from the University of Lagos, Lagos. Currently, he is the Coordinator of Graduate Programmes at the Department of Systems Engineering, Faculty of Engineering of the University of Lagos. He is Immediate Past Chair of the Department of Biomedical Engineering, College of Medicine of the same university. He is also a Registered Engineer in Nigeria. His main areas of specialisation are biomedical modelling and simulations, and biomedical devices; he has produced many portable cost-effective medical devices. He also specialises on renewable energy as an alternative and viable source of energy, and other energy related issues such as witricity. He has published widely both in national and international journals.*

Kehinde Oluwaseyi Fagbolagun *obtained his BSc (Hons) in Cell Biology and Genetics and MSc in Biomedical Engineering from University of Lagos, Lagos, Nigeria. Currently, he is a Research Fellow in the Department of Systems Engineering of the University of Lagos. His research interests are mainly in the areas of tissue engineering where he specialises on thermotherapy and biomedical devices..*

Olayide Paul Folorunso *obtained BSc (Hons) degree in Physics from Ahmadu Bello University, Zaria, MSc degree in Systems Engineering from University of Lagos both in Nigeria. Currently, he is a Research Fellow in the Department of Systems Engineering of the University of Lagos and a registered PhD student of the same university. His research interests are mainly in the areas of biomedical modelling and simulations, biomedical devices, tissue engineering, and bio informatics.*

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Evaluating the State of Product Design in Trinidad and Tobago

Jeewan Ramkissoon [a], and Umesh Persad [b,Ψ]

Design and Manufacturing Engineering, The University of Trinidad and Tobago, O'Meara Campus, 78-94 O'Meara Industrial Park, Arima, Trinidad and Tobago, West Indies;
[a]E-mail: jeewan.ramkissoon@gmail.com
[b]E-mail: umesh.persad@utt.edu.tt

[Ψ] *Corresponding Author*

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Abstract: *This paper describes a study of product design and manufacturing companies in Trinidad and Tobago. Using the Trinidad and Tobago Manufacturers' Association (TTMA) database, three companies engaged in original mechanical or electrical product design and manufacturing agreed to participate in the study. Design process and product audits were used to evaluate the current design practice and quality of the designed products. The research findings demonstrate that local design process capabilities and product quality are lacking within Small and Medium Enterprises (SME's). This was due to companies not being able to afford full-time product design expertise and formal design skills not being appreciated by business owners. Recommendations were made to address this situation including design education workshops to sensitise business owners about product design techniques and audits, and national incentives to encourage and support the business of product design through product design partnerships.*

Keywords: *Product Design, Design Process Improvement, Design Audit, Design Management*

1. Introduction

In 2016, the Petroleum sector accounted for 32% of Trinidad and Tobago's (TT) Gross Domestic Product (GDP), whereas the Manufacturing sector only contributed to 7.8%, which has been decreasing from 8.6% since 2011 (Ministry of Finance, 2016). In the presence of the country's current financial crisis with decreasing fossil fuel revenues, the need for development in the manufacturing sector is not only imperative but has now become long overdue as several companies have already decreased production investments or have gone out of business entirely.

Scholarly publications targeting the local industry's product design practice are rare. One study concluded that the current use of Integrated Manufacturing Technologies (IMT) within manufacturing firms in Trinidad and Tobago is not at required levels to facilitate the design and development of new products (Chowdary, 2009). Another study found that Trinidad and Tobago and the wider Caribbean region lack product and process innovation capabilities that lead to a wider range of manufactured goods as a vital response to the dependency on tourism and depleting oil and gas reserves (King and Cameron, 2013).

In order to expand local innovation initiatives, a sound understanding of current local product design practice is necessary. Given that the state of product design in the Trinidad and Tobago industry needs in-depth investigation, the study presented in this paper seeks to identify local manufacturing companies that are engaged in mechanical or electro-mechanical product design, and capture the design processes, product quality, and environmental forces affecting innovative product development. Based on the results of the study, recommendations are made for improving local product design practice.

2. Background

A nation's economy is heavily dependent on effective product design (Sentence and Clarke, 1997; Mynot, 2000). For example, in a study of 60 small engineering firms, it was found that companies with a robust design orientation showed high growth trends (Black and Baker, 1987). A five-year study including 51 companies concluded that firms exhibiting good design were more competitive in all business performance measures (Hertenstein et al., 2001). It is therefore prudent for companies engaged in product design to continually evaluate and improve their design process and product design quality. Studies conducted on the local design and manufacturing context (Chowdary, 2009; King and Cameron, 2013) did not focus specifically on the particular role of the design process and the design environment. In addition, the quality of the designed products was not assessed for potential improvement.

To specifically address this gap, a research strategy was developed to specifically audit the design process (Otto and Wood, 2000, Clarkson and Ekert, 2005, Eppinger and Ulrich, 2007) and the quality of the designed products of local companies engaged in original product design. Moultrie and Fraser (2004) present a comprehensive workbook suited for auditing small to medium manufacturing businesses taking into

account the marginalisation of design functions in SME's.

According to Moody (1980), this marginalisation occurs because design activities are viewed as tasks that can be done by anyone with common sense. A symptom of this marginalisation is design activities being performed by individuals with no specific design training referred to as 'Silent Design' (Gorb and Dumas (1987).

Using product and process audits, the workbook allows firms to determine current product performance and design process effectiveness against key design dimensions. A product's design strengths and weaknesses are highlighted from the product audit and represent that product's design quality, from both the company's and consumer's perspectives. The design process audit evaluates 24 significant design activities at four performance levels. The results of each audit (numerical scoring and graphical representations) provide benchmarks from which improvements can be made and tracked. A high-level overview of the audit methodology will be described for the purposes of this paper. For details on the product and process audit, the reader is referred to Moultrie and Fraser (2004).

The product audit assesses the design performance of products using seven key aspects of 'good product design' or 'product design quality' and five key aspects of 'design importance to customers', as shown in Figure 1. Each key aspect, like Engineering Quality, is broken down into more detailed issues, like Reliability or Durability. Each issue is then scored on a scale from 1 to 4, where 1 represents a poor performance and 4 represents great performance. An average of the scores for all the issues is then found resulting in an overall performance score for the respective product's design aspect being considered.

Similarly, the design process audit is used to assess each company's design activities focusing on design execution and design management. These two design headings are broken down into five design areas from which a total of 24 corresponding key activities are identified, shown in Figure 2. Each activity is evaluated across four maturity levels where maturity is defined as, "The degree to which processes and activities are executed following 'good practice' principles and are defined, managed and repeatable." The audit was designed following process maturity principles, using a maturity grid to describe the design behaviours exhibited by a firm. Each activity for a particular area is scored individually using a separate detailed grid. Then, all the activity scores are placed on the respective design area's summary grid shown in Figure 3. Finally, all scores for the design areas and design activities are collated to identify performance gaps for the respective design headings.

By using the process and product audits, a complete picture of the design function and product quality could be ascertained. In addition, a PESTLE analysis (Political, Economic, Social, Technological, Legal and Environmental) is a useful tool to gauge the environmental factors that affect a business's product design plights. Using a combination of these tools, the methodology was developed for determining and hence evaluating the state of product design in Trinidad and Tobago.

3. Methodology

For inclusion in the study, the main criterion was that a firm should design the products that they manufacture. Participants were sourced from the TTMA's membership directory (August 2016). The criteria used for study suitability screening were as follows:

1) Companies must have their design operations resident in Trinidad and Tobago.
2) Companies must practice 'in house' product design, including design idea generation.
3) Company produces physical products with electrical and/or mechanical properties.
4) Company products are marketed to the end consumer rather than as an input to any other industrial process.

Figure 1. Seven aspects of design quality and five aspects of design importance to customers from Moultrie and Fraser (2004)

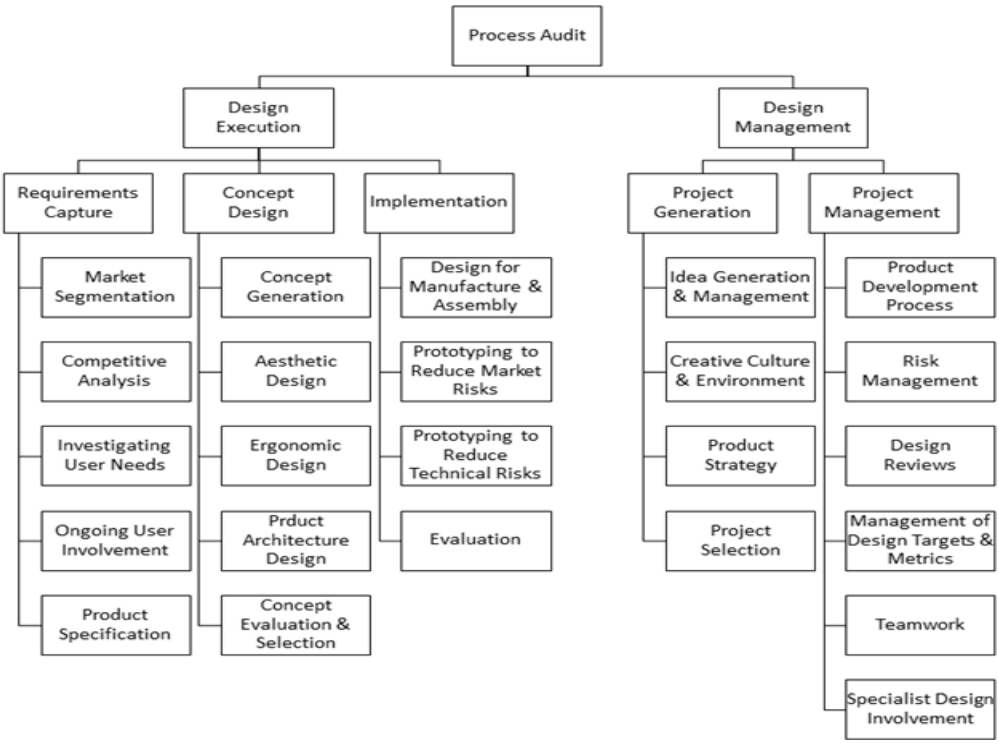
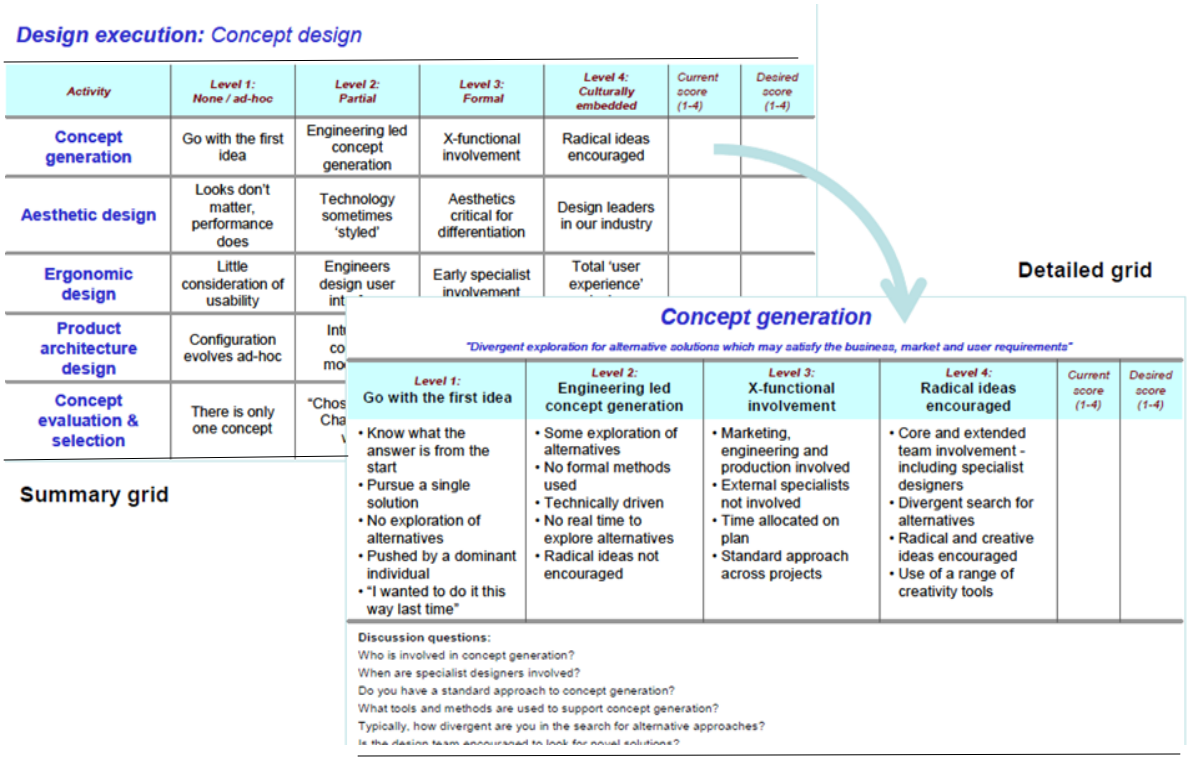


Figure 2. Design process audit categories from Moultrie and Fraser (2004)



Design execution: *Concept design*

Activity	Level 1: None / ad-hoc	Level 2: Partial	Level 3: Formal	Level 4: Culturally embedded	Current score (1-4)	Desired score (1-4)
Concept generation	Go with the first idea	Engineering led concept generation	X-functional involvement	Radical ideas encouraged		
Aesthetic design	Looks don't matter, performance does	Technology sometimes 'styled'	Aesthetics critical for differentiation	Design leaders in our industry		
Ergonomic design	Little consideration of usability	Engineers design user	Early specialist involvement	Total 'user experience'		
Product architecture design	Configuration evolves ad-hoc					
Concept evaluation & selection	There is only one concept					

Summary grid

Detailed grid

Concept generation

"Divergent exploration for alternative solutions which may satisfy the business, market and user requirements"

Level 1: Go with the first idea	Level 2: Engineering led concept generation	Level 3: X-functional involvement	Level 4: Radical ideas encouraged	Current score (1-4)	Desired score (1-4)
• Know what the answer is from the start • Pursue a single solution • No exploration of alternatives • Pushed by a dominant individual • "I wanted to do it this way last time"	• Some exploration of alternatives • No formal methods used • Technically driven • No real time to explore alternatives • Radical ideas not encouraged	• Marketing, engineering and production involved • External specialists not involved • Time allocated on plan • Standard approach across projects	• Core and extended team involvement - including specialist designers • Divergent search for alternatives • Radical and creative ideas encouraged • Use of a range of creativity tools		

Discussion questions:
Who is involved in concept generation?
When are specialist designers involved?
Do you have a standard approach to concept generation?
What tools and methods are used to support concept generation?
Typically, how divergent are you in the search for alternative approaches?

Figure 3. Design process audit scoring (detailed and summary grids) from Moultrie and Fraser (2004)

Companies were contacted by telephone and preliminary screening produced 16 companies who claimed to carry out original product design. The final screening stage separated the companies who merely made this claim from the ones who are actually actively involved in the practice. To achieve this, a questionnaire

was developed and disseminated to the 16 companies. The responses received were discussed during interviews with the respondents. The qualitative nature and "product design depth" of the questionnaire and discussions held during interviews allowed for the identification of the companies that are in fact engaged in original design practice.

Out of the 16 companies solicited, nine (9) companies responded, of which three (3) responses were usable for the study. The overall response rate was therefore 56.25% (9/16) and the effective response rate was 18.75% (3/16). Table 1 gives summary details about the company solicitations and final selection.

The questionnaires and subsequent interviews used for final screening also gathered data on the respective company's design activities and experiences (Yin, 2003, Robson, 2016). This data was collected in four segments:

1) *Design Process* - In addition to mapping the design process used within the companies, data on the personnel involved and their qualifications was collected along with any resources used for designing (e.g. Equipment, Software and Information Sources). Participants were also asked to describe any improvements that can be made to their design activities, the subsequent results expected and requirements to make these improvements.
2) *Designed Products* - This section examined what factors were considered by the company when assessing the design quality of products and whether the company has been able to attain unique product designs using their respective design process.
3) *Design Environment* - A PESTLE analysis was used to gather information on the environmental forces that affect the business of product design. Financial investments and budgetary allocations toward product design were also investigated.
4) *Current and Future Design Projects* - This section dealt with the willingness to collaborate with tertiary level institutions for ongoing company design projects and the value adding expertise expected from such institutions.

4. Results

4.1 Design Process

None of the three companies were found to have any established protocols for executing or managing design activities. It was found that the discussions held were the first time any thought was being put into this matter. An overall design process and its activities were hence deduced from enquiring about how new product ideas were obtained and their transformations into manufacturable products.

The industry's design process activities were found to be quite similar across the three companies shown in Table 2. The design process involved Ideation, Conceptual Design, Prototyping, Testing and Production. Emphasis is placed on prototyping and testing concepts very early during design projects. This is done to determine product specifications since enhancements are made to the concept after each iteration until a satisfactory design is attained.

It was found that no formal engineering design or market analytical skills resided in any of the companies interviewed. Usually, a director or owner with 20-30 years manufacturing experience and a draughtsman, with primary drawing software certifications (mainly AutoCAD) are involved in design activities. Occasional feedback is sought from shop floor employees.

Table 1. Participant Company Solicitation results

Status	Declined to Participate	No Response	Non-Usable Responses	Usable Responses
No. of Companies	3/16	4\16	6/16	3/16
Details	- Information is too sensitive to divulge. - Respondents too busy. - Study not beneficial to the company.	- No response after receiving the questionnaire.	- Clients provide design specifications. - Information provided about the construction environment. - Information required was not part of daily operations. - Design is done by foreign entities.	**Company 1:** Concrete Products. [Blue] **Company 2:** Construction and Building Materials. [Green] **Company 3:** Wood and Wood related. [Black]

Table 2. Industry Design Process Activity Descriptions

Design Activity	Description
Ideation	Ideas for new products are gained from attending international trade shows, observing competitors and internet articles.
Conceptual Design	Hand sketches are prepared. Usually one concept is generated and developed along the process. Evaluation factors: Product Functions, Aesthetics, Structural Integrity, Producibility and Profitability
Prototyping	Prototypes are made in-house using typical manufacturing equipment. Designs may be altered here to resolve any construction issues.
Testing	Prototypes are tested in-house or sent to external entities for structural testing.
Production	Once testing is complete, the product is marketed and mass produced for sale.

During the "Ideation" phase, companies source new product ideas from international tradeshows and competitors, then alter aspects of existing designs to suit market buying preferences. The absence of engineering design expertise during the design project revealed that standard design methods were unheard of and not used for making design decisions. Instead, decisions are made based on the experience and gut feelings of the individuals involved.

Participants reported the method of designing products for around 50 years and were able to attain unique products and ideas. Any specific engineering expertise required is sourced externally and mainly serves as a validation of the product designed. Companies reported to invest $30,000 to $500,000 (TT dollars) annually in product design projects, from which approximately half is allocated to procuring design expertise and the remaining half used for prototyping and testing.

4.2 Designed Products

Participants reported that they were able to attain product designs that were unique to their respective companies. Unique, in this sense, meant that these designs have different aesthetics and product life spans from competitors. Design quality is assessed in terms of the design's producibility, product functions and structural integrity. This assessment is usually done during testing and comparing with similar competitor products.

4.3 Design Environment

With respect to challenges being faced within the larger environment, participant companies described the following:

1) *Political*: Participants expressed concerns for the level of corruption and nepotism they say exists in the country's political system. They explained, for example, inefficient products are purchased from other companies as a means of repaying political favours. This happens despite having proposed newly designed products that would achieve better outcomes at reduced material costs for numerous government projects. They also mentioned that the product design practice itself is not genuinely supported by government. This position was taken due to the lack of a national policy or ministerial body, to their knowledge, to guide businesses in their design activities. The same was said for design incentives.
2) *Economic*: Profitability is problematic given the current high cost of design mainly due to numerous prototype reiterations and accessing design expertise. Participants reported that they do not know of any support systems, from any entity, that can assist with lowering these costs and reducing time to market periods. The country's current unfavourable economic situation has made conducting business more challenging, even with the increased need for local solutions. Unfortunately, locally designed products are far less competitive when compared to cheaper imports that are heavily incentivised. A swift culture change to a more informed and rational one would be required to set the country's current economic state on a path to resolution.
3) *Social/Cultural*: Participants were of the view that the local product design culture is not as vibrant as it should be or at least not heading in any successful direction. From their experiences, consumers prefer to use traditional products and methods, even though they may be less efficient. As such, any proactive developments created are generally not appreciated or financially rewarding. This, participants said, contributed to the current creativity-deficient population as there are not many people in the "design-manufacture-market" business. This culture thrived under the current failed "fossil fuel-overdependent" economy from which recovery is slow since Oil and Gas revenues may not ever be the same. Respondents also believed that the design engineering education being taught in institutions does not practically address the issues facing SME's. Most graduates are not capable for hire, in their opinion, since the solutions proposed are not practically achievable or profitable.
4) *Technology*: It was found that respondents were limited in their active knowledge and use of design technologies. According to them, although these technologies are accessible, the hardware and its required skills are too expensive to justify the investments.
5) *Legal*: The companies surveyed reported that some of their designed products are unique and patentable. However, local patenting procedures are too long, expensive and at times, corrupted. Even judicial processes, respondents say, are quite inefficient and outdated when it comes to dealing with intellectual property issues. For these reasons, respondents would prefer to patent and license their inventions abroad (mainly the United States), where these issues are more seriously addressed.
6) *Environmental*: Participants are aware of using eco-friendly materials in their products, however, using these materials would result in a higher product cost since they are not readily available. Also, the skills necessary to use these materials, like engineering and manufacturing, do not reside in the company. Participants also mentioned that the current local culture is not environmentally conscious enough to even venture into such avenues.

In treating with these issues, companies currently outsource necessary skills and seek new product

inspirations from international tradeshows and symposiums. Participants have indicated that there is little they can individually do to effect any meaningful change with the above issues that are negatively affecting the local design environment. They have suggested that these issues be culturally addressed in homes and educational systems, particularly at the tertiary level. In a national sense, political entities need to consult with industry to produce and effect meaningful policies and regulations that foster diversified product creations.

4.4 Current and Future Design Projects

Participants have indicated that they are willing to work with educational entities to improve any industry situation, and have done so in the past, but they have yet to realise any material benefit. Prototyping and technical insights were pinpointed as the main expectations from current and future collaborations.

4.5 Product and Process Audits

After interviewing participants, product and process audits, as outlined by Moultrie and Fraser (2004), were conducted at the respective participant's design locations. The results of these audits are presented in the following sections.

4.5.1 Product Audits

From each company, one product was selected and audited. The selected products, according to participants, were designed in-house and were unique to the respective company. The summarised results of the product audits are shown in Table 3. Current Performance vs. Importance to Customers was then plotted as shown in Figure 4. From this, the Product Design Performances of each product were identified and are shown in Table 4.

Excess design performances in the areas of "Benefits" and "Engineering Quality" were seen for Company 1 because the product audited was overdesigned for its function. These results show that product design specifications were not properly determined, a symptom of not involving engineering design expertise and/or conducting adequate market requirements research. It was later confirmed that the owner alone designed this product using his experience and thought that the product's exceptional performance during testing was a sign of good design. The product also scored low "Profitability" ratings due to a high material cost to produce the item (it was being sold at a low profit margin to be competitive).

Low usability scores were attained due to unconventional product installation procedures and troublesome in-service product maintenance. This suggests that product testing results did not include feedback from intended users. Products with low "Desirability" performances were noted to be similar to the company's other products and did not cater for the personal expectations of users. Participants stated that "Novelty" was considered during the design of the products audited and that industry experiences were used to evaluate this feature. However, the results of the product audits show either excess or low novelty performance. Excess novelty can result in a lot of marketing required to sensitise consumers about the product whereas low novelty could result in the product being easily copied or overlooked by alternatives.

Table 3. Product Audit Summary Results [Company 1 - blue, Company 2 - green, Company 3 – black]

Product performance

Issue	Poor performance	Score (1-4)				Great performance			
Producibility	Overall poor producibility	1	2	3	4	Overall good producibility	2.4	2.3	2
Profitability	Overall poor profitability	1	2	3	4	Overall good profitability	1.4	2	1.8
Benefits	Overall few real benefits	1	2	3	4	Overall significant benefits	2.75	2	1.75
Engineering quality	Overall poor engineering quality	1	2	3	4	Overall great engineering quality	3.25	2.75	2.5
Usability	Overall poor usability	1	2	3	4	Overall highly usable	1.6	1.8	2.3
Desirability	Overall low desirability	1	2	3	4	Overall highly desirable	1.5	2.2	2.6
Novelty	Overall little novelty	1	2	3	4	Overall highly novel	2.2	1.8	2

Importance to customers

Issue	Poor performance	Score (1-4)				Great performance			
Benefits	Overall few real benefits	1	2	3	4	Overall significant benefits	1.5	2	1.5
Engineering quality	Overall poor engineering quality	1	2	3	4	Overall great engineering quality	2	3	2.5
Usability	Usability not important	1	2	3	4	Usability highly important	3.5	3	3
Desirability	Desirability not important	1	2	3	4	Desirability highly important	3.5	4	2.5
Novelty	Novelty not important	1	2	3	4	Novelty highly important	1	3.5	3.5

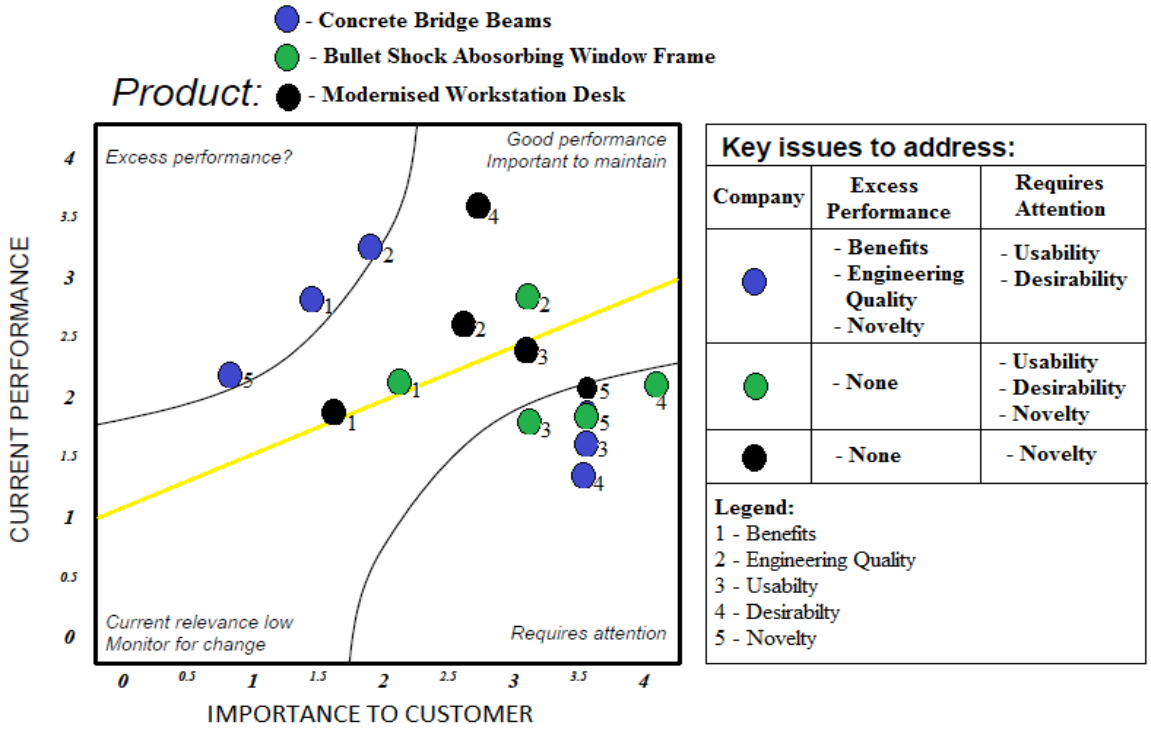


Figure 4. Product Performance vs. Importance to Customer

Table 4. Product Design Performance

Participant	Design Issue Performance		
	Excess	Good	Low
Company #1	Core Benefits	None	Usability
	Engineering Quality		Desirability
	Novelty		
Company #2	None	Core Benefits	Usability
		Engineering Quality	Desirability
			Novelty
Company #3	None	Core Benefits	Novelty
		Engineering Quality	
		Usability	
		Desirability	

Good product design ratings attained served to not discredit the design decisions made based on the participants' experiences. However, participants admitted to not having considered these issues as comprehensively in relation to how the issues were being audited since they simply reused features from other successful products.

4.5.2 Process Audits

For this aspect of data collection, ongoing product design projects were observed in addition to further discussing the design process relayed in the questionnaire stage. Company representatives explained prior actions leading up to the project's current status as well as future design intentions. Any design documentation available was reviewed (mainly sketches) to get a better understanding of the design project being undertaken. This information was collectively used to rate the respective Design Execution and Management activities of the process audit. The audit summary results are presented in Tables 5 and 6, respectively.

The process audit results highlight several deficiencies in the execution and management of design projects. These deficiencies confirmed the reasons for the undesirable design performances attained during the product audits. For instance, companies were found to be weak in conducting market research for the purpose of capturing design requirements. The marketing staffs' roles were mainly aligned with advertising and sales support. As such, specifications are set by the persons involved, based on experience, and are later changed based on prototype testing results. Intended product users are hardly involved in design projects.

No concept generation methods were being used resulting in usually one concept being generated and enhanced along the project. This makes concept evaluation and selection either a biased or non-existent decision. Designs are produced with some manufacturing and assembly considerations. However, these aspects do not carry much decision-making weight during the project and are dealt with in more detail after the design is complete. As discovered earlier, no formal

design process was established in any of the companies. Creativity, project generation and selection rested mainly with the business owners who used no methods, aside from industry experience and common sense, to manage or conceptualise generated ideas.

Table 5. Process Audit Summary Results - Design Execution

Area	Activity	Current performance (Scores & consensus) Level 1	Level 2	Level 3	Level 4
Requirements capture	Market segmentation				
	Competitive analysis				
	Investigating user needs				
	Ongoing user involvement				
	Product specification				
Concept design	Concept generation				
	Aesthetic design				
	Ergonomic design				
	Product architecture design				
	Concept evaluation and selection				
Implementation	Design for manufacture & assembly				
	Prototyping to reduce market risks				
	Prototyping to reduce technical risks				
	Evaluation				

Table 6. Process Audit Summary Results - Design Management

Area	Activity	Current performance (individual scores & consensus) Level 1	Level 2	Level 3	Level 4
Project generation	Idea generation & management				
	Creative culture & environment				
	Product strategy				
	Project selection				
Project management	Product development process				
	Risk management				
	Design reviews				
	Design targets & metrics				
	Teamwork				
	Specialist design involvement				

5. Discussion and Recommendations

5.1 Design Education

A major problem affecting the design practice is the lack of, or an appreciation for, product design knowledge in the industry, especially among SME owners/management. Product design workshops seeking to generate awareness and appreciation for what "good product design" entails with its associated benefits might be useful. Market data collection and interpretation methods, design process execution and management as well as design methods for key design process stages would be useful focus areas for these workshops. These elements would serve to assist business owners with engaging the market for possible product innovations and then convey these ideas constructively to design personnel.

It was noted that SME owners could not afford to hire and retain full-time experienced design engineers. However, engineering technicians with design proficiencies (design technicians) may be a suitable alternative. Technical institutes could incorporate relevant design theories and technological practical training courses into their programme deliverables to provide these skills. Innovation and Entrepreneurship education would also compliment design competencies to produce well-rounded individuals capable of developing effective and profitable solutions.

5.2 Training in Industry Product and Process Audits

Participants in this study responded well to the proceedings of the product and process audits conducted. Though many aspects of good product design were not being performed, participants were able to grasp the general idea of what was required and were able to give examples of how they could perform these actions as well as the perceived benefits. The audits also provide a means to benchmark design capabilities, as demonstrated in this project, and should now be used to track the improvements of the product design practice alongside companies.

5.3 New Product Development Incentives and Partnerships

In an effort to encourage business owners to pursue new product development projects, relevant governmental entities should consider incentivising beneficial aspects of the design trade. For instance, tax exemptions can be granted to help with the purchasing of prototyping equipment or modelling software. Companies that already owned these technologies can also be encouraged to enter into arrangements with individual entrepreneurs to combine resources to materialise and market innovative product ideas.

5.4 Company Cataloguing by Product Types

Finding participants for this study was somewhat challenging since no database of product design companies existed. The TTMA's membership directory was useful in finding study participants but required multiple screening phases against several criteria. Overlapping of different company categories was encountered for the same product types. For example, some companies were replicated under both "Construction and Building Materials" and "Concrete Products" when the company produces concrete building blocks. Cataloguing company data by product type rather than company category is a more efficient way to collate and present this information. GS1 presents a comprehensive list of standardised Global Product Classifications for such a purpose (GS1, 2017). Formulating a database using these standards would aid in finding appropriate participants for future industry research activities.

5.5 Product Design in other Manufacturing Sectors

This scope of this research was restricted to companies that design and manufacture products that possess electrical and/or mechanical properties. However, the research methodology in this paper can also be utilised to investigate product design practices in other manufacturing sectors with adjustments of the audit to take into account the type of products being audited.

6. Conclusion

The research findings present some evidence that electro-mechanical product design capabilities are relatively poor within SME's in Trinidad and Tobago. Companies not being able to afford full-time product design expertise and formal design skills not being appreciated by business owners seem to be the main reasons. Product design was found to be carried out by the business owners themselves who do not possess any design skills or training aside from their relevant industry experiences.

It was found that companies were incapable of conducting and analysing market research for the purposes of identifying avenues for product innovations and determining effective product requirements. Design decisions are made based on gut feelings and experience rather than through any design method or evaluations. Altering foreign product designs to suit local market purchasing behaviours is widely practiced. In order to improve this situation, much work remains to be done in terms of educating business owners on how to design new products, how to carry out process and product audits, and how Government and Tertiary Institutions could assist in making the product development process easier.

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References:

Black, C. D. and Baker, M.J. (1987), "Success through design", *Design Studies*, Vol.8, pp.207-216.

Chowdary, B.V. (2009), "A study on integrated manufacturing technologies in the Caribbean manufacturing firms", *West Indian Journal of Engineering*, Vol.31, pp.36-53.

Clarkson, J. and Ekert, C. (2005), *Design Process Improvement: A Review of Current Practice*, Springer Verlag, London.

Eppinger, S.D. and Ulrich, K.T. (2007), *Product Design and Development*, 4th Edition, McGraw-Hill.

Gorb, P. and Dumas, A. (1987), "Silent design", *Design Studies*, Vol.8, pp.150-156.

GS1 (2017), *Global Product Classification (GPC)*, The Global Language of Business, June 2017 [Online]. Available: https://www.gs1.org/gpc.

Hertenstein, J.H., Platt, M.B. and Brown, D.R. (2001), "Valuing design: Enhancing corporate performance through design effectiveness", *Design Management Journal*, Vol.12, pp.10-19.

King, G.S. and Cameron, C.R. (2013), "An enhanced model for university-industry collaboration for innovation in Trinidad and Tobago", *The West Indian Journal of Engineering*, Vol.36, pp.86-94.

MOF (2016), *Review of the Economy*, Ministry of Finance, Government of Trinidad and Tobago, Port-of-Spain.

Moody, S. (1980), "The role of industrial design in technological innovation", *Design Studies*, Vol.1, pp.329-339.

Moultrie, J. and Fraser, P. (2004), *Better Product Design: Assessing and Improving Product Design Capability*, Institute of Manufacturing, University of Cambridge, UK.

Mynot, C. (2000), "Successful product development: Key management issues", Paper presented at *the Successful Product Development Seminar*, The Imperial War Museum, Duxford, UK.

Otto, K. and Wood, K. (2000), *Product Design: Techniques in Reverse Engineering and New Product Development*, Prentice Hall.

Robson, C. and McCartan, K. (2016), *Real World Research*, John Wiley & Sons.

Sentence, A. and Clarke, J. (1997), *The Contribution of Design to the UK Economy*, Centre for Economic Forecasting, London Business School, London

Yin, R. (2003), *Applications of Case Study Research*, Sage Publication, Beverly Hills, USA.

Author's Biographical Notes:

Jeewan Ramkissoon *acquired a B.Sc. (Hons.) in Mechanical Engineering from The University of the West Indies (UWI.) in 2014 and a Technician's Diploma in Mechanical Engineering from The University of Trinidad and Tobago (UTT) in 2010. Subsequent to his technical and undergraduate studies, Mr. Ramkissoon has held positions as an Engineering/Operations Professional across multiple industrial sectors including; Energy, Manufacturing, Construction, and Food Processing. His post-graduate research interests surround the local design practice as it relates to innovation and entrepreneurial competencies for inspiring national economic diversification and hence sustainability.*

Umesh Persad *is an Assistant Professor in Design and Manufacturing at The University of Trinidad and Tobago. He obtained his BSc. in Mechanical Engineering (First Class) from The University of the West Indies, and his Ph.D. from The University of Cambridge in the area of Engineering Design, with a special focus on Inclusive Design.*

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A Rapid Post-Hurricane Building Damage Assessment Methodology using Satellite Imagery

Bheshem Ramlal[a,Ψ], Dexter Davis[b] and Kevern De Bellott[c]

Department of Geomatics Engineering and Land Management, Faculty of Engineering, The University of the West Indies, St. Augustine, Trinidad and Tobago, West Indies;

[a] E-mail: bheshem.ramlal@sta.uwi.edu;
[b] E-mail: dexter.davis@sta.uwi.edu:
[c] E-mail: kevernd@gmail.com

[Ψ] *Corresponding Author*

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Abstract: *In the immediate aftermath of a hurricane, rapid and reliable assessment of building damage is critical. The timely delivery of such information is essential for emergency responders to identify those areas that are severely impacted so that they can act accordingly. This step is crucial for saving lives and reducing economic losses. This paper demonstrates the potential of Remote Sensing for rapid building damage detection using an automated approach in small island states in the Caribbean. Object-Based and Pixel based methods were compared with visually identified reference information from high resolution imagery for the 2004 Hurricane Ivan impact on Grenada. The efficacy of the Object-Based approach is demonstrated using image segmentation and classification in eCognition Developer Software. This approach utilises not only the spectral content but also the context, morphological and textural properties of image objects. In relation to the reference data, the object-based method achieved over 85% classification accuracy among a three damages grade classification scheme in two separate scenarios with different study area extents.*

Keywords: *Hurricane Ivan, Rapid Assessment, Building Damage, Object-Based Classification*

1. Introduction

The Economic Commission for Latin America and the Caribbean (ECLAC) reports that the Caribbean has been impacted by more than 165 natural disasters since 1990, resulting in estimated losses of more than US$136 billion. With the likely increase in extreme natural disasters in years to come, especially in light of global climate change and sea level changes, Caribbean islands are increasingly challenged to give serious consideration to all matters relating to natural disasters (ECLAC, 2011). In the aftermath of natural disasters such as hurricanes or earthquakes, assessment is one of the first actions that usually take place. In this context, assessment refers to emergency response in which data is collected and analysed to get an impression of the extent and severity of damage and loss. These assessments must be done in a timely and accurate manner for effective response (Gusella, Adams and Bitelli, 2007).

Rapid detection and accurate assessment of damage and loss depend mainly on factors such as the quick identification of impacted areas, access to those impacted areas and efficient tools and techniques used to collect and analyse damage data. A higher priority is usually placed on assessing building damage, since these structures house the population and population represents lives that may be at risk (van Westen, 2013).

Traditionally, damage assessments have been conducted through ground-based field survey and aerial reconnaissance. These methods are not always safe, applicable, or cheap to execute (Kerle and Oppenheimer 2002). There is therefore a need for information, which does not depend on actual physical access to the disaster area. The objective of this paper is to develop a rapid post-hurricane building damage detection methodology to facilitate the timely acquisition of information to aid in post-disaster emergency response in Caribbean small island development states (SIDS).

2. Post Hurricane Damage Detection

Post-hurricane damage and loss assessments are conducted at various scales including: Global, Regional, National, City/Community and Building scale. There are several factors that influence what scale of assessment should be selected. van Westen (2013) suggests that these should be based on the objective of the assessment, the type of hazard and the operational scale whereby these hazard processes are set in motion and made manifest.

Building scale assessment provides the most amount of detail about damage and loss but is also the most time consuming. The assessment is carried out by local officials or certified engineers, and may require weeks to months to complete. The main outcomes are to determine an estimate of the recovery cost, structural

integrity of buildings and approval for demolition, retrofitting or permission for continued use of buildings (CDC, 2010).

A summary of the Disaster Management Cycle is shown in Figure 1. The response, recovery, mitigation and preparedness stages are depicted in relation to an event. Rapid assessments seek to take place early in the response stage to assist in emergency activities while detailed assessments can potentially provide valuable information for restoration and activities. Collecting and storing detailed damage information is important (Friedland, 2009). However, rapid assessment should take priority during the emergency phase of disaster. A rapid damage assessment functions to estimate the magnitude and nature of damage, and to evaluate building conditions in a swift manner in damaged areas after the impact of a hurricane (Massarra, 2012). It may be noted that, while rapid assessments are less time consuming and generates significantly more building data than detailed assessments, the levels of detail and accuracy of the data collected are reduced. Figure 2 shows the relative difference between the results of rapid and detailed assessments for data collection based on the number of buildings, the time taken to collect information per building, the level of details collected and the assessment accuracy achieved.

Figure 1. Disaster Management Cycle
Source: Abstracted from Quora (2018)

Data required in post-hurricane disaster management has an important spatial as well as a temporal element. Remote sensing combined with Geographic Information Systems (GIS) has proven to be of significant importance for the different phases of disaster management (Barrington et al., 2011; Vatsavai, 2011; van Westen and Hofstee, 2000; World Bank, 2010; CHARIM, 2016; Tu et al., 2016). Remotely sensed data may provide the most rapid post-disaster data. These data are particularly useful in disaster response, especially for severely impacted and inaccessible areas (Yamazaki, Vu, and Matsuoka, 2007).

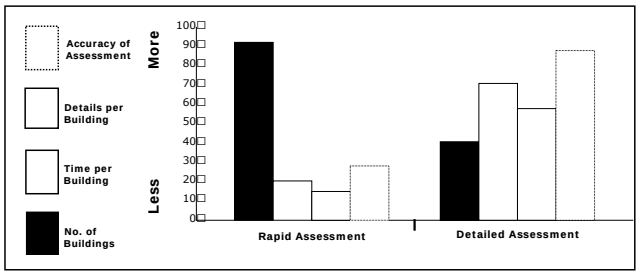


Figure 2. Comparison between rapid and detailed assessments using four measures
Source: Massarra (2012)

Additionally, comprehensive multi-temporal coverage of large areas in real time and at frequent intervals is the main advantage of using remotely sensed data in post-disaster management (Ozisik, 2004). Various qualitative and quantitative methods can be applied to remotely sensed data to assess the damage near real-time and after impact of the hurricane (Vatsavai, 2011). However, remote sensing methods also present several challenges when compared to traditional methods. Key challenges include spatial, temporal and spectral resolution of the data available. Friedland (2009) adds, a remotely sensed damage method must also be verified against ground-based data in order to provide meaningful results.

During the emergency response phase of disaster, emergency managers need to make crucial decisions that would affect the lives of the impacted population. They need to know the geographical extent of the disaster, the damage distribution, and information about the status of infrastructure and critical facilities (Lindell et al., 2006). Table 1 identifies the critical geospatial and non-geospatial baseline data required for rapid damage and preliminary loss assessment.

After hurricane impact, rapid information concerning damage to infrastructure and affected regions is crucial for immediate response in terms of relief efforts and situation reporting. Whatever the method of assessment selected, certain key information products must be generated: (i) general building damage maps; (ii) damage to critical facilities including hospitals, shelters, fire services, police, utilities, and prisons and government offices; and (iii) damage to transportation facilities such as roads, bridges, hubs, airports, and ports are critical

3. Damage Detection Approaches

Building and other infrastructural damage usually manifest themselves as disturbed spatial or spectral patterns, detectable using optical remote sensing methods.

Table 1. Baseline Data for Post-Hurricane Damage and Loss Assessment

Data type	Description
RS Data	May include variety of pre and post aerial and satellite imagery options but not limited to, HR optical images and multiband optical sensors such as IKONOS (1m), QuickBird (0.6m), Worldview1 (0.5m), SPOT 6&7 (1.5m), Landsat 7&8. Active sensor data options such as Radarast-2 (1-3m), LiDAR (0.25-2m), TerraSar-X (0.25-3m)
Buildings	Predominant type (e.g. residential, commercial, industrial) construction material, type of roof, building height, building age, total floor space, replacement costs, age of building or structure, photo.
Critical Facilities	General location and number of facilities, including but not limited to, Emergency Shelters, Schools, Hospitals, Fire Brigade Stations, Police Stations etc.
Population	Density, distribution in space (parish, community, enumeration district), age distribution, gender distribution, disabled, daytime population, nighttime population, people per building, single parent households, low income groups.
Transportation Facilities	General location of transportation facilities including, Roads, Railways Public Transportation Routes, Harbor Facilities, Airport Facilities. General traffic density information, classification (main road, minor road etc).
Life Lines	Location of detailed network of life lines facilities such as Water Supply, Waste Water, Electricity Supply and Communication.
Environmental Data	Location and status of environmental assets including Ecosystems, Protected areas, Natural Parks, Forests, Marine environment.
Economic Data	Spatial distribution of economic activities, type of economic activities.
Agricultural Data	By parish or community - Crop variety, crop yield, crop cycle, agricultural buildings, fiscal activities, rate of employment
Administrative Boundaries	Location, names, of Parish, Community, Districts.

Source: Adapted from Planning Institute of Jamaica (2012)

There are several different methods that involve manual and automatic building damage detection using high-resolution satellite images. However, selection of a particular method requires an understanding of the damage characteristics displayed, which depends on the damage mechanism. In some cases, detection methods may be similar despite the damage mechanism (wind, flood, and quakes). Damage from hurricane events is mainly direct wind damage, which results in significant roof and structural impact and may also be subject to significant water damage due to flooding.

3.1 Visual Analysis

Visual analysis of an image is a traditional method that uses visual interpretation to identify features and damage characteristics through vision and perception. This form of analysis is costly since it is labour intensive, tedious, time consuming and always subject to error; especially if low-resolution images are used. However, when applied to high spatial resolution imagery it yields the most accurate and detailed assessments (Olwig et al., 2007).

3.2 Pixel-Based Image Analysis

Pixel-based image classification uses spectral data to classify the image by considering the spectral correspondence in distinct classes (Gao and Mas, 2008; Kim and Shan, 2007). Pixel based supervised classification can easily discern distinct spectral classes including water, buildings, trees, and bare land. However, high spectral variation within the same land cover class and the low spectral variation between different land cover types, make the classification difficult. Hay and Castilla (2006) argue that "traditional pixel-based image analysis is limited because image pixels are not true geographical objects and the pixel topology is limited, and pixel based image analysis largely neglects the spatial photo-interpretive elements such as texture, context, and shape."

3.3 Object-Based Image Analysis

Object-based techniques have been developed as an alternative to manual digitisation through visual assessment and pixel-based methods (Laliberte, Rango, and Fredrickson, 2005). Land cover types including buildings, roads and parking lots have very similar spectral signatures and thus it is difficult to separate buildings through spectral analysis of high resolution images (Salehi et al., 2012).

Object-based image analysis (OBIA) allows the analyst to decompose the scene into many relatively homogenous, continuous, and contiguous image objects or segmentation. Three (3) main approaches to segmentation include thresholding, edge-based methods and region-based methods. Research has focused on multi-source classification which incorporates ancillary data including LiDAR, DEMs and vector data (Watanachaturaporn, Arora, and Varshney, 2008; Zhang, 2010; Tuia et al., 2010). As a result, there is reduced mis-registration between different objects/layers in the scene. Multi-source classification however, may be problematic due to the lack of co-registration of layers.

OBIA was used to classify building damage from post-hurricane image by developing rule sets to detect damaged building feature values and thresholds that indicate their various levels of damage. The first step is a multi-resolution segmentation, which groups areas of similar pixel values into objects. Subsequent refinements exploit the content (scale), context (shadow and contrast) and morphological (shape) image object information. To do this, a hierarchical rule-set framework was executed

in eCognition® Developer software using Cognition Network Language (CNL) (Definiens, 2009). Rule-sets for automated damage indication and change detection are coded in CNL, which presents a modular programming background for image-object management. Rule-sets were developed using a subset of QuickBird imagery as input. Then, algorithms to be executed on an image object domain (buildings) were defined and combined with different rule-set development parameters in an iterative manner until a satisfactory result was achieved (see Figure 3).

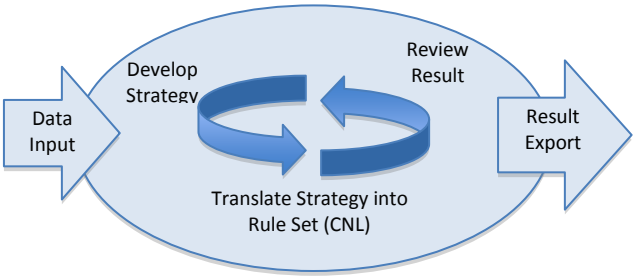
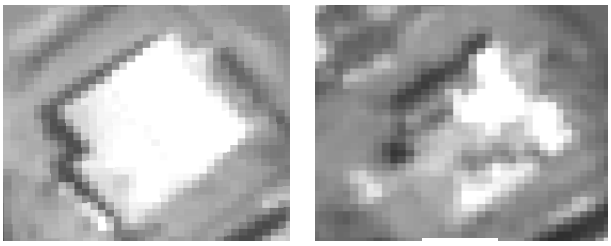


Figure 3. Rule-set Development Process
Source: Adapted from Definiens (2009)

Damage assessments may include both exterior and in-house components. However, the main focus is the assessment of the building's roof to classify damage. Unlike earthquakes and other phenomena, hurricane damage is unique. The damage characteristics are mainly roof and structural wind force damage and sometimes coupled with flood damages as well. In this context, damage classes therefore depend heavily on the textural and spectral distinction in the post-event image. Damage grade was therefore selected based on key damage cues detected in the post-hurricane image (Brunner, Lemoine, and Bruzzone, 2010). Figure 4 shows the textural, spectral and morphological properties of damage.

The output of the remote sensing image analysis is the detection of damage in the form of a damage classification map.



(a) (b)

Figure 4. Textural, Spectral and Morphological Properties of Damage (a) Intact roof characteristics, (b) damaged roof characteristics

4. Methods and Procedures

4.1 Study Area

The State of Grenada is located between latitudes 11°59´ and 12°20´ North and longitudes 61°36´ and 61°48´ West (see Figure 5). The main island, Grenada, is 18 km (11 miles) wide, 34 km (21 miles) long with an area of 312 square km (121 sq. miles) (OECS 2004). Grenada is located on the southern end of the hurricane belt. Over the past century, three devastating hurricanes had hit the island, in addition to numerous tropical storms and hurricanes that passed north of the island (World Bank 2005). The study area is located in the parish of St. George, situated on the southwestern portion of the main island. St. George parish is approximately 65 km2 with a population of 36,823; which accounts for about 36 % of the total population of the country.

Hurricane Ivan struck Grenada on the 7th of September 2004. The hurricane was classified as a Category 3 hurricane on the Saffir-Simpson scale with sustained winds of 193 Km/h (120 mph) and gusts of up to 233 Km/h (145 mph) as it passed over the island, lasting for about six hours (OECS 2004). Thirty-nine people died and most of the population of Grenada was affected. Damage from flooding and mudslides was not extensive since the hurricane did not produce heavy rainfall (World Bank, 2005). Approximately 90% of the houses were damaged or destroyed amounting to economic losses of approximately EC $1,381M. Total direct and indirect losses from all sectors of the economy amounted to EC $2,389.6M (CDERA, 2005). The other hurricanes of this magnitude to impact Grenada were Hurricanes Janet in 1955 and Flora in 1963.

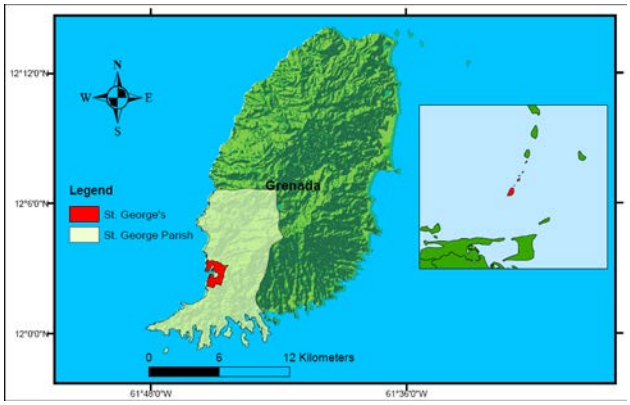


Figure 5. Map of Study Area

4.2 Data Used

Data used in this research is divided into three (3) main types: remotely sensed imagery, GIS data and ancillary data. Two archived QuickBird satellite scenes captured on April 26th 2003 and September 19th 2004 (pre and post hurricane Ivan) were acquired. Each epoch had both multispectral (MS) and panchromatic (PAN) scenes of

the study area. The pre-event scene was captured fifteen months before hurricane Ivan and the only available post-event scene, 11 days after impact. In order to exploit the high spatial resolution of the PAN image (0.6m), the MS image was pan-sharpened to the resolution of the PAN (see Figure 6).

Developing a pre-event inventory for assessing building loss involves obtaining geospatial and attribute information on building stock within the study area. Once building footprints were acquired, other pertinent attribute information were collected and added to the attribute database on a per-building basis. Information fields stored in the building attribute database were determined by reviewing literature (van Westen and Hofstee, 2000; Eguchi et al., 2008; Friedland, 2009; PIOJ, 2012).

Figure 6. Pan-sharpened QuickBird MS image in false color

4.3 Methods

A rapid post-hurricane damage detection and preliminary loss assessment methodology was developed to increase the delivery and efficiency of these assessments in disaster response for Caribbean countries. Three different damage detection methods are applied to multi-temporal images of St. Georges, Grenada, taken before and after Hurricane Ivan. They include Visual Interpretation/Analysis, Pixel-Based Image Analysis and Object-Based Image Analysis.

4.3.1 Visual Interpretation

Figure 7 shows the damage map overlaid on building footprints in the study area as a result of visual damage classification.

4.3.2 Pixel-Based Image Differencing

Figure 8 shows the image differencing result, processed using a change detection algorithm. Areas in red represent 'change pixels' above a determined threshold. The pixel-based analysis provides a quick, simple and relatively cheap method for damage detection. However, the main disadvantage of this technique is that it does not account for radiometric differences between images, such as atmospheric noise or haze. The image differencing result is binary (change/no change) and does not give an indication to the degree of change and therefore cannot be graded using visual and object based methods.

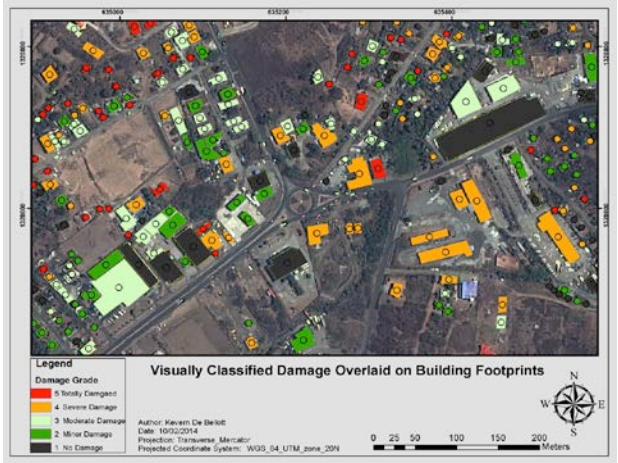


Figure 7. Visually interpreted Map Overlaid on Building Footprints

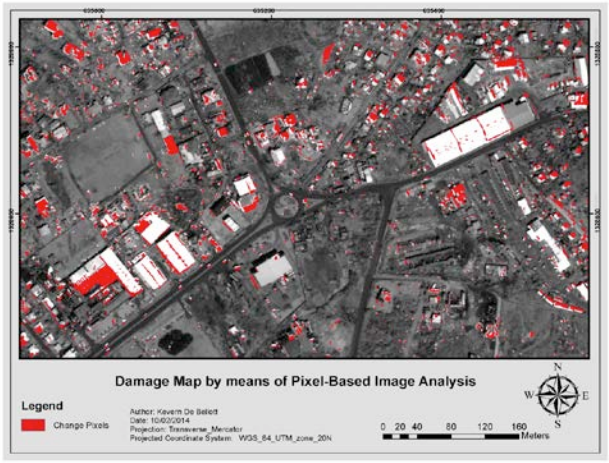


Figure 8. Image Difference Results

4.3.3 Object-Based Image Analysis

The OBIA procedure used is summarised in Figure 9. First, a multi-resolution segmentation of the 'Post Image,' is completed. This divides the image into a number of image objects or 'image object primitives' using spectral and shape criterion, thus minimising the average heterogeneity and maximising its homogeneity. Homogenous areas result in larger objects. Subsequent steps involve the identification of the appropriate feature values and thresholds then translating these into rule-sets in the eCognition image analysis software.

5. Strategy and Rule-set Development

5.1 For Grade 1 Damage

The strategy for classifying undamaged buildings (Grade 1) was based on the fact that spectral values for an undamaged building would be higher than a damaged one; an undamaged building will remain elevated; undamaged buildings cast a distinct shadow; and undamaged buildings maintain shape and smooth texture. This first round of classification also includes some moderately damaged buildings, since not all damaged buildings will collapse. However, it was a starting point prior to further refinement. Next, 'Class Related' context information (neighbor objects) was used to refine the undamaged building class. In this case, the rule-set must represent the situation where a 'building class' that has a low common border to a neighborhood object (shadow); that building should be classified as undamaged.

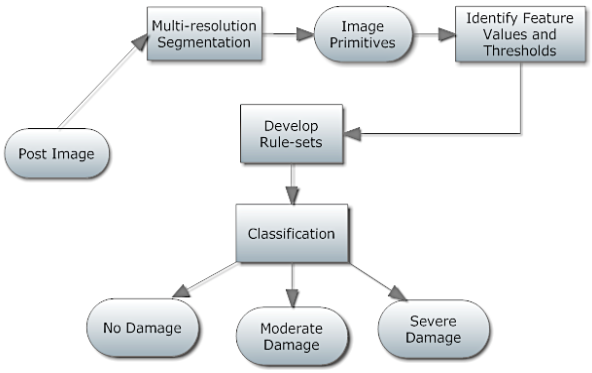


Figure 9. Summary of OBIA Approach

5.2 For Grade 2 Damage

The strategy for classifying moderately damaged buildings (Grade 2) was based on the following characteristics: spectral values for a moderately damaged building would be lower than an undamaged one; partially damaged buildings would have moderately contrasting neighbor objects; and partially damaged buildings' texture is moderately altered.

To translate these characteristics into rule-sets, threshold values were determined by visualising the range of spectral values for all building class objects, classified in the segmentation step. These threshold values were then used to assign a damage 'grade 2' to all buildings that satisfy these values. Initially, this step included buildings that belonged to 'damage grade 3' so the result needed to be refined to remove these from this class. To do this, a threshold for the standard deviation of sub-objects was determined (see Figure 10).

In this context, damage is detected by how different pixels are to one another within the extent of a classified building object. Severely damaged buildings exhibit a high standard deviation while moderately damaged buildings would have a lower value. Finally, objects were then refined using geometry/area criteria.

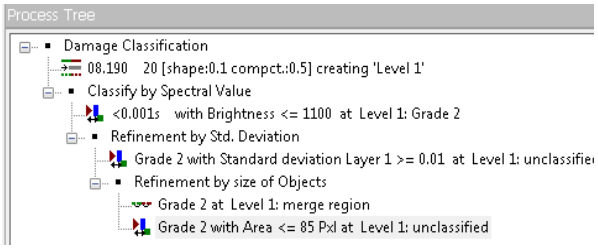


Figure 10. Process Tree with Rulesets for Damage Grade 2

5.3 For Grade 3 Damage

The strategy for classifying severely damaged buildings (Grade 3) was based on the following characteristics: spectral values for a severely damaged building would be very low compared to an undamaged or moderately damaged one; these buildings would have highly contrasting neighbor objects; severely damaged buildings' texture and geometry is heavily degraded; these buildings may also collapse and thus lack neighboring shadows; and additionally, some sampling was carried out to use as 'training sites' to help the classifier. Figure 11 presents the final damage classification map using the OBIA approach in eCognition Developer Software.

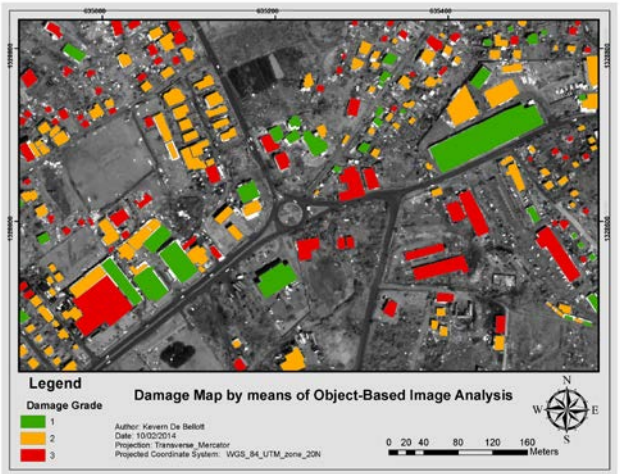


Figure 11. Damage Map by means of Object-Based Analysis

6. Accuracy Assessment of Methods

By using the information obtained through Visual Interpretation (VI) as reference data, relative accuracy percentages were calculated. Pixel-Based damage detection method had a relative accuracy of 98.5%

Table 2. Confusion Matrix of Object-Based Damage Classification

OBIA Classification Results	Damage Grade	Reference Data (Visual Interpretation) No. of Buildings				
		No Damage	Moderate Damage	Severe Damage	User's Acc. (%)	Comm. Error (%)
	No Damage	32	5	0	86.5 %	13.5%
	Moderate	9	101	11	83.5%	16.5%
	Severe	0	3	81	96.4%	3.6%
	Producer's Acc (%)	78.1%	92.7%	88.0%	----	----
	Omission Error (%)	21.9%	7.3%	12.0%	----	----
Overall Accuracy: 88.4%						

Table 3. Classification Error Matrix for Validation of Object-Based Method

OBIA Classification Results	Damage Grade	Reference Data (Word Bank Assessment) No. of Buildings				
		Grade 1	Grade 2	Grade 3	User's Acc. (%)	Comm. Error (%)
	Grade 1	483	67	4	87.2	12.8%
	Grade 2	86	2644	457	82.9	11.1
	Grade 3	7	344	6659	95	5
	Producer's Acc. (%)	83.85	86.5	93.5	----	----
	Omission Error (%)	16.15	13.5	6.5	----	----
Overall Accuracy: 86.1%						

(Number of Pixel-Based 'Damage' buildings/ VI 'Damage' buildings*100) and an over-classification of 3 buildings in the 'No Damage' class. Object-Based detection method produced an over-classification of 4 'Damage' buildings and 90.2% accuracy in the 'No Damage' class. Although these accuracy estimates are high, these may not be reflected on a building-to-building correlation. Table 2 presents the confusion matrix used to assess the accuracy of the Object-Based approach against the reference data provided by means of visual identification.

To validate the performance of the object-based classification result, the method was put under further scrutiny by expanding the study area. The expanded study area includes terrain that significantly varies in elevation, slope, vegetation cover and building density and is therefore more reflective of landscapes found on many other Caribbean islands. The reference data classification scheme (World Bank, 2004, 2005) was condensed from 6 to 3 classes (Grade 1 – Grade 3). This process is summarised as follows: 'Grade 1' consists of buildings categorised as 'No Damages' and 'Level 1'. 'Grade 2' consists of both 'Level 2' and 'Level 3' and 'Grade 3' comprise both 'Level 4' and 'Level 5' categories. Table 3 provides the Classification Error Matrix generated from expanding the analysis to the St. George's Parish level.

A total of 11,367 buildings were classified in the reference data. A total of 9,786 were correctly classified at the parish level, giving an overall accuracy of 86.1%. A minimum and maximum class accuracy of 82.9% and 95% respectively was achieved.

The classification result of the OBIA at the parish level was used to prepare a damage intensity map shown in Figure 12. A damage intensity map is a typical geospatial information product used to show the locations and intensity of damage across a large study area.

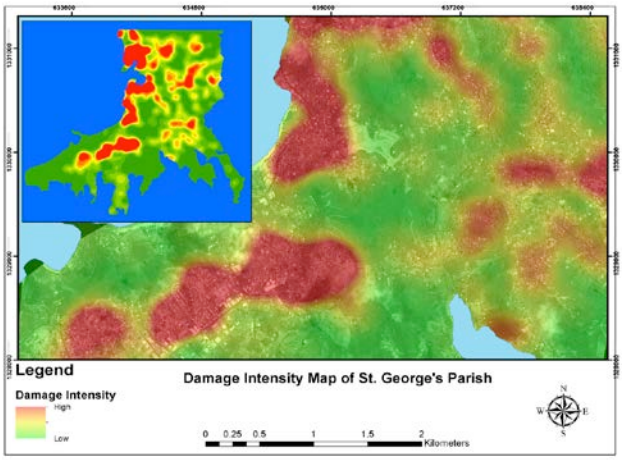


Figure 12. Map showing Damage Intensity across St. George's Parish

7. Discussion

In order to verify the reliability and accuracy of the processing outputs it was necessary to have a normalised format to evaluate on equal terms, hence the condensation of VI and Object-based classification into 'Damage/No Damage' for comparison with pixel-based image differencing. This binary scale classification revealed a high level of relative accuracy between the various methods to detect damage.

Compared to the reference data, which identified 201 buildings as damaged, Pixel-Based Image Differencing reproduced 98.51% (198 buildings) as damaged.

Although a high accuracy was achieved this may be misleading to some extent. This was also evident in object-based result which was compressed into a binary classification, indicating that all the buildings classified as damaged in the visual truth data were also classified as damaged in the object-based output with an excess of four buildings totaling to 205. This information was put in a more accurate context by generating the confusion matrix to verify the accuracy of the Object-Based classification scheme. Overall accuracy of the object-based classification was 88.4% with a minimum and maximum class performance of 83.5% and 96.4% respectively.

Many of the damaged buildings (Grades 2 and 3) were correctly identified but 'Undamaged' class had a high error of omission, which was not anticipated since that particular class seemingly had the strongest rule-set strategy in theory. However, the results were still within an acceptable error margin. The individual class accuracies establish the robustness of the object-based analysis method for damage detection. Reviewing the user's accuracy indicates the capacity to accurately detect undamaged and severely damaged (Grade 1 and Grade 3) buildings using the object-based method. This may be attributed to the fact that a robust rule-set strategy was achieved based on image object values and thresholds that were consistent with those particular damage grades. On the other hand, detection of moderately damaged buildings (Grade 2) was less accurate. Out of 121 buildings, 20 (16.5%) were classed incorrectly. Strengthening of the rule-set development strategy may help in reducing this margin of error.

One of the main difficulties with the object-based detection is the presence of false positives caused by the presence of debris in the immediate surroundings of buildings. In review of the rule-set development result for each individual damage grade, one can notice the difference in the segmentation of objects that comprise the class. Damage grade 1 has very compact outlines that fall mostly within the extent of the building footprint. However, for grade 2 and 3 the objects classified as damage extends beyond the extent of the building boundaries. These classified areas outside the bounds of the actual building are referred to as false positives. Clusters of debris can actually be mistaken for entire buildings. This effect however, did not affect the overall accuracy of the classification since the error matrix produced deals with buildings as objects and not pixels.

8. Conclusions

The overall aim was to develop a rapid post-hurricane building damage detection methodology in order to facilitate the timely dissemination of these information products to aid in post-disaster emergency response in small island states in the Caribbean. Several shortcomings still limit the application of remote sensing for rapid damage detection in the Caribbean. These are associated with the image acquisition time span, availability of cloud free images immediately after the event, and access to computer systems and software resources. Additionally, OBIA techniques require skilled and experienced personnel to develop and execute segmentation and classification rule-sets. Nonetheless, this methodology can be used to aid post-hurricane emergency responders and decision makers by providing quick and reliable information about the extent, location and intensity of building damage.

It was noted before that many Caribbean countries have mountainous terrains with steep slopes and dense vegetation that may limit the value of image analysis in rural areas. However, the focus here is on developed areas. It may also be observed that no single data acquisition technique is likely to address all the pre or post disaster data needs of a country. The strategy is to be able to draw one or more relevant methodologies from a suite of available options.

References:

Barrington, L., Ghosh, S., Greene, M., Har-Noy, S., Berger, J., Gill, S., Lin, Y-M.A. and Huyck, C. (2011), "Crowdsourcing earthquake damage assessment using remote sensing imagery," *Annals of Geophysics*, Vol.54, No.6, pp.680-687.

Brunner, D., Lemoine, G., and Bruzzone, L. (2010), "Earthquake damage assessment of buildings using VHR optical and SAR imagery", *IEEE Transactions on Geoscience and Remote Sensing*, Vol.48, No.5, pp.2403-2420.

CDC (2010), *Damage Assessment and Needs Analysis Plan*, Civil Defense Commission, Government of Guyana, available at: http://www.ifrc.org/docs/idrl/846EN.pdf, Accessed September 2017.

CDERA (2005), *Survey on the Status of Disaster Preparedness in Grenada*, Caribbean Disaster Emergency Response Agency, available at: http://siteresources.worldbank.org/EXTLACREGTOPNUT/Resources/4160377-1357590589927/8996498-1357590799892/8996560-1357606712727/CDERA_2005.pdf, Accessed September, 2017.

CHARIM (2016), "Section 9.4: Damage assessment using high resolution imagery/ Activation of International Charter on Space and Major Disasters for Post Disaster Relief and Response", *Caribbean Handbook on Risk Information Management*, http://charim.net/use/94, Accessed September, 2017.

Definiens AG (2009), *Definiens eCognition Developer 8 User Guide*, Definens AG, Munchen, Germany.

ECLAC, UN (2011), *Disaster Risk Reduction in the Education Sector among Selected Caribbean Small Island Developing States*, The United Nations Economic Commission for Latin America and the Caribbean, available at: https://www.cepal.org/en/publications/38676-disaster-risk-reduction-education-sector-among-selected-caribbean-small-island, Accessed September, 2017.

Eguchi, R.T., Huyck, C.K., Ghosh, S., and Adams, B.J. (2008), "The application of remote sensing technologies for disaster management", Proceedings of the 14th World Conference on Earthquake Engineering, Beijing, China, October 12-17, pp. 1-17

Friedland, C.J. (2009), "Residential building damage from hurricane storm surge: Proposed methodologies to describe, assess and model building damage", Louisiana State University. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwjJoXB6pvaAhUEmeAKHXEwC5sQFggnMAA&url=https%3A%2F%2Fdigitalcommons.lsu.edu%2F

cgi%2Fviewcontent.cgi%3Farticle%3D3896%26context%3Dgradschool_dissertations&usg=AOvVaw1FSCeNQx39QF_As1QSxj_G, Accessed September, 2017.

Gao, Y., and Mas, J.F. (2008), "A comparison of the performance of pixel based and object based classifications over images with various spatial resolutions", *Online Journal of Earth Sciences*, Vol.2, No.1, pp.27-35.

Gusella, L., Adams, B.J. and Bitelli, G. (2007), "The use of mobile mapping technology for post-disaster damage information collection and integration with remote sensing imagery", *The International archives of Photgrammetry, Remote sensing and Spatial Information Sciences*, Vol.34, Part XXX, pp.1-8.

Hay, G.J., and Castilla, G. (2006), "Object-based image analysis: Strengths, weaknesses, opportunities and threats (SWOT)", *ISPRS Archives*, Vol.XXXVI-4/C42, pp.1-4.

Kerle, N., and Oppenheimer, C. (2002), "Satellite remote sensing as a tool in lahar disaster management", *Disasters*, Vol.26, No.2, pp.140-160.

Kim, J.S., and Shan, J. (2007), *Hurricane Damage Assessment Using Remote Sensing Techniques: A Case Study in New Orleans*, available at: https://www.researchgate.net/profile/Jie_Shan/publication/265875141_Hurricane_Damage_Assessment_Using_Remote_Sensing_Techniques_-_A_Case_Study_in_New_Orleans/links/54f1e60c0cf2b36214ace5cb.pdf, Accessed September, 2017.

Laliberte, A.S., Rango, A., and Fredrickson, E.L. (2005), "Classification of arid rangelands using an object-oriented and multi-scale approach with quickbird imagery", *Proceedings of the ASPRS 2005 Annual Conference on 'Geospatial Goes Global: From Your Neighborhood to the Whole Planet'*, Baltimore, Maryland, March 7-11, pp.1-89.

Lindell, M.K., Perry, R.W., Prater, C., and Nicholson, W.C. (2006), *Fundamentals of Emergency Management*, available at: https://www.researchgate.net/publication/265494805_Fundamentals_of_ Emergency_Management, Accessed September, 2017.

Massarra, C.C. (2012), *Hurricane Damage Assessment Process for Residential Buildings*, Louisiana State University, available at: http://digitalcommons.lsu.edu/cgi/viewcontent.cgi?article=1519&context=gradschool_theses, Accessed September 2017.

OECS (2004), *Grenada: Macro-Socio-Economic Assessment of the Damages Caused by Hurricane Ivan*. Available at: http://www.gov.gd/egov/docs/reports/Ivan-Report-07-09-04.pdf, Accessed September, 2017.

Olwig, M.F., Sørensen, M.K., Rasmussen, M.S., Danielsen, F., Selvam, V., Hansen, L.B., Nyborg, L., Vestergaard, K.B., Parish, F., and Karunagaran, V.M. (2007), "Using remote sensing to assess the protective role of coastal woody vegetation against tsunami waves", *International Journal of Remote Sensing*, Vol. 28, Nos.13-14, pp.3153-3169.

Ozisik, D. (2004), *Post-earthquake Damage Assessment Using Satellite and Aerial Video Imagery*, available at: http://www.itc.nl/library/Papers_2004/msc/upla/derya_ozysik.pdf, Accessed September, 2017.

Quora (2018), What is disaster management cycle? Available at: https://www.quora.com/What-is-disaster-management-cycle, Accessed March 2018

PIOJ (2012), "A quick guide to undertaking an assessment using the DaLA methodology following an extreme event in Jamaica", In: *Socio-economic and Environmental Disaster Impact Assessment Handbook for Jamaica*, Planning Institute of Jamaica, Kingston.

Salehi, B., Zhang, Y., Zhong, M., and Dey, V. (2012), "Object-based classification of urban areas using VHR imagery and height points ancillary data", *Remote Sensing*, Vol.4, No.8, pp.2256-2276.

Tiede, D., Lang, S., Füreder, P., Hölbling, D., Hoffmann, C., and Zeil, P. (2011), "Automated damage indication for rapid geospatial reporting", *Photogrammetric Engineering and Remote Sensing*, Vol.77, No.9, pp.933-942.

Tu, J., Sui, H., Feng, W., and Song, Z (2016), "Automatic building damage detection method using high-resolution remote sensing images and 3D GIS model", *The ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol.III-8, pp.43-50 (https://doi.org/10.5194/isprs-annals-III-8-43-2016).

Tuia, D., Ratle, F., Pozdnoukhov, A., and Camps-Valls, G. (2010), "Multisource composite kernels for urban-image classification", *IEEE Geoscience and Remote Sensing Letters*, Vol.7, No.1, pp.88-92.

van Westen, C.J. (2013), "Remote sensing and GIS for natural hazards assessment and disaster risk management", In Schroder, J.F., and Bishop, M.P. (ed), R*emote Sensing and GIScience in Geomorphology*, Elsevier, San Diego, p.259-298

van Westen, C.J., and Hofstee, P. (2000), "The role of remote sensing and GIS in risk mapping and damage assessment for disasters in urban areas", *Fernerkundung und Naturkatastrophen*, Vol.7, pp.442-450.

Vatsavai, R., Tuttle, M., Bhaduri, B., Bright, E., Cheriyadat, A., Chandola, V. and Graesser, J. (2011), "Rapid damage assessment using high-resolution remote sensing imagery: Tools and techniques", Proceedings of the 2011 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), available at: http://ieeexplore.ieee.org/document/6049338/, Accessed September 2017.

Watanachaturaporn, P., Arora, M.K. and Varshney, P.K. (2008), "Multisource classification using support vector machines: an empirical comparison with decision tree and neural network classifiers", *Photogrammetric Engineering and Remote Sensing*, Vol.74, No.2, pp.239-246.

World Bank (2004), *Grenada: Preliminary Damage Assessment*, available at: http://siteresources.worldbank.org/INTDISMGMT/Resources/grenada_assessment.pdf, Accessed September, 2017.

World Bank (2005), *Grenada - A Nation Rebuilding: In An assessment of reconstruction and economic recovery one year after Hurricane Ivan*, Latin America and the Caribbean Hazard Risk Management Unit.

World Bank (2010), *Post-disaster building damage assessment using satellite and aerial imagery interpretation, field verification and modeling techniques, 2010 Haiti Earthquake*, Final Report #107, GFDRR and ImageCat, World Bank.

Yamazaki, F., Thuy Vu, T., and Matsuoka, M. (2007), "Context-based detection of post-disaster damaged buildings in urban areas from satellite images", Paper presented at the *Urban Remote Sensing Joint Event*, https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwjg0ae-gZzaAhWymuAKHd1oBQIQFggnMAA&url=http%3A%2F%2Fares.tu.chibau.jp%2F~papers%2Fpaper%2FUrban%25202007%2FUrban2007_Vu.pdf&usg=AOvVaw3YvmsYOIzX9VShPpstiQzD, Accessed September, 2017.

Zhang, J. (2010), "Multi-source remote sensing data fusion: Status and trends", *International Journal of Image and Data Fusion*, Vol.1, No.1, pp.5-24.

Authors' Biographical Notes:

Bheshem Ramlal *is Senior Lecturer in Geoinformatics, Cartography and Geomatics Engineering. His research is focused on data acquisition using remote sensing, data quality, standards and policy, and the design and implementation of Spatial Data Infrastructure in the Caribbean.*

Dexter Davis *is Lecturer in Geomatics Engineering. His research is focused on engineering surveying, digital photogrammetry and*

digital mapping, geodesy and geodetic applications, and GNSS and hydrographic surveying. Some of his current areas of research expertise include sea level monitoring and low cost and disaster relief mapping.

Kevern De Bellott *is a Geo-Information Consultant. He is a graduate of the MSc. Geoinformatics programme offered by the University of the West Indies, St. Augustine Campus. His research is focused on utilising Geoinfromatics for Disaster Management and development of rapid response systems for the purpose of saving lives and quickly assessing the impacts of natural disasters.*

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Assessment of Smart Buildings in the City of Port of Spain, Trinidad and Tobago: Some Findings and an Approach

Jeffrey Barsatie [a,Ψ], and Kit Fai Pun [b]

Faculty of Engineering, The University of the West Indies, St. Augustine, Trinidad and Tobago, West Indies;

[a]Email: j_barsatie@hotmail.com
[b]E-mail: KitFai.Pun@sta.uwi.edu

[Ψ] *Corresponding Author*

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Abstract: *This paper investigates into the levels of smart building (SB) designs, and reports the findings of a recent study on adopting a standalone versus integrated SB strategy in Trinidad and Tobago (T&T) namely the capital city of Port of Spain. It explains the need to initialising a SB Assessment approach and discusses how the approach could incorporate the SB elements into assessing building designs adopted in facilities management and construction sector. Incorporation of a review on various common SB strategies with related developments in T&T, a two-stage methodology comprising a questionnaire survey and a series of personal interviews, was employed to acquire views from building practitioners (including owners, developers, operators, and managers) in T&T. The analysis addressed multiple conditions of building strategies, and identified gaps between the design concepts and performance of SBs in T&T. The findings provided some empirical ground for deriving a five-step SB assessment approach, comprising 1) building governance, 2) defining SB, 3) deriving SB indices, 4) developing component/attributes index, and 5) mapping building design. The proposed SB assessment serves as a practitioners-oriented approach to assess SB solutions in T&T and a wider Caribbean region. Future study would validate the key elements identified for SB designs and strategies of varied residential purposes and commercial/operations nature.*

Keywords: *Smart Buildings, Design, Strategies, Assessment, Trinidad and Tobago*

1. Introduction

The Republic of Trinidad and Tobago (T&T) has had the construction boom in its fifty (50) years of independence, the first in the 1970s and then the 2000s. Many buildings have been constructed, such as the Eric Williams Financial Complex in 1986, the Waterfront Financial Centre, the Hyatt Regency Hotel, the Nicholas Towers, and the National Academy for the Performing Arts in 2009 (Barsatie, 2015). With these multi-million dollar projects, concerns were raised regarding the maintenance and after-life of such buildings over time. These buildings have been adopted some elements of smart building (SB) (or intelligent building (IB) technology either in part or as a whole. Many building owners and tenants also like the idea of 'green', but do not necessarily understand various components of a greener building (GBCTT, 2017). In T&T, there exists no national building standard to follow when venturing into SB or IB projects. The present Small Building Guide, TTS 599: 2006 is not suitable for large buildings, and has no information relevant to SB practices (Lalla 2011).

Although there are various rating methods for facilitating SB assessments (Chen, 2006; Ghaffarianhoseini et al., 2016), many building practitioners (including owners, developers, operators, and managers) pay little attentions to the functional variations amongst different types of buildings in T&T (Chen, 2006; Ragbir, 2014). The adoption of SB strategies would reside upon the architects, facility managers or building owners, and these strategies would either be implemented in the pre-design phase and/or post-construction of buildings (Villfana, 2014; Choy, 2014). Moreover, many practitioners would opt not to disclose the SB impact level of their building(s) with respect to any negative image on corporate and social responsibility. Some would even not be able to quantify the impact level of their building(s) (Burke and Ramsumair, 2014). This paper incorporates a review of common SB strategies, and presents the findings obtained from a recent study on the adoption of SB concepts in T&T. A 5-step SB Assessment approach is proposed, and an illustrated case is presented.

2. Notion of 'Smart' and 'Intelligent' Buildings

The terms, smart building (SB) and intelligent building (IB), are always used interchangeably. While the concept of SB (or IB) has been promoted since the late 1980s, on-going cost reductions in technology, broad deployment of networks and the development and widespread adoption of open standards for building system communications protocols have made these projects viable (Ehrlich and Diamond, 2009; Wang, 2010; Ghaffarianhoseini et al., 2016). Salsbury (2009) advocates that a building is made 'smart' through the application of intelligence or knowledge to automate the

operations of building systems, which involves the installation and use of advanced and integrated building technology systems.

Although there is no single, universal definition of a SB, there exists an agreement about some of the key elements of the concept (ITU, 2017). Sinopoli (2010) contends that SBs are built on standards which make several characteristics possible: 1) inter-application communication; 2) efficiencies and cost savings in materials, labour, and equipment, and 3) interoperable systems from different manufacturers. These systems include building automation, life safety, telecommunications, user systems and facility management systems. The Asian Institute of Intelligent Buildings (AIIB, 2017) adopted a rating method for assessment with indicators centring on architecture, engineering, environment, economics, management and sociology. The idea of combining information from different systems to implement new and smart strategies extends easily to system groups that traverse traditional boundaries. The general trend is for the operation of systems and appliances to be connected to a common network as depicted in Figure 1.

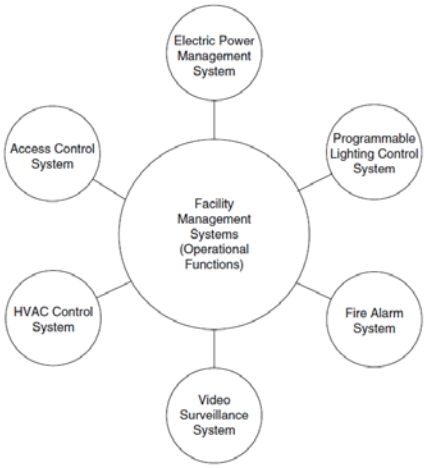

Figure 1: A Common network of SB Management System

SBs encompass a variety of technologies across various types of buildings, including commercial, residential and government buildings (Salsbury 2009). They are designed to leverage such systems as heating, ventilation and air-conditioning (HVAC), cabling, internet access, as well as access and security in the building. Building strategies are not only limited to the way a building has been made smarter, but also include planning, design, construction, commission operating and maintenance (Salsbury, 2009). A key part of the consensus is that SB strategies improve the productivity of people and processes in buildings for the improvement of the facility (Simens, 2013). Optimal building intelligence is the matching of solutions to occupant needs (So, Wong and Wong 1999). These buildings would maintain an effective working environment, run automatic systems and be flexible enough to adapt to future changes in the needs of the working environment (Barsatie, 2015).

3. A Two-Stage Stage SB Study in T&T

In 2015, an exploratory study was undertaken to investigate into the challenges associated with the current SB designs, and identify the factors affecting the SB adoption in T&T (Barsatie, 2015). A 2-stage methodology was employed, comprising a questionnaire survey and a series of personal interviews. Similar approach was adopted by researchers to define the sustainability assessment indicators and their weights in the sustainability assessment of large services buildings (hospitals) in Portugal (de Fátima Castro et al., 2017). For the survey stage, a sample technique advocated by Krejcie and Morgan (1970) was adopted, and a targeted sample of 40 respondents in facilities management and building designs and constructions were determined. The main goal of this purposive sampling was to focus within the capital city, Port of Spain, because of its developed infrastructure in T&T. A set of structured questionnaire was designed, and Likert-scale was employed to facilitate the analysis of findings. Questions being raised varied from number of years' experience in building management, types of systems employed at locations and perceived benefits of the building that were considered just to name a few. Administration and analysis of returned questionnaires was done via the means of Google Survey. For the conduct of personal interviews, a group of targeted building practitioners were invited. Profiling of the participants was undertaken in determining the population decision-making capability within respective organisations.

4. Stage-1 Survey Finding and Analysis

4.1 Response Rate and Respondents' Profile

Twenty (20) completed questionnaires were received, yielding a response rate of 50% from the targeted sample size. Because of the reduced dimension of the country, this targeted number represents a high percentage of the T&T facility management and building designers in T&T (Barsatie, 2015). The majority of respondents held mid-level decision-making ability in respective organisations. About 10% of the respondents held senior positions involved in decision-making in building design and associated operations, and another 40% outsourced the responsibility of management. From this, some 85% of respondents had been in control of at least one building for multi-site operations.

Approximately, 38 acres (or 1,668,700 square feet) of building space were included in the study of which many office buildings were once residential homes in the Port-of-Spain area. Most buildings fell under a range of 10,000 square feet, and the age of these buildings varied.

About 45% of buildings had been constructed over 10 years. Moreover, many respondents (70%) indicated that there had been upgrades of building undertaken over the last 10 years. The results showed that 55% stated fire alarm system followed by HVAC system at 40%. Video surveillance system and electric power management control totalled 35%. Data network 30%, access control system 25%, wireless system 20%, facility management system 20%, intrusion detections system 15%, uninterruptible power supply (UPS) system 10%, video distribution system 10%, audio visual system 10%, programmable lighting control system 10%, structured cable 5%, grounding system 5% and Voice over Internet (VoIP) 5%. However, usage of green technology (such as solar or wind) has been non-existent. Security, data networks and facilities management systems were seen to be important.

4.2 Identification of SB Performance Attributes, Benefits and Obstacles

While questioning how building practitioners/operators' ranked their performance attributes of building, the highest record, as seen in Figure 2, was environmental friendliness and safety of structure. Space utilisation and flexibility was second, followed by human comfort and management process and security. The remaining attributes (including health and sanitation or the life cycle costing) were of less attention among respondents. The findings also provided evidences that the adoption of SB designs had not been popularised in T&T.

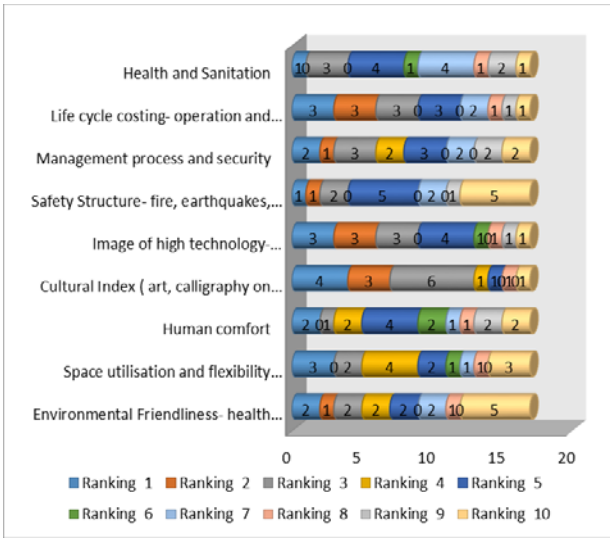

Figure 2: Respondents' Ranking of SB Attributes

Respondents were also asked to share views on a list of benefits from adopting SB strategies. An average of 2.15 responses per person was recorded. The result shows that a better working environment was perceived to be the highest benefit. A safer working environment was the second and financial savings was the third. Respondents shared multiple views on various obstacles preventing SB adoption. About 40% of respondents indicated that the organisation budget was the main reason for not implementing any smart strategies in their buildings. When comparing with the importance of the building and business continuity, only 5% of respondents regarded this to be high, while 15% found it to be low. The remaining 80% was distributed between the ranges of 1-9. From which, 25% was within the ranges 4-5, giving it a medium impact ranking. The results provided insights into the importance of SB adoption with respect to the business operations of respondents' organisations.

4.3 Ranking of SB Strategies

Respondents were asked to rank the importance of the strategies using a 100-point scale. Table 1 shows a breakdown of the ranking of respective strategies. In total, seventeen (17) respondents (i.e., 85%) shed their knowledge about the importance. Of the SB strategy categories, access control, HVAC, and fire alarm systems were noticed to be the most important elements. Computerised management systems (CMS), electrical power management, video surveillance and intrusion detections systems had between 6-9 respondents been acknowledged as a smart strategy used in their building. The results lend support that a few elements comprised as a strategy for a SB in T&T. As such, only 30% of respondents considered their buildings to be smart or intelligent. Most respondents (70%) shared that their SB strategies did not integrate with another building strategies. Some argued that costing implications for the concept of SB would always be an issue.

In identifying elements for a SB, half of respondents (50%) indicated that 'Green' building concept with design should be first and important. Twenty-five percent (25%) saw integration of building automation and software as the key. While asking respondents to share views on implementing SB strategies, an average response was 5.15 per person as more choices were allowed (see Table 2). Results show that safety and security are high as strategy, followed by fire protection, HAVC systems and CMS. Electrical management and building automation were of mid-level importance. Software analytic and green building concepts were ranked as a mid-level importance. Despite respondents recognised the need to integrate green technology with building design, only 30% of them claimed this as important.

5. Stage-2 Interviews Findings and Analysis

5.1. Practitioner's Ranking of SB Strategies

Interviews with nine (9) facilities managers, building owners and operators were conducted parallel to the distribution of the surveys. All interviewees had substantial work experience (20 years and more) in

building designs and management. Findings showed that HVAC systems, access control and fire alarms (safety and security systems) were amongst the common SB strategies, either as a stand-alone or as an integrated system. Other strategies (such as smart grids, usage of green materials, solar power, water management systems, and electrical power management) did not receive much attention (see Table 2).

5.2 Comments on 'Smart' Status of Buildings

While asking interviewees to comment on the 'smart' status of buildings in T&T, the answers varied with opinions. Four interviewees (some 45%) advocated that investments into SB have been made as it related to the use of the technology and modern features (such as HVAC or access control). However, other respondents argued that it would be unwise and difficult to regulate technology with respect to the current level of technology status and building intelligence in T&T. For them, technology such as solar panels, energy efficient grids, HVAC or water drainage systems was not seen as an integrated part of SB designs. Some further stated that the adoption of these system(s) would be attributable to the concern of corporate and social responsibility

Table 1: A Breakdown of the Ranking of Elements for SB Strategies

Elements for SB Strategies	**Ranking**										
	0	10	20	30	40	50	60	70	80	90	100
Data Network /| Information and Communication System	55%	25%				5%					
Structured Cable	70%	10%		5%							
Grounding System	75%			5%		5%					
Solar Power Technology	75%	10%									
Voice Over Internet (VoIP)	70%	5%			5%			5%			
Uninterruptible Power Supply System	65%	10%				5%		5%			
Video Distribution System	70%	5%	5%			5%					
Audio Visual System	60%	20%				5%					
Access Control System	25%	15%		15%	10%	5%	5%	5%			5%
Video Surveillance System	55%	5%			5%	5%	5%		5%	5%	
Intrusion Detections System	40%	10%			5%	10%	10%		5%	5%	
Wireless System	55%	15%	5%			5%		5%			
HVAC Management Control System	30%	10%		15%		10%	10%	5%		5%	
Electric Power Management Control	55%	5%			5%		5%	5%	5%	5%	
Programmable Lighting Control System	70%	15%									
Fire Alarm System	35%	5%	5%		20%			5%	5%		10%
Elevator Systems Controls	75%	5%						5%			
Facility Management System / CMS	45%	10%	5%	5%		10%	5%			5%	
Integration of Business System	70%		5%			10%					
Green Building Technology (e.g. Green roofing, facades)	70%	10%	5%								
Building Automation System (BAS)	75%				5%				5%		
Drainage System	75%		5%		5%						
Building Interior Layout	70%		10%			5%					
Water Management System	75%			5%				5%			

Table 2: Adoption of SB Strategies

Types/Options of SB Strategies	**Adopted**	**Percent**
Safety and Security Management System	**13**	65%
Fire Protection System	**12**	60%
HAVC System	**13**	65%
Electrical Management System	**9**	45%
Lighting Management System	**2**	10%
Drainage Management System	**4**	20%
Transportation Systems	**2**	10%
Building Automation System (BAS)	**9**	45%
Building Façade	**1**	5%
Building Interior Layout	**2**	10%
Computerised Management System (CMS)	**10**	50%
Software Analytic	**6**	30%
Green Building Concept with Building Design	**6**	30%
Integration of Building Automation and Software Analytic	**3**	15%
Not Sure	**1**	5%
Other	**0**	0%

rather than any effectiveness measures in T&T. Moreover, many building owners and operators argued that it would be more difficult to standardise technology than to have governance over it.

5.3 Contrasting Interview versus Survey Findings

Queries on building intelligence received some mixed responses, leading to the different understating of SB in T&T (see Table 3). From the survey findings, there were not many SB solutions. Similar findings were shared in the interviews, with the top four (4) solutions being: 1) safety and security, 2) fire protection, 3) HAVC, and 4) CMS. Besides, the survey showed that funds have been distributed into the area of building manintenace, but most would still be seen as an expenditure to businesses and not a cost-saving entity. The interview findings however reflected that lacking of incentives had been hindering the SB projects execitions. Many building practitioners were not supportive towards SB adoption. For instance, energy saving strategies would always not be the first priority in T&T. Employing technology solutions as being a SB strategy concept were in an infant stage in T&T. These solutions have been considering as an expense rather than a financial saving to building owners. Even if a SB strategy is utilised, it would largely be classified as stand-alone SB solution.

6. Development of a SB Assessment Approach

An examination into the SB designs in T&T revealed the following gaps:

- Selection of technology is based on owners' discretion;
- No benchmarks are set to verify any benefits derived from strategy;
- Minimal usage of SB materials at designing phase;
- Misconception of SB implementation; and
- Stand-alone technology is considered best practice.

In order to address the gaps identified, a five-step SB Assessment approach was developed, incorporating the analysis of empirical findings from the study. This approach addressed the fundamental issues and weighed the impacts of current building strategies in T&T. Figure 3 depicts the skeleton and process flow amongst these five (5) steps of the approach.

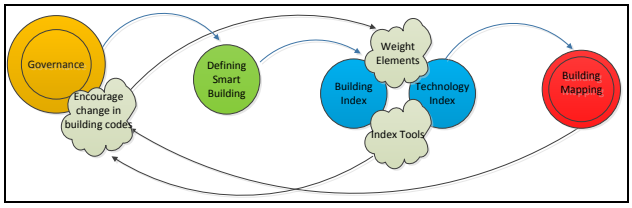

Figure 3: Process Flow of a Five-Step SB Assessment Approach

6.1 Step I: Building Governance

Governance is needed in the form of legislation which would incorporate SBs, and a regulator body or institution is needed (Finch and Clements-Croome, 1997). The legislation would address concerns for a SB governing body, penalties, minimal requirements for SB classification, identify standardise technology for use with SB and the design of a new building code for T&T. This first stage aims to assist with multiple user requirements, working patterns and ambiguity within SB industry. It is envisaged that the governing body would be responsible for building management and foster good building practices to be adopted in T&T. Encouragement towards legislation would increase stakeholders' participation across many business sectors.

6.2 Step II: Defining Smart Building

A SB integrates various systems to effectively manage resources in a co-ordinated mode to maximise technical performance, investment and operating cost savings and flexibility (Wong et al., 2005). There is a need of having a nomenclature definition for SBs for T&T. Once a definition is identified, it should be integrated into the new building code and be supported by the governing body.

Table 3. Comparison of Interview and Survey Findings

	Question	Interview	Survey
1	Knowledge of SB	Experience in SB with Qualification. Ranking 7-10	Ranking 5-6
2	Obstacles Preventing SBs	Lack of Incentives Low Energy Cost	Budget Cost 40%, Stakeholders Interest 70 %
3	Ranking Building Intelligence	Mixed response based on technology used either it is addressing needs or unable to measure intelligence	65% View building as low Ranking, 30% each either satisfied or not with Ranking
4	Current SB Strategy Used	Either stand-alone systems or Limited Integration to Safety and Security, Fire Protection, HAVC and CMS	Safety and Security, Fire Protection, HAVC and CMS
5	Building Codes Consideration	Mixed response but a need to have change in Industry developing technology adaptation	40% Yes, 50% Not Sure 10% No Comment
6	Baseline for SB Strategy	Safety and Security, Fire Protection and HAVC	Safety and Security 65%, Fire Protection 60% and HAVC 13%

Table 4: Priority of Modules Assigned to Buildings

Type of building	P1	P2	P3	P4	P5	P6	P7	P8	P9
Hospitals	M1	M7	M3	M4	M9	M2	M5	M8	M6
Weight	9	8	7	6	5.5	5	2	1.5	1
Residential buildings	M3	M5	M7	M1	M4	M9	M2	M8	M6
Weight	9	8	7	6.5	6.5	3	2	1.5	1
Commercial (office) buildings	M4	M2	M9	M3	M1	M7	M6	M5	M8
Weight	9	8.5	8	7.5	7	6.5	6	6	3
Transportation terminals	M7	M3	M1	M6	M4	M9	M8	M2	M5
Weight	9	8.8	8	7	6	6	4	3	2
Educational Institutions	M4	M7	M2	M5	M9	M1	M3	M8	M6
Weight	9	8.8	8.5	8.2	8	7	6.5	6	5

Source: Adopted from Wong and So (2002)

6.3 Step III: Deriving Smart Building Index

The need to measure the intended building performance should be conducted, in compliance with the nine Quality Environment Modules (QEM) that were advocated by AIIB (Ho et al. 2005). These QEM are listed below:

M1: Environmental friendliness – health and energy conservation;
M2: Space utilisation and flexibility;
M3: Cost effectiveness – operation and maintenance with emphasis on effectiveness;
M4: Human comfort;
M5: Working efficiency;
M6: Safety and security measures - fire, earthquake, disaster and structural damages, etc.
M7: Culture;
M8: Image of high technology;
M9: Construction process and structure; and

Different types of buildings would have different design criteria (such as residential, commercial, educational and religious). In order to promote proper building maintenance and management through the use of market forces, a need to develop a Building Quality Index (BQI) is needed (Ho et al., 2005). This is to assign different modules in priorities. Table 4 shows an example of assigned modules of five (5) different buildings, assigning P1 for the highest rating and P9 for the lowest rating for each type of building (Wong and So, 2002; Wong et al., 2005).

For the purpose of mapping the ranking to individual scores and obtaining their weights, AIIB utilised Cobb-Douglas production function. The overall IBI is defined as:

$$I = M_1^{\frac{w_1}{w_1+\ldots+w_9}} \quad \ldots \quad M_9^{\frac{w_9}{w_1+\ldots+w_9}}$$

$$1 \le I \le 100; \quad 1 \le M_i \le 100; \quad \text{and} \quad 9 \ge w_i \ge 1 \quad \text{for } i = 1\ldots9$$

where,

M_i is the score of the ith module (e.g. M 1 = the Green Index); and w_i is the ith module's weight (or importance) relative to other modules, and preferably a positive integer.

From the formula, it can be seen that I is a weighted geometric mean of the individual scores, which is weighted exponentially by their relative importance. The following shows a similar formula used to assess the individual modules score, M_i:

$$M_i = x_1^{\frac{w_1}{w_1+\ldots+w_n}} \quad \ldots \quad x_n^{\frac{w_n}{w_1+\ldots+w_n}}$$

where,

x_i is the score of the ith element and there are n elements; and w_i is the ith module's weight (or importance) relative to other modules.

There are basically three (3) types of conversion formula (So et al., 1999; Barsatie, 2015). The first type is of the form: [*a*, *b*] to (*x*, *y*) where "*a*" and "*b*" are descriptions bearing clear meaning of the elements. "*x*" and "*y*" are scores which are real numbers within the range between 1 and 100. The formula means that a score of *x* will be awarded to the element if the value of it is equal to "*a*" and a score of *y* will be awarded to the element if it is equal to "*b*".

The second type is of the form: [*a*…*b*] to (*x*…*y*). This means that the score calculated based on a linear projection or mapping from the raw value of the element within range from "*a*" to "*b*" to the range of score from "*x*" to "*y*" where "*x*" and "*y*" are scores within the range 1 to 100. The third type is of the form: (excellent, good, fair, and worst) to (*x*1, *x*2, *x*3, and *x4*) where the four *x*s are real numbers within the range from 1 to 100. The overall index obtained will enable the building to be awarded a grade as advocated in Table 5.

Table 5. Ranking of overall performance of the IB

Score	Ranking	Description
80-100	A	Distinction building
60-79.99	B	Credit building
50-59.99	C	Satisfactory building
35-49.99	D	Fair building
1-34.99	E	To be improved

Source: Adopted from Wong and So (2002)

By relating the IBI ranking to the current situation of T&T, a four-ranking index is proposed (as illustrated in Table 6) for the SB Assessment.

Table 6. A Conceptual Ranking Index for SB Assessment

Score	Ranking	Description
80 +	A	Distinction Building
50 - 79.99	B	Credit Building
20 - 49.99	C	Fair Building
0 - 19.99	D	Need for Improvement

6.4 Step IV: Developing Component/Attributes Index

In this step, the types of components are to be identified, and their criticality for use in buildings be examined. This included an identification of several factors concerning the evaluation of the 'intelligent level' of buildings (Wong and Li, 2006). These factors would be classified into nine (9) criteria groups, for example, green, space, comfort, work efficiency, culture, high-tech image, safety and security, construction process and structure, and cost-effectiveness. Table 7 shows a summary of factors affecting the selection of SB systems and components.

Table 7: Factors Affecting the Selection of SB Systems and Components

Selection of intelligent building systems and components
Selection attributes Reference
Safety and security system
Work efficiency
Time needed for public announcement of disasters (second/minute)
Time needed to report a disastrous event to the building management (second/minute)
Time for total egress (minute)
Connectivity of CCTV system to security control system
Number (or percent) of monitored exits and entrances
Earthquake monitoring devices
Wind load monitoring devices
Structural monitoring devices
Maintainability of installation
Comprehensive scheme of preventive maintenance AIIB
Life span (year)
Allow for further upgrade
Compatibility with other building systems
Integrated with BAS
Technological related
Existence of artificial intelligent (AI) based supervisory control
Modernisation of system
Area monitored by CCTV
Cost effectiveness
First cost
Life cycle cost

These factors would be rated according to the importance of the numerous building systems. A Likert five-point scale could be used to measure and rank the attributes according to their mean score ratings (Wong and Li, 2006). The mean score rating could be calculated using the following formula:

$$\text{Mean} = \frac{1(n_1) + 2(n_2) + 3(n_3) + 4(n_4) + 5(n_5)}{(n_1| + n_2 + n_3 + n_4 + n_5)},$$

where, n_1, n_2, n_3, n_4, and n_5 represent the total number of responses for attributes as 1 to 5, respectively.

Secondly a t-test analysis should be employed to identify the "important" and "most important". The null hypothesis (H_0), $\mu_1 < \mu_0$, against the alternative hypothesis (H_1), $\mu_1 > \mu_0$, were tested, where μ_1 represents the population mean, and μ_0 represents the critical rating above which the attribute considered is most important. The value of m_0 should be a fixed number as to represent "importance" and "extremely importance" attribute according to the scale in the questionnaire (Wong and Li, 2006). A decision rule can be to reject null hypothesis (H_0) when the calculation of the observed t-values (t_0) (Equation (2)) was greater than the critical t-value (t_c) (Equation (3)), as follows.

$$t_O = \frac{\bar{\chi} - \mu_0}{\widehat{s}_D/\sqrt{n}} \quad \text{Equation 1}$$

$$t_C = t_{(n-1,\alpha)} \quad \text{Equation 2}$$

$$t_O > t_C \quad \text{Equation 3}$$

where $\bar{\chi}$ is the sample mean, $\widehat{s}_D/\sqrt{n}$ is the estimated standard error of the mean of different score

6.5 Step V: Mapping the Building Design

The selection attributes identified from Step VI would be used to judge the impact of the building components. Once the ranking has been identified, a certificate would be awarded to the building. To accomplish the mapping process, the awarded rank buildings would be categorised either as (1) performance-based building (2) serviced-based building (3) system-based building as advocated by Wang (2010). Once the building is ranked, the benefits being achieved could be evaluated.

7. A Case of SB Assessment Implementation

The importance of encouraging governance would allow for stakeholders to buy-in the industry (i.e., Step I). Once this governance is implemented, the building owners and operators can realise the pay-outs of SBs not only as a financial gain, but also the potential of leading towards a smart city design. Step II looks at addressing this issue of an adaptable SB definition. This is an area for continual research and acceptance by the governing body.

The methodologies outlined at Steps III and IV follow a practitioners-oriented approach from leading countries within the SB or IB industry. These methods

are geared towards ensuring that the building infrastructure and components are optimal, and reassure that the building has an approved structure. Step III requires a building to be classified by purpose of design. Safety-structure and environmental friendliness would be considered. Once a building has met the minimal requirements for a ranking, it would be considered as SB (Step IV). The weights for various SB components would be identified. The building would then be mapped, ensuring satisfaction and convenience of persons residing and working inside (Step V).

For illustrating SB assessment implementation, the respondents' answers to the "Ranking a Building" (see Table 8) are used to assist with the application of the proposed SB assessment approach. Assuming that there is minimal assessment of 10 points for each weight element, the response from one invited building practitioner was used. This assists with applying Cobb-Douglas utility function tool and the formula, as follows:

$$I = M_1 \frac{W1}{W1+W2+W3+W4+W5+W6+W7+W8+W9} \ldots\ldots$$

$$M_9 \frac{W9}{W1+W2+W3+W4+W5+W6+W7+W8+W9}$$

Table 9 shows the computation of the SB assessment of the respondent's building. The overall SB ranking based on the respondent's assessment is computed as: $I = 10.01$. The ranking versus the overall SB ranking could then be mapped. The computed index of the building is 10.01 that falls into Grade D being described as a need for improvement. This method shows a conceptual adaption for a building index which allows for expansion in identifying a greater number of weight assessments per M_i count. The expansion would be the responsibility of the governing body to identify additional weights when designing a Likert-scale Questionnaire. However, the foundation shows benefits if adapting for evaluating a building's overall impacts and functionality, thus enabling building practitioners (owners, managers and operators) to define the building purpose and ensure that a ranked status is maintained for the building life-span.

The overall functional requirements could be suited for relatively new structures. This practitioners-oriented approach would be effective if there is a classification of buildings based on their respective design purpose. Allowance is needed for a standardise designing for a base number of weight assessment. Once classification of buildings is implemented, there would be a difference in weighted assessment for each building. For example, a hospital weight assessment would vary from that of an office building. In order to ensure buildings of a similar type are assessed appropriately, the number of weighted assessments should be evenly distributed for each type of building (for example, an office building should have no less than 50 weighted assessments per M_i).

Table 8. Respondents' Answers to the Ranking of SB Attributes

Respon-dents	SB Attributes*								
	M1	M2	M3	M4	M5	M6	M7	M8	M9
1	1	1	1	1	1	3	1	1	3
2	1	1	1	1	1	1	1	1	1
3	2	1	4	1	1	2	3	1	3
4	3	3	5	5	3	7	5	3	5
5	3	3	3	3	3	5	3	3	3
6	4	4	5	4	2	5	5	3	5
7	4	4	4	2	3	5	4	2	5
8	5	5	5	3	2	5	5	2	5
9	5	4	5	2	2	5	2	2	7

* - The 9 Quality Environment Modules (QEM) as advocated by AIIB (Ho et al. 2005)

Table 9. Computation of a Sample Assessment of SB Attributes

SB Attributes*	Assessment		Weights
M1	10	W_1= Weight of M1	4
M2	10	W_2= Weight of M2	4
M3	10	W_3= Weight of M3	4
M4	10	W_4= Weight of M4	2
M5	10	W_5= Weight of M5	3
M6	10	W_6= Weight of M6	5
M7	10	W_7= Weight of M7	4
M8	10	W_8= Weight of M8	2
M9	10	W_9= Weight of M9	5
		W_1+….+W_9	33

* - As advocated by AIIB (Ho et al. 2005)

Table 10. Likert-Scale Attribute Component for Buildings A, B and C

	BAS	Infosys	Fire	HVAC	Electrical	Lighting	Drainage	Building Façade	Building layout	Mean	Variance	Standard Deviation
Building A	4	4	5	4	3	4	4	3	5	4.0	0.5	0.7
Building B	5	5	5	5	5	5	4	1	1	4.0	3.0	1.7
Building C	2	3	1	4	2	3	1	4	4	2.7	1.5	1.2
Benchmark Standard	5	5	5	5	5	5	5	5	5	5.0	0.0	0.0

One methodology would be to utilise a Likert-scale approach, awarding points for more benefits derived. From this data, obtaining an average for each attribute can be found using the formula for deriving a specific baseline number:

Mean =

$$\frac{1(n1) + 2(n2) + 3(n3) + 4(n4) + 5(n5)}{(n1 + n2 + n3 + n4 + n5)}$$

This would assist with categorising the building as a performance-based, or service-based, or system-based building. This methodology would allow respondents to measure each element on an interval basis using the five-point scale, and rank the attributes in descending order where "1" represents not important and "5" represents importance. Once a mean is derived, then a value can be assumed as an accepted benchmark of a selected SB technology area. A building whose attributes are scored above the benchmark value per element is eligible for awarding a certificate for SB compliance.

Moreover, the individual levels of technological capabilities of buildings could be compared, using the hypothetical data that were obtained from the attribute component questionnaire (see Table 10). The relative technological ranks of buildings could then be derived. Figure 4 shows a diagrammatic representation of benchmark standard amongst Buildings A, B and C. The levels of consistency per buildings could be ascertained. For example, the drainage-capacity of Building B significantly exceeds the status of its façade and layout characteristics. Building B is in close proximity to the benchmark standard due to its relatively high mean rank of 4.0.

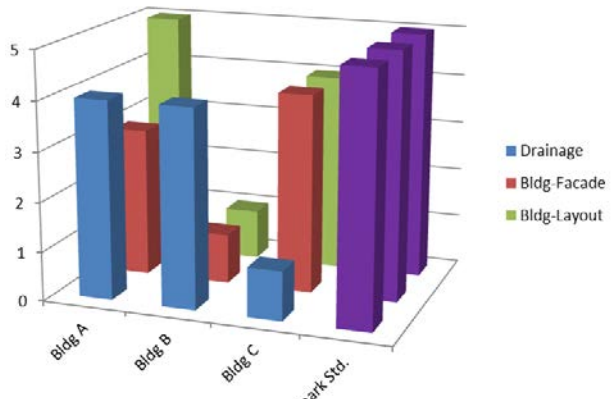

Figure 4: Diagrammatic Representation of the Benchmarks amongst Buildings

7. Conclusion

The construction booms in T&T during the 1970s and then in the 2000s saw the birth of many high-rise buildings, both by private and government entities. The development raised many questions about the afterlife care of these buildings. This paper discussed the problems associated with the adoption of SB concepts in T&T. The results showed that the architects, facility managers and building owners in T&T had perceived the importance of Smart buildings such as HVAC, fire protection and security systems in a working environment. For facilitating stakeholders to promote the SB concepts towards design and performance, this study contributed to the development of a proposed 5-steps SB assessment approach.

The SB approach built upon the AIIB's nine Quality Environment Modules (QEM) (Ho et al. 2005; AIIB, 2017), and incorporated factors concerning the evaluation of the 'intelligent level' of buildings advocated by Wong and Li (2006). The approach is more practitioners-oriented, comprising 1) building governance, 2) defining SB, 3) deriving SB index, 4) developing component/attributes index, and 5) mapping building design. A Likert-scale and calculations for Cobb-Douglas / t-Test are instrumented for standardising the variance of buildings. The SB elements are to be captured and then calculated. The utilisation of an index is to evaluate building strategies. The approach is geared towards enabling building practitioners (owners, developers, operators, and managers) who become conscious of ensuring their building is certified for human occupation and that consistency is adopted in selection of SB solutions in T&T.

It is anticipated that the adaption of a building index and assessment would ensure that SBs become the main building strategies in moving forward in T&T. Future study could validate the key elements identified for SB design and strategies of varied residential purposes and commercial/operations nature. Comparative evaluations and case studies are suggested to examine critical processes and individual steps for conducting SB assessments in T&T.

References:

AIIB (2017), *IE Technical: What are IBs?* Asian Institute of Intelligent Buildings, available at http://www.aiib.net/index_topic.php?did=248228&didpath=/248063/248228 (Accessed 01 June 2017)

BEI (2017), *What is a Smart Building*? Building Efficiency Initiative, available at: http://www.buildingefficiencyinitiative.org/articles/what-smart-building (Accessed 01 June 2017)

Barsatie, J. (2015), *Development of an Assessment Approach for Assessing the Impacts of Smart Building Strategies on Buildings in Trinidad and Tobago*, Project Report, Faculty of Engineering, The University of the West Indies, Trinidad and Tobago

Burke, K. and Ramsumair, S. (2014), *Interview by Jeffrey Barsatie* (5 September 2014).

Chen, Z., Clements-Croome, D.J., Hong, J., Li., H. and Xu, Q. (2006), "A review of quantitative approaches to intelligent building assessment", *Renewable Energy Resources and a Greener Future*, Vol. VIII 6-2 / *Proceedings of the Sixth International Conference for Enhanced Building Operations*, Shenzhen, China, November 6 - 9, 2006/

Chow, L.K H and Leung, A.Y.T. (2005) "New intelligent building index for buildings around the World: A quantitative approach in building assessment experience with Hong Kong tallest building,

Two International Finance Centre: Action for sustainability", *Proceedings of the 2005 World Sustainable Building Conference*, Tokyo, Japan, September, pp.2302-2309

Choy, C.L. (2014), *Interview by Jeffrey Barsatie* (11 September 2014).

de Fátima Castro, M., Mateus, R. and Bragança, L. (2017), "Development of a healthcare building sustainability assessment method: Proposed structure and system of weights for the Portuguese context", *Journal of Cleaner Production*, Vol.148, April, pp.555-570

Ehrlich, P. and Diamond, R. (2014), *Building Intelligence Group*, Available at: http://www.buildingintelligencegroup.com. 8 April 2009 (Accessed 01 January 2014).

Finch, E., and Clements-Croome, D. (1997), "University courses in intelligent buildings: New learning approaches", *Facilities*, Vol.15, No.7/8, pp.171-176.

Finley, Jr., M.R. , Karakura., A. and Nbogni, R. (1991), "Survey of intelligent building concepts", *IEEE Communications Magazine*, Vol. 29, No.4, April, pp.18-23 (doi: 10.1109/35.76554)

GBCTT (2017), *Green Building Council of Trinidad and Tobago*, Available at: http://ttgbc.org/about-us/ (Accessed June 2017)

Ghaffarianhoseini, A., Berardi, U., AlWaer, H., Chang, S., Halawa, E., Ghaffarianhoseini, A., and Clements-Croome, D. (2016), "What is an intelligent building? Analysis of recent interpretations from an international perspective", *Architectural Science Review*, Vol.59, No.5, pp.338-357

Ho, D.C.W., Chau, K.W., Yau, Y., Cheung, A.K.C. and Wong, S.K. (2005), "Comparative study of building performance assessment schemes in Hong Kong", *Hong Kong Surveyor*, Vol.16, No.1, pp.47-58.

ITU (2017), *The Definition of Intelligent Buildings*, İstanbul Teknik Üniversitesi, Available at: http://web.itu.edu.tr/~onaygil/ebt614e/IB_Definition.pdf (Accessed June 2017)

Krejcie, R., and Morgan, D. (1970), *Determining Sample Size for Research Activities*, National Emergency Training Center

Lalla, S. (2014), "Towards National Building Code T&T", *Trinidad and Tobago Guardian Newspaper*, Available at: http://www2.guardian.co.tt/letters/2011/07/14/towards-national-building-code-tt 15 July 2011 (Accessed January 14, 2014).

Ragbir, D. (2014), *Interview by Jeffrey Barsatie* (September 2014).

Salsbury, T.I. (2009), *Springer Handbook of Automation*, Purdue University, London

Siemens (2013), *Using Smart Building Strategies to Meet Energy, Sustainability Goals*, Available at: http://www.facilitiesnet.com/whitepapers/pdfs/20130930-Siemens.pdf 30 September 2013 (Accessed December 14, 2013).

Sinopoli, J. (2010), *Smart Building Systems for Architects, Owners and Builders*, Butterworth-Heinemann, Burlington, MA

So, A.T.P., Wong, A.C.W. and Wong, K.C. (1999), "A new definition of intelligent buildings for Asia", *Facilities*, Vol.17, No.12/13, pp.485-491.

Villfana, R. (2014), *Interview by Jeffrey Barsatie* (5 September 2014).

Wang, S. (2010), *Intelligent Buildings and Building Automation*, Spon Press, New York

Wong, A.T.P. and So, K.C. (2002), "On the quantitative assessment of intelligent buildings", *Facilities*, Vol.20, No.5/6, pp.208-216.

Wong, J. and Li, H. (2006), "Development of a conceptual model for the selection of intelligent building systems", *Building and Environment Journal*, Vol.41, No.8, pp.1106-1123

Wong, J.K.W., Li, H., and Wang, S.W. (2005), "Intelligent building research: A review", *Automation in Construction*, Vol.14, pp.143-159.

Authors' Biographical Notes:

Jeffrey Barsatie *has more than 10 years' experience in both Information Technology (IT) and the Facilities Management fields. He holds a Bachelor's degree in Computer Science from the University of Hertfordshire (U.K.) and is a graduate from The University of the West Indies (The UWI), St. Augustine Campus with a Master's degree in Project Management.*

Kit Fai Pun *is Chair Professor of Industrial Engineering (IE) and the coordinator of IE Research Group at The University of the West Indies (UWI), St Augustine, Trinidad and Tobago. He is Chartered Engineer in the UK, and Registered Professional Engineer in Australia, Europe, Hong Kong, and The Republic of Trinidad and Tobago. Professor Pun is the Chair of the Local Member Community of The American Society for Quality (ASQ), Trinidad and Tobago, and the Chair of the Technology and Engineering Management Society Chapter of the IEEE Trinidad and Tobago Section. His research activities include industrial and systems engineering, engineering management, quality management, performance measurement, and innovation systems.*

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The Impact of an Occupational Safety and Health Module on University Students' Safety Attitudes

Marcia Nathai-Balkissoon

Department of Management Studies, The University of the West Indies, St. Augustine, Trinidad and Tobago, West Indies;
E-mail: mnbalkissoon@gmail.com

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Abstract: *This paper defines safety attitude as a person's mental state pertaining to safety, which is cumulatively shaped from inputs such as experiences, observations and learning about safety, and which influences how that individual perceives safety, behaves, and makes decisions in safety-related situations in work and other spheres of life. Safety attitude research has typically been done in the context of workplace safety culture and little focus has been placed on evaluating safety attitudes before an individual enters the working world. This paper reports on how a taught safety module impacted the university student safety attitudes and makes recommendations based on the findings. The module addressed hazard identification and risk assessments, using face-to-face and online teaching and assessment modes along with real-world risk assessments. Following collection of pre- and post-intervention data, a t-test identified 15 statistically significant improvements to students' safety attitudes within five areas, namely attitudes to learning about safety, personal safety outlook and behaviours, focus on safety of others, outlook on safety and safety leadership, and state of safety knowledge. Recommendations are made to research how workplaces shape safety attitudes, as well as what levels of safety awareness and safety attitudes exist before students enter the workplace or the university system.*

Keywords: *Safety attitude, Safety culture, Safety education, Occupational safety and health, University teaching*

1. Introduction

In a work setting, safety attitudes, and ultimately safety performance, are influenced by organisation safety culture (Cooper, 2000). Safety culture and safety climate may sometimes be used as equivalent terms, but safety climate changes from one point in time to another (Cox and Flin, 1998; Flin et al., 2000; Gadd and Collins, 2002). It is notable that, while safety culture concerns a workplace's overarching safety context/habits/ characteristics, it can differ in various locations of the same company (Edwards, Davey, and Armstrong, 2013), e.g. from one department to another or from one site to another. Given these variations, it is interesting to consider how safety attitudes of individuals might influence organisational safety, as opposed to looking at the effect of a company's overarching safety culture.

While studies have typically focused on measuring safety attitudes within industry sectors or other specific settings, such as healthcare (Berman et al. 2018), construction (Stiles, Ryan, and Golightly 2018), shipping (Lu, Hsu, and Lee, 2016), and transport (Ram and Chand 2016; Warmerdam et al. 2018), there has not been much research on the safety attitudes of individuals in more general contexts.

Based on an interest in better understanding how safety attitudes are shaped at the level of the individual, this study has measured student safety attitudes before and after the delivery of an occupational safety and health module to a group of university students to:

1. determine how the Occupational Safety and Health module impacted students' safety attitudes, and
2. make curricular and other recommendations based on the study's findings.

2. Literature Review

2.1 Safety Attitude

The word attitude was explained by Allport (1935), as an experience-informed mental state that influences a person's response to situations and objects. Further, according to Pickens (2005), attitudes are formed when an individual learns, has experiences, or models behaviours or beliefs based on observing others. The author therefore proposes that a "safety attitude" is a person's mental state pertaining to safety, which is cumulatively shaped from inputs such as experiences, observations and learning about safety, and which influences how that individual perceives safety, behaves, and makes decisions in safety-related situations in work and other spheres of life.

According to Gadd and Collins (2002) safety failures typically trace back to failures at the employee level (inclusive of individual safety attitudes) as well as at the company level (i.e. safety management). As a result of this understanding, researchers have performed safety studies that have looked into safety attitudes in the workplace (Gadd and Collins, 2002). Also, Williamson et al. (1997) caution that safety failures could be expected if worker safety attitudes are not considered.

Although so much focus has been placed on surveying individuals' safety attitudes in the context of their place of work, it is difficult to locate research that simply looks at individuals' attitudes toward safety in general. Loughlin and Barling (2001) expressed a related concern about the need to evaluate how young workers' attitudes, values, and behaviours are being shaped before they join the workforce. They posited that work safety attitudes can be shaped through a youth's part-time work experiences, latently through a child's life experiences, and even indirectly from their parents' work experiences. This highlights that safety attitudes begin to be shaped long before a person has any substantive experience as a worker, and raises the question of what role safety education plays in the shaping of safety attitudes.

2.2 Safety Attitude Considerations

When considering safety attitudes, the focus should include learning about safety, since such learning develops "good" safety culture (Pidgeon and O'Leary, 1994; 2000) and promotes safe behaviours (Jones, Cox, and Rycraft, 2004). Employees who prioritise safety can be expected to want to learn about safety. Therefore *having a positive attitude to learning about safety* appears to support company safety. Furthermore, an improved *state of safety knowledge* in individuals could indicate that employees are making an effort to enhance their knowledge about safety topics, to be able to act more safely.

The safety questionnaires that have looked into attitudes to safety have typically focused on safety climate within a workplace (Zohar, 1980; Mearns et al., 1997), as opposed to safety attitudes of individuals. Attitude scales have been context dependent and vary by sector (Cox and Flin, 1998), but generally research has shown that the higher the safety climate measures, the lower the accident rates of companies. Jeffries (2011, 200) found that safe behaviour was influenced by intrinsic factors, namely people's ability to be morally mature, (i.e., to "reason through the information surrounding a situation and make an ethical decision") and to understand the context and consequences of decisions.

Policy, standards, and culture at the company level and attitudes at the individual level can influence safety behaviours and cause safety failures (Cullen, 1990; Smallman and John, 2001; Parker, Lawrie, and Hudson, 2006; Zohar, 2010; Van Nunen et al., 2017). The desire of workers to look out for their own safety, and ability to obtain knowledge about safety (Nahrgang, Morgeson, and Hofmann, 2011) are important considerations when seeking to develop good safety practices. In this regard, there is value in looking into individuals' *personal safety outlook and behaviours* (Geller, 1994; Flin, 2007). Another positive aspect reported in safety culture research was workers' practice of *looking out for the safety of others* (Geller, 1994), and so this would be important when considering individual safety attitudes.
Finally, research within the field of safety has pointed to the role of managers in inspiring employee buy-in and developing effective safety management systems (Nahrgang, Morgeson, and Hofmann, 2011; Yorio, Willmer, and Moore, 2015; Nathai-Balkissoon and Pun, 2016). When looking at an individual's *attitudes about safety leadership*, consideration should therefore extend to whether they recognise management's influence on safety within the workplace.

3. Methodology

3.1 Survey Instrument

A safety attitudes questionnaire was used to measure student safety attitudes for this study. This instrument was administered as an online survey. The instrument was developed and validated in a separate study (publication in development) that included a factor analysis and structural equation modelling (SEM) study exploring how various factors influence safety attitudes. The scale had a Cronbach-alpha of 81.9%, and the reliability remained over 80% when considering the potential effect of deleting individual items from the instrument.

The questionnaire measured student attitudes in five areas, namely:

1. attitudes to learning about safety,
2. outlook on safety and safety leadership,
3. focus on safety of others,
4. personal safety outlook and behaviours, and
5. state of safety knowledge.

Attitudes to learning about safety looked at student interest in safety, focus on auto-learning (or seeking out safety information on their own), recognition that understanding safety impacts on safe practices, and willingness to work without sufficient training.

Outlook on safety and safety leadership focused on students' understanding of responsibility for safety, including the role of leaders in establishing safety priorities.

Items about the *focus on safety of others* surveyed students' instincts in emergencies and feelings of responsibility about others' safety.

Personal safety outlook and behaviours considered how students view and prioritise their own safety and whether they are willing to take up a safety leadership role when needed.

Finally, insight was sought about students' current *state of safety knowledge*, specifically whether students had furthered their knowledge about safety beyond what had been taught in the module.

3.2 Target Group and Survey Administration

The survey was administered to a group of 67 students registered for a Masters level course on business strategy and management at The University of the West Indies

(The UWI). In the class 68.7% were female, and 31.3% were male. Most of the students (94%) were in their first year of the programme. Only 31.3% were parents or guardians. 77.6% were employed in full-time or part-time jobs, 9% had less than one year's part time work experience, and only 6% had no work experience. Just under half of the respondents (44.8%) considered themselves as having worked in high-risk jobs before, and about half (50.7%) reported that they had a parent who had worked in a high-risk job. 11.9% of respondents had been seriously hurt in a personal or work-related accident before, and 59.7% knew someone who had been seriously hurt in such an accident. Respondent characteristics are presented in Table 1.

The same survey was administered as both pre-test and post-test. The online pre-test was opened for student completion between weeks two and four of the semester, and all 67 students submitted responses. The safety materials posted on the University's learning management system were not opened up for student access until after the pre-test had been completed. The post-test survey was opened for student completion in week 11 (immediately after the teaching and coursework elements of the module had been completed) and closed in week 13. Due to student de-registrations and withdrawals, the post-test was completed by 61 students.

3.3 The Taught Module

Teaching was done once weekly, in a 3-hour session that ran from 5 to 8 p.m., including a 10-minute break. Table 2 summarises the instructional and in-course assessment approach used. The taught module focused on developing students' ability to:

1. recognise hazards that may be present at work and in other spheres of life,
2. assess risk resulting from such hazards, and
3. develop simple action plans to mitigate risk.

The module was intended to enhance students' grasp of technical content related to hazards and risk assessment, and these were assessed both during the course and a final exam. It was also hoped that exposure to the module would improve students' safety attitudes in the areas listed in Section 3.1, as measured by the survey instrument.

According to Pickens (2005), attitudes may be shaped if interventions include both cognitive and emotional elements. The material used in the module was content-rich and sought to convey much technical safety knowledge to students. Attempts were also made to boost students' emotional connection with the material, such as by eliciting their experiences, opinions, and observations, and encouraging them to apply techniques in class activities and real-world projects that would show how safety could influence their everyday lives. Reading materials (e.g. slides, a few journal articles, short text documents) were uploaded to the University learning management platform to share underlying theory.

The long and late class could have been a barrier to learning so student-centred instruction was employed often. The importance of safety was underscored by sharing photos, videos, experiences, opinions, and stories, as well as through role play and group challenges in the classroom. For example, one group activity tasked groups with performing their first risk assessment based on a workplace scenario and photo (see Figure 1).

The teaching and assignments were intended to develop students' "moral maturity" (Jeffries 2011, 200) and their understanding of how simple conditions and acts could pose potentially severe OSH threats to their own safety and the safety of others.

3.4 Analysis of Findings

Respondent data were collected electronically within the online survey website, and exported to SPSS 21 for analysis. The data were coded so that each item's least desirable response had the lowest code and the most desirable response had the highest code. Means were calculated based on the pre-test and post-test data. Then, to assess whether the taught module had a statistically significant impact on student safety attitudes, a paired t-test was performed to compare the means of each item from the two datasets. The t-test results were first checked at the 95% confidence level, and next at the 90% confidence level. Items with statistically significant t-test outcomes were reported.

Table 1. Survey Respondent Characteristics

Characteristic		Frequency	Percentage
Gender	Male	21	31.3%
	Female	46	68.7%
Year of study	First year of postgraduate studies	63	94.0%
Status as parent	Parents/guardians	21	31.3%
Employment status	Currently employed	52	77.6%
	Less than 1 year part-time work experience	6	9.0%
	No work experience	4	6.0%
Accident and risk exposure	Do high-risk work	30	44.8%
	Parent(s) had high-risk work exposure	34	50.7%
	Seriously hurt before in personal/work accident	8	11.9%
	Knows someone who was seriously hurt in personal or work accident	40	59.7%

Total number of respondents - 67

Table 2. Instructional Approach Used for the Occupational Safety and Health Module

Wk	Topic	Instructional Time	In-Class Instructional Approach	Assessment Approach	Materials
1	Introduction: the OSH Act of T&T	Class contact: 40 min At-home: 1½hr	20 minute Teacher slide presentation: OSH Act requirements 20 minute discussion with class: Why are certain elements (e.g. safeguarding, risk assessment, maternal protection) addressed in the Act? Teacher highlights areas such as employee duties and rights, importance of OSH advocacy. Teacher points out that some questions raised/ observations made relate to material beyond the scope of the module (e.g. emergency preparedness), and advises students that they could learn more through their own efforts.	Not assessed: The OSH Act	Teacher's slides Online link to the OSH Act of T&T (optional reading) Video: safeguards
	Differentiating between hazards and risks	Class contact: 30 min	30 minute role play scenario supplemented with teacher-led discussion: The setting is a busy, poorly maintained road used by heavy vehicular traffic and many pedestrians. Visibility varies as route is a winding one. There are few road signs or marked pedestrian crossing areas. Students volunteer to play roles of a brawny, able-bodied male pedestrian, a small-framed 7 year old girl, and a car driver. Activity illustrates how the same hazards can result in different levels of risk depending on factors such as the time of day, driver characteristics, type and speed of vehicle.		Teacher's slides
	At-risk groups	Class contact: 20 min	20 minute Teacher presentation highlighting common at-risk groups, e.g. lone workers, pregnant and nursing mothers, young workers.		Teacher's slides
	Introduction to Hazard Types	Class contact: 40 min At-home: 1 hr	20 minute "Spot the Hazard" activity: One by one, photos illustrating scenes with considerable physical hazards, chemical hazards, biological hazards, psychological hazards, and ergonomic hazards are presented to the class. Students work in small groups to identify 3-4 hazards per picture 20 minute Teacher consolidation to broaden student awareness of the range of hazards that exist in each photo, how different hazards may affect different at-risk groups, and to direct students to further resources.	Hazard Identification Blog Assignment (Individual): Students required to review and briefly critique an undergraduate student's safety blog article, posting feedback as a comment to the article.	Teacher's slides presenting range of hazards to boost student awareness and provide support for the assignment
	Physical Hazards	Class contact: 30 min At-home: ½ hr	25 minute Teacher slide presentation: Broad range of physical hazards illustrated and discussed, along with brief stories from teacher and student experiences. 5 minute lecture summary		Teacher's slides
2	Chemical Hazards Biological Hazards Psychological Hazards Ergonomic Hazards	Class contact: 2 hours, 20 min At-home: 2 hr	Four slide presentations, supplemented with interactive sessions: Teacher uses slides to present a range of hazards under each hazard type in turn. In each segment, teacher illustrates several of the hazards through the use of live demonstrations, photos, videos, sharing of experiences, and discussions with students. Student discussions and sharing of experiences: When have students encountered these hazards at home, at school or elsewhere? Did they ever have near-misses or accidents due to such hazards? Sharing of challenges, successes, and actions taken.		Teacher's slides Supporting online resources
	Introduction to Risk Assessment	Class contact: 30 min At-home: 1 hr	10 minute Teacher slide presentation: 5 Steps to Risk Assessment 15 minute Student discussion: What actions would students recommend to control some of the risks identified in earlier parts of the lesson? 5 minute lecture summary		Risk assessment examples and guidance from osha.gov.tt and hse.gov.uk
3	Risk Assessment	Class contact: 30 min At-home: ½ hr	10 minute recap: Hazards, risk, and risk assessment steps 10 minute Teacher slide presentation: Hierarchy of Controls 10 minute group challenge: For each control type in the Hierarchy of Controls, identify a control that can be found in everyday life (e.g. home, school, society). Write your group's response on the whiteboard.		Online resources on the hierarchy of controls, and how to shape effective risk mitigation action plans
		Class contact: 1 hour, 30 min At-home: 1½hr	60 minute risk assessment group activity: Part 1 (30 minutes): Students use a risk assessment template and document their first risk assessment based on a photo and scenario description provided by the teacher (see example in Figure 1). Part 2 (30 minutes): 2 or 3 groups selected to briefly present their findings with the class. Discussions result in additional hazards and risks being detailed based on other groups' insights. 20 minute Teacher consolidation: Teacher points out how many hazards exist, how hazards can remain hidden and therefore require assessor vigilance, and stresses the need for careful determination of risk mitigation actions that are likely to be effective, rather than just expedient. 10 minute module summary	Risk Assessment Assignment (Group): Students select a real-world setting (whether at a home, school or work location) and conduct a risk assessment that spans all hazard types and identifies all at-risk groups affected by the hazards. A complete action plan must be included on the template supplied by the lecturer.	Teacher's slides

You are the person in charge on site at a solid waste landfill location, and you have 10 people working under your direction. Your task force is required to sort loads of garbage coming in to the site several times each day, with a view to separating biodegradable, non-biodegradable, and toxic materials for different types of disposal. For this, five foot-high skips on wheels, wheelbarrows, plastic drums that are washed and reused, garbage bags, shovels, thick black rubber gloves, cotton-weave face masks, steel-toe boots, coveralls and rubber aprons have been provided. In addition, you must ensure the security of the site and the safety of your workforce. On the template provided, record your risk assessment. You will discuss your findings with the class in 30 minutes' time.

Figure 1. Risk Assessment Activity Example: Photo and Description of a Work Setting

4. Findings and Discussion

A total of 15 items were found to have been positively influenced by the delivery of the taught module of safety. These are presented and discussed below.

4.1 Attitudes to Learning About Safety

Students' interest in, and attitude toward, learning about safety showed significant improvement in three areas (see Table 3). At the 95% confidence level, there was an increase in students' attentiveness to work safety guidelines affecting themselves (mean increased from 4.71 to 4.89). At the 90% confidence level, there were improved safety attitudes in two areas. Learning more about safety increased students' perceptions of work safety as an interesting field (mean increased from 2.96 to 3.07). Also, students reported that they were using the internet more, to actively seek out information about how to stay safe (mean increased from 3.16 to 3.52). Thus, it appeared that students recognised that they could discover more beyond the material that had been taught and had developed an interest in learning even more about general safety and work safety.

4.2 Outlook on Safety and Safety Leadership

Research has found that leaders' commitment has a positive effect on safety management system operation (Zohar and Polachek, 2014). For example, Nathai-Balkissoon (2016) noted that top management involvement is instrumental in setting safety policy, providing safety resources, and positively influencing employee participation in safety management.

Recalling from Section 2.1 that safety attitudes include safety perceptions, Table 4 reflects that students' perceptions about safety leadership improved. They better appreciated that safety leadership is an important factor in boosting employees' safety behaviours. Specifically, students recognised that there are improvements in employee's safe behaviour when top managers meet them to discuss safety issues and share ideas (mean increased from 4.31 to 4.57), communicate with employees in writing about the importance of safety (mean increased from 3.88 to 4.20), and set examples for employees by acting safely themselves (mean increased from 4.21 to 4.49).

4.3 Personal Safety Outlook and Behaviours

The taught module strengthened students' safety outlook, perhaps in part because the assessment approach required them to evaluate hazards and mitigate risks within their own spheres of operation (home, school, and work).

As shown in Table 5, the survey found that they became more safety-centric, incorporating a safety focus within all their activities (mean 3.87 to 4.28) driving safety improvement in their spaces (mean 3.62 to 4.08), adopting a proactive accident-prevention mindset (mean

Table 3. Enhanced Attitudes to Learning About Safety

Item	Pre-test Mean	Post-Test Mean	t	Sig.
If someone offers to share safety guidelines with me about work I am involved in, I would listen attentively.	4.71	4.89	2.282	.024*
Work safety is interesting	2.96	3.07	1.725	.087**
I do online searches just to know how to stay safe	3.16	3.52	1.731	.086**

* significant at 95% Confidence level; ** significant at 90% Confidence level

Table 4. Enhanced Outlook on Safety and Safety Leadership

Item	Pre-test Mean	Post-Test Mean	t	Sig.
When managers and leaders meet with employees to share safety issues and ideas, employees will act more safely	4.31	4.57	2.043	.043*
When managers and leaders write to tell employees that safety is important, employees will act more safely	3.88	4.20	1.757	.081**
When managers and leaders act safely, their employees will also act safely	4.21	4.49	1.922	.057**

* significant at 95% Confidence level; ** significant at 90% Confidence level

Table 5. Enhanced Personal Safety Outlook and Behaviours

Item	Pre-test Mean	Post-Test Mean	t	Sig.
I think about safety in everything I do	3.87	4.28	2.438	.016*
I work to improve safety where I live and/or work	3.62	4.08	2.967	.004*
I handle all situations as if there is a possibility of having an accident	3.47	4.08	3.248	.002*
I follow all safety procedures regardless of the situation I am in	3.90	4.28	2.341	.021*
I think about safety when I enter a room	3.76	4.11	1.806	.073**
I keep my working space well-organised	4.41	4.54	.892	.374**
I keep my gear/ equipment in safe working condition	4.34	4.59	1.872	.064**

* significant at 95% Confidence level; ** significant at 90% Confidence level

Table 6. Enhanced Focus on Safety of Others

Item	Pre-test Mean	Post-Test Mean	t	Sig. (2-tailed)
I am responsible for the safety of those around me	4.28	4.54	2.003	.047*
I encourage my co-workers/ colleagues to be safe	4.24	4.61	2.947	.004*

* significant at 95% Confidence level

Table 7. Enhanced Knowledge about Action in an Emergency

Item	Pre-test Mean	Post-Test Mean	t	Sig.
I know the emergency evacuation procedure for where I am right now	3.91	4.38	2.149	.034*
I know how to act in an emergency	3.91	4.18	1.695	.092**

* significant at 95% Confidence level; ** significant at 90% Confidence level

3.47 to 4.08), and consistently adhering to safety procedures (mean 3.90 to 4.28). Their proactivity was evidenced by their reports that they are safety-focused from the time they enter a room (mean 3.76 to 4.11), keep their workspace in order (mean 4.41 to 4.54) and maintain their gear in good working condition (mean 4.34 to 4.59).

4.4 Focus on Safety of Others

The taught module also required students to interact with others in their work, home, and school settings. They were sensitised to how safety breaches had led to accidents and how seemingly innocuous conditions and events could cause serious safety repercussions. The research revealed that the module increased students' feelings of responsibility for, and commitment to, others' safety.

From Table 6, it can be seen that students assumed greater levels of responsibility for the safety of those around them (mean increased from 4.28 to 4.54) and also increased their overt efforts to encourage those around them to act safely (mean increased from 4.24 to 4.61). This reveals that students went beyond caring about their own safety to caring about others' safety. They became more willing safety advocates, as they were more likely to assume responsibility for others, and tried to influence others to think and act more safely.

4.5 Current State of Safety Knowledge

The taught module included much content about safety, but the survey questions did not focus on how students' knowledge had increased in the areas specifically taught in the module (e.g. types of hazards, how to do a risk assessment). Instead, the researcher was interested in evaluating whether students had ventured beyond the module's content to autonomously grow their safety knowledge. Indeed, while the taught module focused mostly on hazard identification and risk assessment, the teacher had underscored the importance of proactively seeking knowledge about safety in areas beyond what was being taught. The survey questions thus looked into student knowledge about emergency preparedness, a topic that the teacher had noted to the class as being outside of the scope of the module, but important for personal and general safety.

The data revealed that students had become better prepared with respect to functioning in an emergency (see Table 7). Students reported that they knew the emergency evacuation procedure for their current location (mean 3.91 to 4.38) and they had developed their preparedness to act in an emergency (mean 3.91 to 4.18).

5. Study Implications and Recommendations

5.1 University Education Curriculum Development

In this research technical safety practices and content were the focus of the taught module, which was delivered to students pursuing a Masters level management programme. The research found that student safety attitudes significantly improved following delivery of the three-week safety module. Since one of the aims of university education is shaping graduates'

attitudes in efforts to enhance their work-readiness, university programme developers should consider:

1. incorporating more safety training elements in non-science and non-engineering degrees since establishing safety foundations would benefit students' private and work lives, and
2. developing co-curricular courses to allow students from different degree programmes to access safety training together, thereby sharing their diverse experiences and perspectives, and enhancing their development of safety attitudes that could augur well for their private and work lives.

5.2 Implications for Company Managers

To properly manage their people and other resources, company managers must factor safety into their plans and budgets. Proactively managing safety requires time-consuming and potentially costly efforts to be expended, including induction and orientation training, mentoring, ongoing technical training, as well as operation of monitoring and assessment programmes that identify and address shortcomings and continually improve safety systems and performance. Safety practices and safety performance vary from company to company, and this is because safety culture influences the way that managers and employees prioritise safety and carry out their tasks.

Although the training took place in a classroom instead of in a work setting, many of these attitudes would be valued within the workplace. Thus, companies might not need to wait to hire workers to start shaping employee safety attitudes. An alternative could be to begin constructing positive safety attitudes through community interventions or the education system, not only in technical-vocational or science classes, but in all subject areas. Perhaps companies might one day comprehensively screen safety attitudes as a part of their recruitment and selection criteria. The most safety-minded companies should recognise how individuals' safety attitudes could impact on their safety performance and bottom lines. Companies would be well-served if they are able to select candidates with superior safety attitudes.

In this age of corporate social responsibility, companies could create excellent value by supporting safety attitude development programmes in the community and at school, as this would shape better safety attitudes in their own pool of future candidates. In-house safety training could be made much more specific to the work setting, if general safety tenets have already been strongly inculcated before candidates are hired.

5.3 Recommendations for Further Work

While considerable work has been done in the workplace to assess safety considerations including safety culture and workplace safety attitudes, insufficient focus has been placed on measuring and influencing individuals' safety attitudes outside of work settings. This could have important individual safety and economic impacts. Additional work related to safety attitudes is needed to take this thinking further, so the following recommendations are put forward:

1. Develop a model of what constructs contribute to people's safety attitudes. Most research in this area has been constrained within a single field, e.g. healthcare or mining. Exploring safety attitudes from broader contexts would be instructive.
2. Investigate what safety attitudes and safety awareness levels exist before students enter the workplace or university.
3. Learn more about safety attitudes within the workplace. This could include determining how individuals' safety attitudes are shaped within the workplace, and whether there is correlation between candidate safety attitudes at recruitment and employee safety attitudes some time after being hired in various industries. This could give employers insight into safety attitudes resident in employees even before selection, how much impact is achieved by employee training programmes, and how to more effectively design their in-house safety interventions.

6. Conclusion

It was found that teaching a three-week safety module as a part of a 12-week Masters-level Management Studies course had a statistically significant impact on individuals' safety attitudes in 15 areas under five themes, namely attitudes to learning about safety, outlook on safety and safety leadership, focus on safety of others, personal safety outlook and behaviours, and state of safety knowledge.

More research is needed to develop empirically-derived safety attitude models, and to understand how positive safety attitudes could be shaped within the education system and during employment.

References:

Allport, G.W. (1935), "Attitudes", In Murchison, C. (ed.), *A Handbook of Social Psychology*, Clark University Press, Worcester.

Berman, L., Rangel, S., Goldin, A., Skarda, D., Ottosen, M., Bliss, D., Valusek, P., Fallat, M., and Tsao, K.J. (2018), "Safety culture among pediatric surgeons: A national survey of attitudes and perceptions of patient safety", *Journal of Pediatric Surgery*, Vol.53, No.3, pp. 381-395, doi:10.1016/j.jpedsurg.2017.09.011.

Cooper, M.D. (2000), "Towards a model of safety culture", *Safety Science*, Vol.36, pp.111-136.

Cox, S. and Flin, R. (1998), Safety culture: Philosopher's stone or man of straw? Work and Stress, Vol.12, No.3, pp. 189–201.

Cullen, W.D. (1990), *The Public Inquiry into the Piper Alpha Disaster*, Department of Energy. HMSO, London.

Edwards, J.R.D., Davey, J., and Armstrong, K. (2013), "Returning to the roots of culture: A review and re-conceptualisation of safety culture", *Safety Science*, Vol.55, pp.70–80, doi:10.1016/j.ssci.2013.01.004.

Flin, R. (2007), "Measuring safety culture in healthcare: a case for accurate diagnosis", *Safety Science*, Vol.45, No.6, pp. 653–667.

Flin, R., Mearns, K., O'Connor P., and Bryden R. (2000), "Measuring safety climate: Identifying the common features", *Safety Science*, Vol.34, No. 1-3, pp. 177–193.

Geller, E.S., (1994), "Ten principles for achieving a Total Safety Culture", *Professional Safety*, Vol.39, No.9, pp. 18–24.

Gadd, S. and Collins, A.M. (2002), *Safety Culture: A Review of the Literature*, HSL/2002/25, Health & Safety Laboratory, Sheffield. Available at: www.hse.gov.uk/research/hsl (Date visited 18 April 2018).

Jeffries, F.L. (2011), *Predicting Safety Related Attitudes in the Workplace: The Influence of Moral Maturity and Emotional Intelligence*, Institute of Behavioral and Applied Management, Nebraska.

Jones B., Cox S., and Rycraft H. (2004), "Assessing employee attitudes towards behavioural approaches to safety management within UK reactor plants". In Spitzer C., Schmocker U., Dang V.N. (eds.), *Probabilistic Safety Assessment and Management*, Springer, London, doi:10.1007/978-0-85729-410-4_254.

Loughlin, C. and Barlin, J. (2001), "Young workers' work values, attitudes, and behaviours", *Journal of Occupational and Organizational Psychology*, Vol.74, pp. 543-558.

Lu, C.-S., Hsu, C.-N., Lee, C.-H. (2016), "The impact of seafarers' perceptions of national culture and leadership on safety attitude and safety behavior in dry bulk shipping", *International Journal of e-Navigation and Maritime Economy*, Vol.4, pp. 75-87, doi:10.1016/j.enavi.2016.06.007.

Mearns, K., Flin, R. Fleming, M. and Gordon, R. (1997), *Organisational and Human Factors in Offshore Safety*, HSE, London.

Nahrgang, J.D., Morgeson, F.P., and Hofmann, D.A. (2011), "Safety at work: a meta-analytic investigation of the link between job demands, job resources, burnout, engagement, and safety outcomes", *Journal of Applied Psychology*, Vol.96, No.1, pp. 71-94.

Nathai-Balkissoon, M. (2016), "Occupational safety and health management system implementation metrics: Results of a survey of manufacturing companies in a small island developing state", *Journal of the Association of Professional Engineers of Trinidad and Tobago*, Vol.44, No.2, pp. 24-34.

Nathai-Balkissoon, M. and Pun, K.F. (2016), "Factor analysis of elements influencing occupational safety and health management system development in Trinidad and Tobago", *West Indian Journal of Engineering*, Vol.38, No.2, pp.13-23

Parker, D., Lawrie, M., and Hudson, P. (2006), "A framework for understanding the development of organisational safety culture", *Safety Science*, Vol.44, pp. 551–562.

Pickens, J. (2005), *Organisational Behaviour in Health Care*, Jones and Bartlett Publishers, Sudbury.

Pidgeon, N.F. and O'Leary, M. (1994), "Organizational safety culture: implications for aviation practice", In Johnston, N., McDonald, N., and Fuller, R. (eds.), *Aviation Psychology in Practice*, Avebury Technical, England.

Pidgeon, N.F. and O'Leary, M. (2000), "Man-made disasters: Why technology and organisations (sometimes) fail", *Safety Science*, Vol.34, No.1-3, pp.15-30.

Ram, T. and Chand, K. (2016), "Effect of drivers' risk perception and perception of driving tasks on road safety attitude", *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol.42, No.1, pp. 162-176, doi:10.1016/j.trf.2016.07.012.

Smallman, C. and John, G. (2001), "British directors' perspectives on the impact of health and safety on corporate performance", *Safety Science*, Vol.38, pp. 227-229.

Stiles, S., Ryan, B., and Golightly, D. (2018), "Evaluating attitudes to safety leadership within rail construction projects", *Safety Science*, doi:10.1016/j.ssci.2017.12.030.

van Nunen, K., Li, J., Reniers, G., and Ponnet, K. (2017), "Bibliometric analysis of safety culture research", *Safety Science*, doi:10.1016/j.ssci.2017.08.011.

Warmerdam, A., Newnam, S., Wang, Y., Sheppard, D., Griffin, M., and Stevenson, M. (2018), "High performance workplace systems' influence on safety attitudes and occupational driver behaviour", *Safety Science*, Vol.106, pp. 146-153, doi:10.1016/j.ssci.2018.03.016.

Williamson, A.M., Feyer, A., Cairns, D., and Biancotti, D. (1997), "The development of a measure of safety climate: The role of safety perceptions and attitudes", *Safety Science*, Vol.25, No.1-3, pp. 5–27.

Yorio, P.L., Willmer, D.R., and Moore, S.M. (2015), "Health and safety management systems through a multilevel and strategic management perspective: Theoretical and empirical considerations", *Safety Science*, Vol.72, pp. 221-228, doi:10.1016/j.ssci.2014.09.011.

Zohar, D. (1980), "Safety climate in industrial organizations: Theoretical and applied implications", *Journal of Applied Psychology*, Vol.65, pp. 96-102.

Zohar, D. (2010), "Thirty years of safety climate research: Reflections and future directions", *Accident Analysis and Prevention*, Vol.42, No.5, pp. 1517-1522.

Zohar, D. and Polachek, T. (2014), "Discourse-based intervention for modifying supervisory communication as leverage for safety climate and performance improvement: a randomised field study", *Journal of Applied Psychology*, Vol. 99, No. 1, pp. 113-124.

Author's Biographical Notes:

Marcia Nathai-Balkissoon *is a Lecturer at The University of the West Indies (The UWI), St. Augustine Campus, Trinidad and Tobago (T&T). A Registered Professional Engineer and member of the Safety Council of Trinidad and Tobago (SCTT), she has served various industry posts as manager, engineer, auditor, and consultant. Marcia holds a B.Sc. degree in Industrial Engineering and M.Sc. degree in Engineering Management. Her research interests include occupational safety and health, management systems, and teaching and learning. She is currently completing a Ph.D. in Industrial Engineering.*

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Professor Emeritus Harry Orville Phelps (1929-2018): A Memorial

Gyan S. Shrivastava [a,Ψ] and Clément A.C. Imbert [b]

[a] Department of Civil and Environmental Engineering, Faculty of Engineering, The University of the West Indies, St. Augustine, Trinidad and Tobago, West Indies; E-mail: shrivastava.gyan@gmail.com;

[b] Faculty of Engineering, The University of the West Indies, St. Augustine, Trinidad and Tobago, West Indies; E-mail: clementimbert40@gmail.com

[Ψ] *Corresponding Author*

Professor Emeritus Harry Orville Phelps was an engineering icon of Trinidad and Tobago who contributed immeasurably to the development of the field of Engineering. He lived a multifaceted life as an accomplished scholar, academic, sportsman and most of all a perfect gentleman. He served the engineering profession, The University of the West Indies and his country with distinction.

He was born on 4th February, 1929 in Belmont, Trinidad. He received his primary education at Belmont Intermediate School and won a College Exhibition to Queen's Royal College (QRC) in 1940. At QRC, Phelps excelled at football and track. In 1947, he was the champion sprinter at QRC and a member of the QRC relay team that won the National Under-19 Championship that year. He was a member of the QRC football team and represented Trinidad and Tobago in 1948 on the under-19 football team against Haiti.

At QRC, he graduated at the top of his class in the Science Group of the Higher School Certificate Examinations, earning a Colonial Development and Welfare Scholarship to pursue a degree in Civil Engineering at the University of Wales, Swansea, United Kingdom, in 1949. He continued his sporting activities representing the University in football. He graduated with First Class Honours in 1953 and returned to Trinidad, joining the Ministry of Works. At the Ministry he held the position of Assistant Drainage Engineer and rose to the rank of Chief Drainage Engineer in 1961.

The Queens's Royal College (QRC) Football Team in the mid to late 1940s. Harry Phelps is in the front row, far right. He went on to represent Trinidad and Tobago in 1948 on the Under-19 football National Team of Trinidad and Tobago

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Authors' Biographical Notes:

Gyan Shrivastava *is a retired Professor of Civil and Environmental Engineering of The University of the West Indies. As stated below Professor Shrivastava was a student, colleague and friend of Professor Phelps.*

Clément A.C. Imbert *is a Professor Emeritus of the Faculty of Engineering of The University of the West Indies. He was a student, colleague and friend of Professor Phelps whom he knew since 1964.*

In 1961 Phelps joined the fledgling Faculty of Engineering of the University College of the West Indies, as it was then. He was one of its first appointees to the Faculty and proved invaluable during its formative years, heavily involved with the construction of the faculty's buildings and the formulation and direction of its academic programmes. He later completed his PhD under the supervision of J.R.D. Francis, a distinguished Professor in Fluid Mechanics who was the author of the standard university text "A Textbook of Fluid Mechanics for Engineering Students". He was promoted to Senior Lecturer in 1970 and later to Professor in 1974. He was Head of the Department of Civil Engineering for 12 years, from 1972 to 1984 and after his retirement in 1994 he was conferred with the title of Professor Emeritus in 1995. He accepted a post-retirement contract from 1994 to 1997 and continued to teach part-time in the MSc Environmental Engineering programme until 2009.

Professor Phelps lectured in Fluid Mechanics and Water Resources as well as Introduction to Engineering, a course he pioneered in the Faculty of Engineering. Throughout his career in The University of the West Indies he made contributions beyond his role as a Lecturer and Professor of Civil Engineering. He was Vice Dean, acted as Dean on a few occasions and served on the University Academic Committee, the University Senate, the St. Augustine Campus Council and as Chairman of the Publication Board of the West Indian Journal of Engineering. He served as the Public Orator of the St. Augustine Campus for 20 years, from 1974 to 1994, and wrote a short history of the Faculty of Engineering. He worked very closely with Professors Kenneth Julien and I.D.C. Imbert on the major expansion of the Faculty in the late 1970s and 1980s.

Professor Phelps served on several national committees and statutory boards, including Chairman of the Institute of Marine Affairs and the Bureau of Standards. He was Deputy Chairman of the Water and Sewerage Authority and a Member of the Board of the Trinidad and Tobago Electricity Commission and the Working Group to Streamline Procedures for the Civil Service. He was a Foundation Member of the Association of Professional Engineers of Trinidad and Tobago, serving as President from 1975 to 1976, and is a Fellow of the Association and of the Institution of Civil Engineers in the United Kingdom. He also served as the Deputy Chairman of the Board of Engineering of Trinidad and Tobago from 1987 to 1993.

Professor Phelps received many accolades for his work and service, including the award for Career of Excellence in Engineering from the Association of Professional Engineers of Trinidad and Tobago, the Cooper Bronze Medal from the Institution of Civil Engineers for research in fluid mechanics and in 1979 he was awarded the Chaconia Medal (Gold) for long and meritorious service to the Republic of Trinidad and Tobago in the Sphere of Engineering. His accomplishments earned him a place amongst the Caribbean Icons profiled by the National Institution of Higher Education, Research, Science and Technology (NIHERST) [1].

His children [2] have very fond memories of him as a model father, committed to family life despite a relentless work schedule. He set high standards and values of behaviour, excellence and a sound work ethic, balanced by a keen sense of fun with an infectious laugh.

He had a great talent and love for music, learning to play the piano at an early age. With the encouragement of his mother he mastered many difficult pieces, including the classics, and could transpose music that he had heard. As a teenager, he spent time with a jazz musician, the result of which improved his skills tremendously. His love of music and performance were carried throughout his life and he practised every day after work or for a short spell after lunch. His children remembered being exposed to all genres of music and were all encouraged to take up an instrument, two opting for the piano and the other two for the guitar and cuatro. He was also an all-round athlete, football and sprinting being his favourites, but he also had a passion for boxing and tennis which he often played with his children on the UWI tennis courts after school. His children looked forward to the Fathers' Race on Sports Day as he was always first. He would also encourage and coach them before their sprints.

He kept a variety of books in his study and amongst the academic books and journals were classics by authors such as W. Somerset Maugham and John Steinbeck, romantic novels, poems, West Indian literature, history and others. He was also very interested in architecture and Japanese garden design.

The great architect Frank Lloyd Wright moved him to such a degree that in 1977, he commissioned Hayden Franco, a well-known architect in Trinidad, to design a house with similar flair which was nestled on a prime piece of land in Valley View, Maracas Valley, St. Joseph in Trinidad. This house overlooks the lush green hills of the valley which become studded with yellow Poui trees in the dry season. He and his devoted wife, Olga, would sit on the porch every afternoon either sipping tea or rum, relaxing and chatting, gazing at the hills, the greenery and the birds.

They met at University in Swansea, Wales and together they formed a very strong family unit. They enjoyed entertaining and the children remember the great excitement of preparing for the large dinner parties that they held for their friends. Olga was a superb cook and she executed the menus that they planned together. Although she was 'Head Chef', he could cook a mean Stewed Chicken and Crab Back. His Rum Punch and Ponche de Crème were also second to none.

The lead author of this article, Gyan Shrivastava, has the following remembrance of Professor Phelps:

"In 1972, I came to The UWI St. Augustine as his first doctoral student. His remembrance reminds me that for a research student the commitment, compassion and calibre of his/her supervisor surpasses everything else in a university. Over the decades, I came to know him as a teacher, a colleague and a friend. From such a vantage point, it is a privilege to portray some less known aspects of his life.

He took great care with his writing. To him, good writing meant rewriting until there were no superfluous words. He wrote in pencil in his cursive handwriting, deliberated over his words, and made amendments with an eraser in hand. Thus, his letters of recommendation, which he wrote only occasionally, were such that it was difficult for a selection panel to overlook the power of his words.

He strived for excellence in the preparation of examination questions. His questions were always innovative and did not lack any essential information. Further, his solutions and marking schemes were clear and precise. Besides, his yardstick for a suitable undergraduate question, to be answered within thirty minutes, was that if its solution exceeds a letter-sized sheet of paper, it is too long. It brings to mind the words of Alec Skempton [3]: Winston Churchill wouldn't read a memo unless it was less than one page. Terzaghi's drawings were the same. He said if you couldn't get it down on one letter-sized sheet, you weren't thinking clearly

Needless to say, Professor Phelps was self-disciplined. He lived his life like a laminar flow around a grain of sand [4,5], unaffected by turbulence around him. His life exemplified Primo Levi's words - in "If This Is a Man (The Bodley Head, 1965)" - that we must preserve our physical and moral scaffolding under all circumstances.

There is an inscription above a tomb in the crypt of the St. Paul's Cathedral in London. The tomb is of Sir Christopher Wren, this cathedral's architect, and the inscription reads: "Lector, si monumentum requiris, circumspice" – Reader, if you seek his monument, look around. Professor Phelps, over the years, mentored many civil engineers, who have built and maintained lifeline infrastructural works in the Commonwealth Caribbean and beyond. Looking at the accomplishments of these men and women, the same can be said of him."

Professor Phelps receiving his award for Career of Excellence in Engineering from His Excellency Noor Hassanali, President of the Republic of Trinidad and Tobago at the 1994 Awards Dinner of the Association of Professional Engineers of Trinidad and Tobago

Acknowledgements:

The authors would like to thank the children of Professor Phelps, Sarah, Susan, Vivian and Sonja, for providing a personal insight into his life as a devoted husband and father.

Notes:

[1] NIHERST (2007), *Trinidad and Tobago Icons in Science and Technology*, Vol. II, the National Institute of Higher Education - Research, Science and Technology, Trinidad and Tobago

[2] Norton, S., and Brudenell, S. (2018), Personal Communication (Daughters of Professor Phelps)

[3] Alec Skempton (1914-2001) was a pioneering British Engineer in Soil Mechanics and a professor at Imperial College in London. Karl Terzaghi was an Austrian-American Geotechnical Engineer, and a widely acknowledged expert in Soil Mechanics. The quotation is from "Karl Terzaghi - The Engineer as Artist", Richard E. Goodman, ASCE Press, 1999.

[4] Phelps H.O. (1966), *Laminar Flow over Rough Granular Surfaces*, PhD Thesis, University of Manchester Institute of Science and Technology, Manchester, UK.

[5] Phelps H.O. (1975), "Shallow laminar flows over rough granular surfaces", *Journal of the Hydraulics Division*, ASCE 101 (HY3), pp.367-384.

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