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An Ergonomic Critique and Redesign of a Local Cane Chair in Nigeria with User Body Mass Index

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Abstract: *Furniture is designed to satisfy anthropometrical demands of proposed users and to meet intended usage. The comfort and functional utilities of the furniture depend on its physical design in relation to the physical structure and biomechanics of the human body. In this work, the design of a locally manufactured cane chair in Nigeria was critiqued with the goal of providing more ergonomic designs to satisfy both anthropometrical needs and the design goals. A novel combination of qualitative and quantitative design criteria was used in an experimental setting involving 1,000 user-assessors of varying body weights and heights to criticize the design and construction of the local cane chair. Analyses of results of measurements and interviews show discrepancies in standard design parameters and the design features of the cane chair with different Body Mass Indices (BMI). Using a multi-evaluation functional design approach and two novel design criteria, alternative designs were proposed based on analyzed results for different anthropometrical measures. The results were analyzed in relation to human body mass indices, which are health indicators for various health issues including those occasioned by seating. The work demonstrated a balanced approach using both qualitative and quantitative parameters to assess and influence the redesign of a chair in an experimental setting.*

Keywords: *Cane chair, Ergonomics, Anthropometric measures, Body Mass Index, Redesign.*

1. INTRODUCTION

In this technology-driven and competitive age, every locality looks within itself to exert technological influence on the world while maximizing the benefits of technologies developed in other parts of the globe; some societies copy technology. Every society is endowed with one technology or the other, which supports livelihood, no matter how crude. Such is the manufacturing of local cane chairs in Nigeria,

A chair is a stable, raised surface used to sit on, commonly for use by one person. The use of cane in making seat, table, basket, cot, handbag, hand fan etc., has been with us in Nigeria for some time now. The use of its finished products was seen as crude some years back. But with the ever-increasing cost of leather furniture and the quest to explore resources from nature, cane furniture has become appealing even among wealthy people. Some people prefer the cane chair to the chairs made with synthetic materials for the simple reason of its being more natural. Contrary to popular negative perception on durability, cane seats can be very durable depending on individual usage. It can last for as long as six years without any dent if well handled. Raw materials are obtained in quantum locally.

From [1], the structural size of chair has a definite influence on the of human body, productivity and the operator's health and comfort, and have a direct or indirect impact on safety [2]. Some works have appraised comfort with modification of several different parameter settings of chairs and materials characteristics [3], however, the application of cane for chair design in this context is yet to be reported. Also, despite the wide application of cane for furniture making, its performance evaluation and critique have not caught the attention of researchers. This paper presents an attempt to bridge these gaps. The study was predicated by the geometric increase in the number of individuals with seated occupational health hazards and the costs associated with such health issues [4].

1.1 Species and uses of cane

Two species are used in the business of cane chair construction namely – water and willow canes. The water cane is used in constructing or structuring the seats while the willow cane is used in designing. The most common form of seating is a chair. However, seating can also include benches, stools, swings, pillows, balls, baskets and such [5]. While appropriate and well-designed seats and seating enhance comfort and healthy living, inappropriate and ill-designed seating and seats can cause health problems. For example, bad seats or sitting may increase acute low back pain [6, 7]. Seats can also affect human knowledge, behaviour and musculoskeletal risk [8]. Although, sitting is natural, maintaining one seated position for a long time (like the traditional office task position) is not natural. When we sit erect or in a forward leaning position we place enormous stress and tension on our bodies, particularly the lower or lumbar area of the back and spine. That is why some seating researchers maintain that any chair will become uncomfortable over time. The true objective of an ergonomic chair is to provide not only the proper function but to ensure the subtler yet all-important aspects of user comfort. People who are more comfortable in their chairs are more likely to be able to sit and be productive for longer durations ([9 – 11]). Therefore, while comfort is a key user-centred factor in design, biomechanical, physiological, and postural interdependencies that characterize seat users are also taken into consideration.

1.2 Chair analysis and design

Three different design approaches are possible: (1) Design for extremes (2) Design for average and (3) Design for adjustability.

The Design for extremes implies that a specific design feature is a limiting factor in determining either the maximum or the minimum value of a population variable will be accommodated. For example, reach distances such as Functional Forward Reach should be designed for minimum individual, that is, a 5th percentile female arm length [8]. In doing this, 95% of all females and almost all males will be able to reach forward beyond their arm lengths. On the other hand, clearances, such as sitting height, should be designed for the maximum individual, that is, a 95th percentile male stature, so that 95% of all males and almost all females will be able to fit in to it.

Design for the average is the cheapest but least preferred approach. Even though there is no individual with all average dimensions, there are certain situations where it would be impractical or too costly to include adjustability for all features. For example, most office desks have fixed dimensions and the design for extreme principle is not appropriate in this case.

Design for adjustability is typically used for equipment or facilities that can be adjusted to fit a wide range of individuals. Chairs, vehicle seats, steering columns, and tool supports are devices that are typically adjusted to accommodate the population ranging from 5th percentile females to 95th percentile males. Obviously, designing for adjustability is the preferred method of design. However, there must be a trade-off with cost of implementation as it is more expensive to build. Since we are considering an inflexible chair, design for extremes might be the best option to use. The chair height will therefore be determined at the 50th percentile of the popliteal height for the combined male and female populations (roughly the average of the male and female 50th percentile values) so that most individuals will not be unduly inconvenienced. However, the exceptionally tall male or very short female may experience some postural discomfort.

Chair ergonomics entails how the actual design of the chair affects not only the comfort, but also the humans work activities and interactions with other furniture around them. The dual aim of ergonomics is to maximise performance and health. Thus, in chair design, consideration is also given to intended usage, ergonomics (how comfortable it is for the occupant), as well as non-ergonomic functional requirements such as size, weight, stackability, foldability, durability, stain resistance and artistic design considerations. Ergonomic chair analysis and design is sometimes evaluated by measurements on how the chair fits to a given percentage of parts of the body in a given posture (i.e. reclining, working etc.), sometimes by live experiments in which a sitter's feeling of comfort is recorded, but often by a mixture of both measurement and experiment. In the present study, the ergonomic chair design problem is defined as the problem of finding an optimum set of parameters that control the shape of the chair with respect to a given posture.

Two types of Evaluation Functions were included in the problem: a qualitative Evaluation Function based on the designer's evaluation of how suitable the chair looks for a posture and a quantitative Evaluation Function that measure how closely the chair fits to the sitter's posture.

In ergonomic design, the formalization of qualitative criteria and their integration with quantitative criteria can lead to advantages such as flexibility in solution definition and search, reducing design improvement time, better problem understanding, and better solution delivery by taking advantage of human qualitative judgment.

1.3 Essence of this Critique

Local yet competitive alternatives to imported or import-dependent technologies need to be encouraged. Apart from saving enormous foreign exchange, which is particularly critical in a developing economy, a critical assessment of local technologies with a view to proffering alternative construction and design methods is a step forward in growing technologies. This view informs this critique and redesign of a local cane chair made in Nigeria in this work. The rest of the work is organized in the following manner. In Section 2, the qualitative and quantitative methods used in this critique are explained. Section 3 dwells on the results of the investigation culminating in various shades of analyses. In Section 4, conclusions are drawn and extensions to the subject matter proffered.

2. RESEARCH METHODOLOGIES

The thrust of this work was to critically look at the features of an existing cane chair as constructed and redesign appropriately to meet the anthropometrical demands of all groups of users.

2.1 Pre-Study Design of the Cane Chair

The cane chair under study was procured as a standard type of cane chair in Mende village, Lagos, Nigeria. The configuration of the cane chair is as depicted in Figure 1 below.

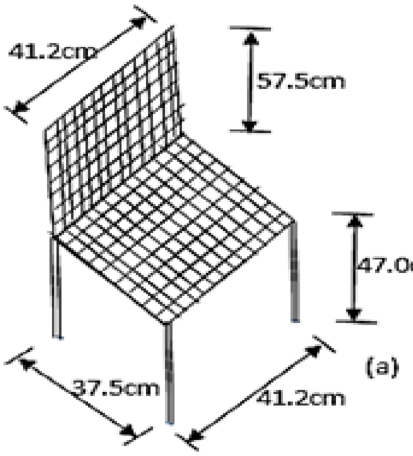

Figure 1: The original cane chair as constructed

The cane chair has neither arm nor foot rests. The backrest was built perpendicular to the seat portion. The chair was constructed solely of cane wood products.

2.2 Experimental Methods

Since this critique was based on both qualitative and quantitative assessment of the cane chair. Both comfort and potential user's liking ratings (qualitative) as well as anthropometrical body data (quantitative) were obtained from potential users using user-responses to questionnaire and direct measurements. For these purposes, a measurement and potential user-response forms were designed for use for individual respondents.

2.2.1 Selected User Distribution

Conscious effort was taken in the selection of respondents so as not to obtain lopsided results. A target total number of one thousand (1,000) respondents were used. Of this number, the guiding gender limitation criterion of using not less than 400 of either male or female gender was used. Two other criteria of selection were height and weight. The weight and height selection considerations for either gender were based on a notion to allow the distributions fit to normal distributions as much as possible. In this respect, the following selection guidelines based on known gender physiological characteristics in the area of investigation were used (Table 1).

All respondents were pre-measured and conscious effort was made to keep to the guidelines in Table 1. These lower bound values of the Weight/Gender and Height/Gender distributions were fitted to Normal Distribution using EasyFit© statistical tool at α=0.05, with critical values of 0.5638 (Kolmogorov-Smirnov, KS, test) and 2.5018 (Anderson-Darling, AD, test). The results for all but one (the male Height/Gender distribution) gave KS statistic of 0.2538 (with p-value of 0.8326) and AD statistic of 0.3263. The male Height/Gender Distribution gave KS statistic of 0.3131 (with p-value of 0.6121) and AD statistic of 0.5032. All computed statistics compared with critical values show good fits to Normal Distribution.

2.2.2 User Comfort Responses

The experiment was designed for user responses rated between 0 and 9 (9 being the highest comfort feeling), varying inclinations (of 90^o, 100^o, 110^o and 120^o with sitting position) for backrest comfort and varying inclinations (of 90^o, 100^o and 110^o with the floor) for leg rest comfort. Each respondent was to sit on the chair for a minimum of one minute. In addition, a user rating (0 – 9) of liking based on aesthetics for the cane chair is also incorporated as part of the qualitative assessment criteria.

Table 1: Selection guidelines for respondents (source: authors' design)

Gender	**Weight (kg) Limitations (Minimum No of Respondents)**				
	< 50	**50 – 59**	**60 – 70**	**71 – 80**	**> 80**
Male	30	100	200	50	20
Female	50	200	100	50	-

Gender	**Height (m) Limitations (Minimum No of Respondents)**				
	< 1.6	**1.6 – 1.69**	**1.7 – 1.79**	**1.8 – 1.89**	**≥ 1.90**
Male	10	150	200	30	10
Female	100	200	50	50	-

2.2.3 Anthropometric Measurements

Anthropometric measurements are quantitative measures for assessing how much a body frame fits into the chair. Different anthropometrical measures such as Functional Forward Reach, Buttock Knee Depth, Buttock Popliteal Depth, Popliteal Height, Thigh Clearance, Sitting Elbow Height, Sitting Eye Height, Sitting Height, Hip Breadth, Elbow to Elbow Breadth, Weight and Height were designed to be measured directly for each respondent sitting on the cane chair. This is with a view to compare with Design for Extreme recommended values found in literature as a means of criticising the chair and a basis for recommending redesign parameters for the chair.

2.3 Methods of Analysis

Analyses were based on responses and measurements obtained from and on respondents. Quantitative and qualitative measurements were adopted for the critique while the hybrid of the two was adopted for redesign.

Furthermore, the investigation was directed in relation to the Body Mass Index (BMI) of the respondents because of the health implications of BMIs and as a pedestal for future work to infer directly on health implications. The BMI is defined as the ratio of the body mass (in kilogrammes) to the square of height of an individual. [12, 13]

$$BMI = \frac{Weight}{(Height)^2}\ kg/m^2 \quad (1)$$

Hence, in this work, a method of critique based on the Body Mass Index of respondents was used in assessing the cane chair in relation to the quantitative, qualitative and hybrid Evaluation Functions spelled out in the latter part of this section.

Three types of Evaluation Functions were included in the problem: a qualitative Evaluation Function based on the user's subjective evaluation of how suitable the chair appears for aesthetic liking and comfort sitting on it (for ergonomic critique) and in addition, comfortability rating for combinations of different configuration of additional feature (for redesign), a quantitative Evaluation Function that measures how closely the chair fits to the sitter's posture based on anthropometric measures and a hybrid of the two. The following Evaluation Functions were defined.

2.3.1 Evaluation Function 1: Qualitative Evaluation Function

$$f_{user} = f_{user}\left(C_p, L_p\right) \quad (2)$$

where

C_p = user rating (on a scale of 0 – 9) of comfort for various postures on the chair for a person p.

L_p = user rating (on a scale of 0 – 9) for liking (aesthetics) for a person p.

For the comfort evaluation ratings, two parameters were obtained: backrest comfort (c_{bip}) and legrest comfort (c_{lip}). The overall comfort rating C_p, for each user is taken as the average of the backrest comfort and the largest comfort ratings for varying back and leg inclinations at 90^o, 100^o, 110^o, and 120^o to the spine and thigh positions (cases $i = 1, 2, 3, 4$ respectively)

$$C_p = \frac{1}{n_c}\sum_{i=1}^{4}(c_{bip} + c_{lip}) \quad (3)$$

where n_c is the number of comfort rating parameter variants (in this case, $n_c = 8$ per person). The qualitative user ratings of the chair from individual persons are then combined and averaged for the overall user Qualitative rating.

$$F_{Ql} = \frac{1}{N}\left[\left(\sum_{p=1}^{N} C_p\right) + \left(\sum_{p=1}^{N} L_p\right)\right] \quad (4)$$

2.3.2 Evaluation Function 2: Quantitative Evaluation Function

The seated human body's sitting positional data obtained using the data acquisition form was used to measure users' anthropometrical measures of the respondents. The anthropometrical data were those of functional forward reach, buttock-knee depth, popliteal height, sitting elbow height, sitting height, elbow-to-elbow breadth, buttock-popliteal depth, thigh clearance, sitting eye height and hip breadth. These measures for individuals used in the designed experiment were compared with Design for Extreme percentile measures for design. The measure of deviation for various cases of height and weight are used as bases of criticism for the designed chair. Finally, redesign parameters for the chair were specified following the measure of deviations established.

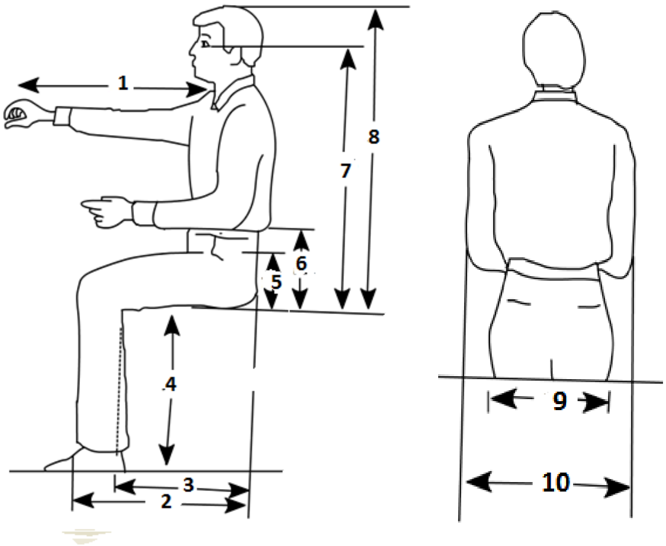

Figure 2: Anthropometric measurements of sited human being

<u>Legend</u>

1 - Functional Forward Reach (FFR)
2 – Buttock Knee Depth (BKD)
3 – Buttock Popliteal Depth (BPD)
4 – Popliteal Height (PH)
5 – Thigh Clearance (TC)
6 – Sitting Elbow Height (SELH)
7 – Sitting Eye Height (SEYH)
8 – Sitting Height (SH)
9 – Hip Breadth (HB)
10 – Elbow-to-Elbow Breadth (EEB)

From literature, Design for Extreme measures [8, 14 – 18] used to compare experimental values for the above anthropometric measures are as below:

Reach Distances – 5th percentile female arm length (for 1 only)
Chair height – 50th percentile popliteal height (for 2, 3 and 4)
Clearances – 95th percentile population (for 5, 6, 7, 8, 9, and 10)

Thus, the evaluation functional measure for the quantitative measures $j = 1, 2, \ldots, 10$, used is composed as follow below. The quantitative measure for every person, f_{Qtp}, p (p = 1, 2, . . . , N) was obtained as a normalised measure, $0 \leq f_{Qtp} \leq 1$ so that it can be comparable because of unit disparity to the qualitative measures which are essentially in that range. [19, 20]

$$f_{Qtp} = \left[\frac{1}{10}\sum_{j=1}^{10}\left(\frac{S_j - X_{jp}}{R_J}\right)^2\right]^{1/2} \quad (5)$$

where,

S_i = Recommended percentile value of measure j, $j = 1, 2, 3, \ldots, 10$

X_{ip} = Person value p, $p = 1, 2, \ldots, N$ of measure j, $j = 1, 2, 3, \ldots, 10$

$R_j = x_j^{max} - x_j^{min}$ = The range of measure j, $j = 1, 2, 3, \ldots, 10$

x_j^{max} = Maximum value of measure j, $j = 1, 2, 3, \ldots, 10$, over all persons measured.

x_j^{min} = Minimum value of measure j, $j = 1, 2, 3, \ldots, 10$, over all persons measured.

From this the overall Quantitative measure is obtained as,

$$F_{Qt} = \frac{1}{N}\sum_{p=1}^{N}\left[\sum_{j=1}^{10}\frac{1}{R_j}\left(S_j - X_{jp}\right)^2\right]^{1/2} \quad (6)$$

$$F_{Qt} = \frac{1}{N}\sum_{p=1}^{N}\left[\sum_{j=1}^{10}\frac{1}{R_j}\left(S_j - X_{jp}\right)^2\right]^{1/2} \quad (7)$$

N = Total number of persons for any case of analysis

2.3.3 Evaluation Function 3: Hybrid of Qualitative and Quantitative Functions

A third Evaluation Function is a linear combination of the Qualitative and the Quantitative Evaluation Functions to serve as a measure of assessment of the chair's ergonomic value on both bases. [20]

$$F_{Ql+Qt} = [(1 - F_{Ql}) + \hat{F}_{Qt}] \quad (8)$$

2.4 Method of Redesigning the Cane Chair

Several design variables can be used for redesigning the chair. These include backrest, angle of backrest to seat, footrest, angles of footrest to seat, seat contour, cushioning and seat height. Of these, the angle of backrest and the footrest were taken cognisance of in this work on account of simplicity.

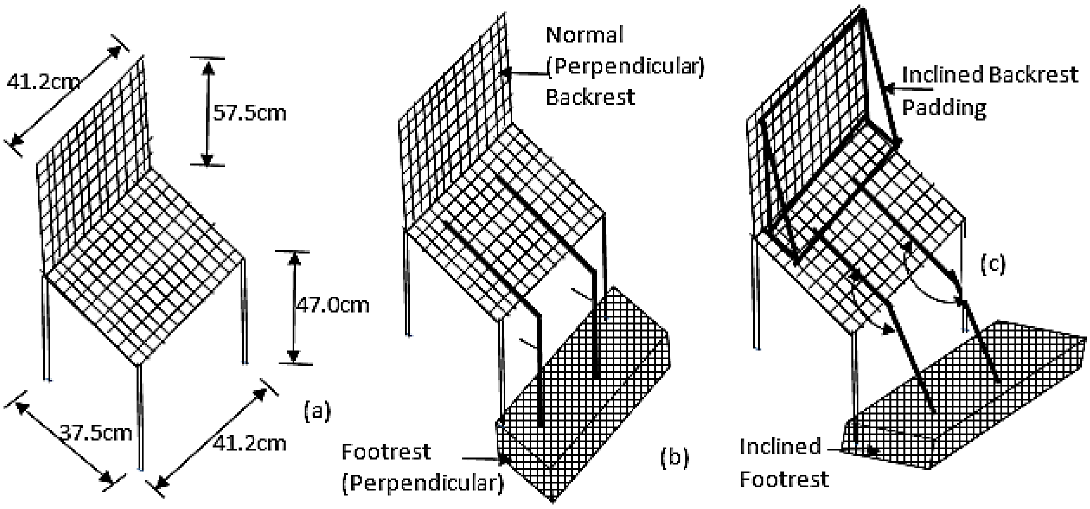

Figure 3: Cane chair configurations (a) As constructed (b) Experimental – perpendicular footrest and backrest (c) Experimental – inclined footrest and inclined (padded) backrest

The formulated Evaluation Functions are overall measures of the chair's ergonomic value. Thus, the chair design parameters, which optimize them, are the best-adjudged design parameters. In addition, the mean deviation values of the various quantitative measures and the mean qualitative ratings are bases of critical evaluation of the chair's ergonomic values. The various angles of inclinations were earlier explained in Section 2.2.

3. RESULTS, ANALYSIS AND DISCUSSION

3.1 Critique

The critique of the cane chair was based on respondents' observations on the chair as well as direct evaluation of quantitative and qualitative Evaluation Functions as defined above with and without weight, height and Body Mass Index (BMI) considerations.

3.1.1 Qualitative Evaluation and Critique Based on Comfort and Liking

Table 2: Qualitative values based on comfort and liking

WHO Classes	BMI Class	Frequency	Average Liking	Average Comfortability	Average Qualitative Value
Severe thinnes	< 16.00	7	0.5571429	0.535714	0.546428
Moderate thinness	16.00 - 16.99	11	0.5454545	0.564773	0.555114
Mild thinness	17.00 - 18.49	63	0.5625	0.544922	0.553711
Normal Range	18.50 - 24.99	637	0.6136792	0.498369	0.556024
Obese Class 1	25.00 - 34.99	282	0.6131206	0.472178	0.542649

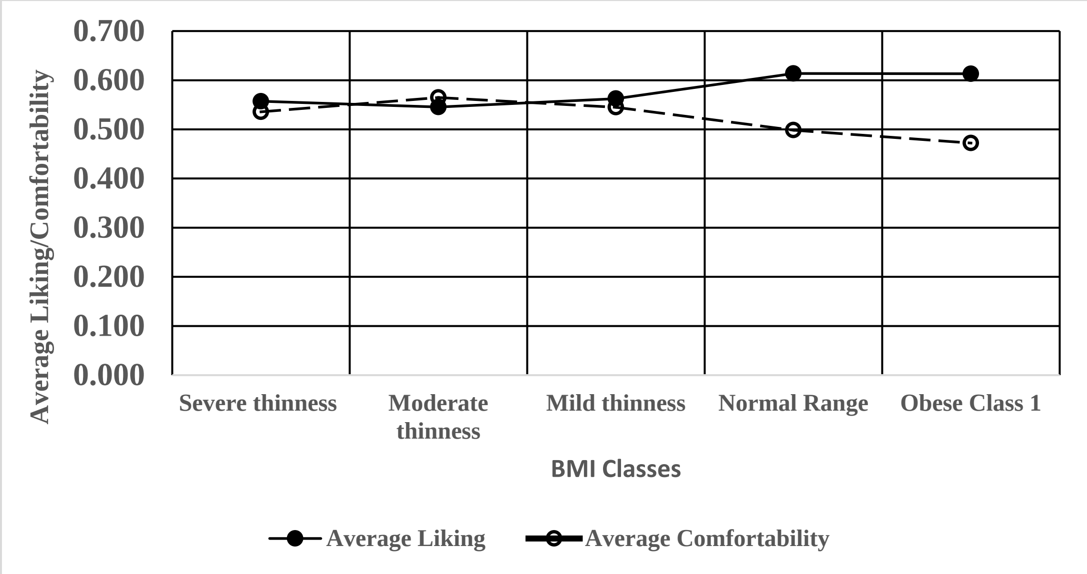

Figure 4: Average liking/comfortability variation with BMI

From Table 2 and based on the World Health Organisation (WHO) classification, there are marginal differences in qualitative assessment of respondents. However, respondents in both the normal and Obese Class 1 Body Mass Index (BMI) range express better liking and worse comfortability with the cane chair compared to the assessment of the uppermost BMI classes in the thinness group. In particular, the cane chair appears more uncomfortable in general as the tendency for obesity increases. The liking assessment tends to be more of a psychological assessment of the supportability of the cane chair for which the more obese have more liking for.

3.1.2 Quantitative Evaluation and Critique based Anthropometrical Measures and BMI

The cane chair critique was also performed based on anthropometric measures with weight and height being components on one hand and solely anthropometrical measures compared to Classes of Body Mass Index (BMI) on the other hand. The first case established whether weight and height considerations could affect quantitative assessment of the cane chair while the second was used to run the critique based on Body Mass Index (BMI).

Table 4 presents the Percentile measures of anthropometric measures of the 1000 respondents for males, females and the whole population of respondents.

Table 3: Percentile anthropometric body measurement of respondents

Body Dimensions (cm)	FEMALE			MALE			POPULATION		
	5th	50th	95th	5th	50th	95th	5th	50th	95th
Functional Forward Reach	64.4	69.5	76.9	71.1	79.5	85.0	64.4	73.1	82.0
Buttock-Knee Depth	50.6	56.0	61.0	53.4	57.9	62.9	49.8	57.9	64.4
Buttock-popliteal Depth	43.6	48.1	54.5	44.1	48.9	54.1	41.3	48.9	55.0
Popliteal Height	36.8	42.2	47.0	38.0	43.7	50.6	33.0	50.6	51.6
Thigh Clearance	12.6	16.3	20.0	11.6	14.2	18.4	11.0	15.9	**18.4**
Sitting Elbow Height	17.4	20.0	22.6	17.1	22.4	27.3	16.8	23.0	**27.3**
Sitting Eye Height	63.8	67.2	71.7	68.5	77.0	83.4	63.2	72.0	**83.4**
Sitting Height	73.3	78.5	87.6	80.8	88.2	93.2	73.3	80.7	**88.2**
Hip Breadth	31.0	36.7	42.3	29.7	34.6	40.5	29.3	34.3	**36.7**
Elbow-to-Elbow Breadth	36.5	41.6	49.0	34.3	40.5	48.8	33.2	42.0	**41.6**
Weight	47.4	57.7	70.3	52.5	66.4	82.1	51.0	**66.4**	81.4
Height	156.5	163.5	174.2	158.6	170.5	182.2	157.0	**170.5**	178.5

Table 4: Quantitative functional evaluation based on respondents' weights

Height Class (m)	Mean Deviation from Design for Extreme Anthropometric Measures	
	Without Height	With Height
0 - 1.55	3.807	4.020
1.56 - 1.60	3.288	3.327
1.61 - 1.65	3.217	2.978
1.66 - 1.70	3.098	2.711
1.71 - 1.75	3.048	2.670
1.76 - 1.80	2.979	2.764
1.81 - 1.85	2.811	2.900
1.86 - 1.90	3.543	4.071
1.90 - 2.00	2.267	3.400

For Design considerations and comparative measures for experimental values, the Design for Extreme anthropometric measures is as highlighted in Table 3 above.

Using these and the quantitative Evaluation Function defined earlier (Equation 7), the minimum Euclidean deviation from Design for Extreme measurements were obtained for cases of when weights and heights of respondents were included or excluded from the set of anthropometric measures. The essence of these was to determine whether weight, height or both have statistical significance in the use of the anthropometrical measures in the chair ergonomic evaluation. Using the Microsoft Excel Correlation Coefficient function between the two groups of values (with and without respondents' weights) a Correlation coefficient of 0.51 was obtained. This shows there is a lean correlation between the two cases. By implication, weights of respondents influence the quantitative Evaluation Functional measurements and should thus be taken into consideration.

In a similar way, the Quantitative Functional Evaluation with and without respondents' heights were also obtained as in Table 5 below.

Table 5: Quantitative evaluation functions based on respondents' heights

Height Class (m)	Mean Deviation from Design for Extreme Anthropometric Measures	
	Without Height	With Height
0 - 1.55	3.807	4.020
1.56 - 1.60	3.288	3.327
1.61 - 1.65	3.217	2.978
1.66 - 1.70	3.098	2.711
1.71 - 1.75	3.048	2.670
1.76 - 1.80	2.979	2.764
1.81 - 1.85	2.811	2.900
1.86 - 1.90	3.543	4.071
1.90 - 2.00	2.267	3.400

Using the Microsoft Excel Correlation Coefficient function between the two groups of values (with weight and without heights), a Correlation coefficient of 0.22 was obtained. This shows there is a weak correlation between the two cases. By implication, heights of respondents influence the quantitative Evaluation Functional measurements and should thus be taken into consideration.

From the foregone, both the weights and the heights of the respondents need to be taken into consideration. Of the two measurements, it is obvious that the height has the higher dis-correlation with the Quantitative Evaluation Functional measurements and is expected to influence the Quantitative Evaluation Functional value more. However, a veritable relationship between weight and height of an individual, which also have medical implications, is the Body Mass Index defined earlier.

Table 6 shows the evaluations of the Quantitative Evaluation Function with and without weights and heights based on Body Mass Index (BMI). With the exclusion of the Obese classes 1 and 2 for which there were no respondents and using Microsoft Excel's Correlation Coefficient function, Correlation Coefficients of 0.985 was obtained for the classifications based on Body Mass Index (BMI). This shows that there is high correlation between the two groups (with and without weights and heights). By inference, the effects of both heights and weights were taken care of and with or without weights and heights measurements when responses were classified into BMI classes.

Using the deductions in this sub-section, the maximum, mean and minimum values of the Quantitative Evaluation. Functional values were obtained for various classes of BMI and deductions made as to the percentage of deviation of the average from the minimum (assuming a design for average approach) as well as the Root Mean Square Error (RMSE) of deviation from the global minimum Evaluation Functional value as depicted in Table 7 and Figure 5.

Table 6: Quantitative functional evaluation based on respondents' Body Mass Indices (BMI)

WHO Classes	BMI	Mean Deviation from Design for Extreme Anthropometric Measure	
		Without Weight and Height	With Weight and Height
Severe thinness	< 16.00	2.880	3.460
Moderate thinness	16.00 - 16.99	2.808	3.225
Mild thinness	17.00 - 18.49	2.797	3.131
Normal Range	18.50 - 24.99	2.590	2.612
Obese Class 1	25.00 - 34.99	2.647	2.869
Obese Class 2	35.00 - 39.99	0.000	0.00
Obese Class 3	>= 40.00	0.000	0.00

Table 7: Quantitative functional evaluation and percentage deviations (based on design for average approach)

WHO Classes	BMI Class	Quantitative Evaluation Function Analysis				
		Minimum	Average	Maximum	% Deviation	RMSE
Severe thinness	< 16.00	17.17	25.62	30.76	18.15	18.96
Moderate thinness	16.00 - 16.99	19.85	25.10	33.86	23.16	18.10
Mild thinness	17.00 - 18.49	13.01	25.08	44.94	10.40	18.30
Normal Range	18.50 - 24.99	7.44	23.79	61.05	0.00	17.08
Obese Class 1	25.00 - 34.99	10.66	24.14	57.10	6.01	17.41
	Global	7.44		61.05		

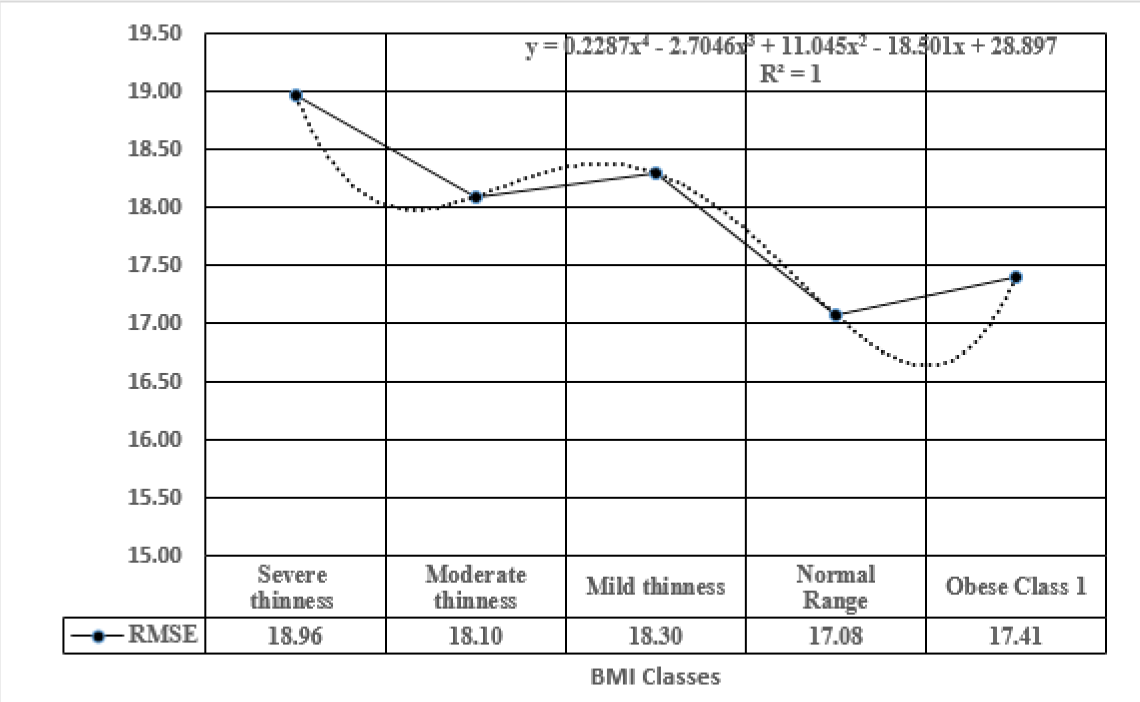

Figure 5: RMSE of quantitative evaluation functional values with BMI classes

The normal BMI class offers the minimum percentage absolute deviation (of zero) and an RMSE of 17.08 from the global minimum. This suggests that persons within normal range BMI are best suited to use the cane chair based on the Quantitative Evaluation Function alone, while the use of the cane chair will suit the group of people in class of severe thinness the least. Using a fitted polynomial of order 4 the trend line for the variation of RMSE with BMI was obtained at a coefficient of determination (R^2) of 1 suggesting the variation can be approximated with the polynomial,

$$y = 0.2287x^4 - 2.7046x^3 + 11.045x^2 - 18.501x + 28.897 \quad (9)$$

where y = RMSE value and x = BMI Classes (in the range 1 – 5) in the order listed from the Severe thinness class. The approximated values 18.9661, 18.0994, 18.3025, 17.0698 and 17.3845 of RMSE were therefrom obtained for the respective classes of BMI. This approximation shows that people in the Normal BMI class are the most suited for the cane chair based on the hybrid Evaluation Function evaluated. The global minimum also lies in the Normal class confirming the finding further. Marginally, it can be asserted that the more obese a person is, the better suited the cane chair is to support his or her body frame. This deduction was corroborated by the average liking qualitative assessment returned by the respondents.

The global minimum RMSE value of the approximating function is 16.6282 within the Normal range BMI class at

$x = 4.508405$ corresponding to an approximate BMI of 18.57.

The anthropometric measurements corresponding to the Design for Extreme anthropometric measures derived (as in Table 4), those corresponding to the 50th percentile of Quantitative Evaluating Function (assuming design for average) and those corresponding to the global minimum RMSE (Quantitative) of the approximating function are exhibited in Table 8. The anthropometric measures (FFR, BKD, BPD, PH, TC, SELH, SEYH, SH, HB and EEB) are as earlier defined in sub-Section 2.3.2)

For a single-factor Analysis of Variance at a level of significance of $\alpha = 0.05$, there was no established statistical significance between the means of the three groups with a calculated F-value of 0.0578 compared to an F-Critical value of 3.3541 corresponding to the degrees of freedom of 2 and 27 between and within the groups respectively. Thus, any of the three criteria is good enough to be a basis for design of the cane chair based on quantitative method employed here. However, further scrutiny using cross-correlation analysis performed aimed at testing the level of significance of difference in each pair of measures using the CHISQ.TEST function in Microsoft Excel are as depicted in Table 9. From Table 9, it is obvious that the Minimum RMSE Criterion has the higher cross-correlation coefficients of 0.94341 and 0.958812 with the Average and averagely good correlation with the Design for Extreme Criterion. The RMSE Criterion can thus be safely adopted as the Design criterion, even in place of the stop-gap or middle-of-the-road approach the Average Criterion is based on.

3.1.3 Hybrid of Qualitative and Quantitative Evaluation and Critique

Further critical evaluation of the cane chair's suitability can be performed by using the hybrid Evaluation Function given by Equation 8. Since the results in using Quantitative Functional evaluation shows the effects of weights and heights of respondents significantly influence evaluation, the hybrid Evaluation Function (Qualitative and Quantitative) are also based on BMI classification. Table 10 shows the variations of the Normalised Hybrid Functional evaluation based respondents' Body Mass Index (BMI).

Table 8: Anthropometric measures based on design for extreme, average and RMSE quantitative criteria

	ANTHROPOMETRIC MEASURES									
	FFR	BKD	BPD	PH	TC	SELH	SEYH	SH	HB	EEB
EXTREME	64.4	57.9	48.9	50.6	18.4	27.3	83.4	88.2	36.7	41.6
AVERAGE	68.63	57.09	54	44	14.8	19.6	69.6	78	38.64	41.6
MIN. RMSE	67.78	60.22	47.61	42.41	19.07	22.93	72.39	78.02	38.66	46.39

Table 9: Cross-correlation coefficients for chair criteria design with anthropometric measures

	Extreme	Average	Min. RMSE
Extreme		0.36592	0.70673
Average	0.52173186		0.958812
Min. RMSE	0.77547395	0.94341	

Table 10: Hybrid functional evaluation based on respondents' Body Mass Indices (BMI)

WHO Classes	BMI	Normalised Hybrid Evaluation Functional Values	
		Without Weight and Height	With Weight and Height
Severe thinness	< 16.00	0.546	0.511
Moderate thinness	16.00 - 16.99	0.545	0.519
Mild thinness	17.00 - 18.49	0.554	0.532
Normal Range	18.50 - 24.99	0.576	0.571
Obese Class 1	25.00 - 34.99	0.568	0.552
Obese Class 2	35.00 - 39.99	0.000	0.000
Obese Class 3	>= 40.00	0.000	0.000

With the exclusion of the Obese classes 2 and 3 for which there were no respondents and using Microsoft Excel's Correlation Coefficient function, Correlation Coefficients of 0.998 was obtained for Hybrid functional evaluations with and without the height of the respondents based on Body Mass Index (BMI) classification. The implication of these high correlation coefficients is that when classified into different BMI classes, the effects of both heights and weights are taken care of and with or without weights and heights measurements. Using the deductions in this section, the maximum, mean and minimum values of the hybrid Evaluation Functional values were obtained for various classes of BMI and deductions made as to the percentage of deviation of the average from the minimum (assuming a design for average approach) as depicted in Table 11 and Figure 6. From the Hybrid Evaluation Functional analysis above, the moderate thinness BMI class offers the minimum percentage absolute deviation of 0.077 but in terms of RMSE the Mild thinness class offers the minimum value of 0.284 (which is a marginally higher value compared to the 0.309 and 0.300 for the normal and Obese 1 classes respectively) from the global minimum. This suggests that persons within the mild thinness, Obese 1 and normal BMI classes more suited to use the cane chair in that order while the persons within severe thinness BMI class are least suited.

However, using a fitted polynomial trend line of order 4 for the variation of RMSE with BMI obtained at a coefficient of determination (R^2) of 1 suggests the variation can be approximated with the polynomial,

$$y = -0.0332x^4 + 0.4156x^3 - 1.7811x^2 + 2.9318x - 1.0106 \quad (10)$$

where y = RMSE value and x = BMI Classes (in the range 1 – 5) in the order listed from the Severe thinness class. The approximated RMSE values 0.5225, 0.5222, 0.2869, 0.3182 and 0.3209 were therefrom obtained for the respective classes of BMI. With this approximation, it can be deduced that persons in the mild thin BMI class are most suited to use the cane chair based on hybrid qualitative/quantitative evaluation. The global minimum RMSE of the approximating function is conclusive and based on the Hybrid (Qualitative and Quantitative) Evaluation Function defined and the high coefficient of determination of the trend line used for approximating the trend, the more obese a person is the better suited the cane chair to support his body frame. This deduction was corroborated by the deductions made in the case of use of Quantitative Evaluation Functional value alone and average liking qualitative assessment returned by the respondents.

The global minimum RMSE value of the approximating function is 0.2658 within the Mild Thinness BMI class at $x = 3.3563$ corresponding to an approximate BMI of 17.534.

The anthropometric measurements corresponding to the Design for Extreme anthropometric measures derived (as in Table 4), those corresponding to the 50th percentile of Hybrid Evaluating Function (assuming design for average) and those corresponding to the global minimum RMSE (Hybrid case) of the approximating function are exhibited in Table 12.

Table 11: Hybrid functional evaluation and percentage deviations based on design for average approach

BMI Classes	BMI	Hybrid Evaluation Functional Analysis				
		Minimum	Average	Maximum	% Absolute Deviation	RMSE
Severe thinness	< 16.00	0.594	0.546	0.476	0.035	0.522
Moderate thinness	16.00 - 16.99	0.592	0.545	0.484	0.008	0.521
Mild thinness	17.00 - 18.49	0.641	0.554	0.432	0.083	0.284
Normal Range	18.50 - 24.99	0.742	0.576	0.274	0.077	0.309
Obese Class 1	25.00 - 34.99	0.724	0.568	0.324	0.294	0.300
	Global	**0.274**		**0.742**		

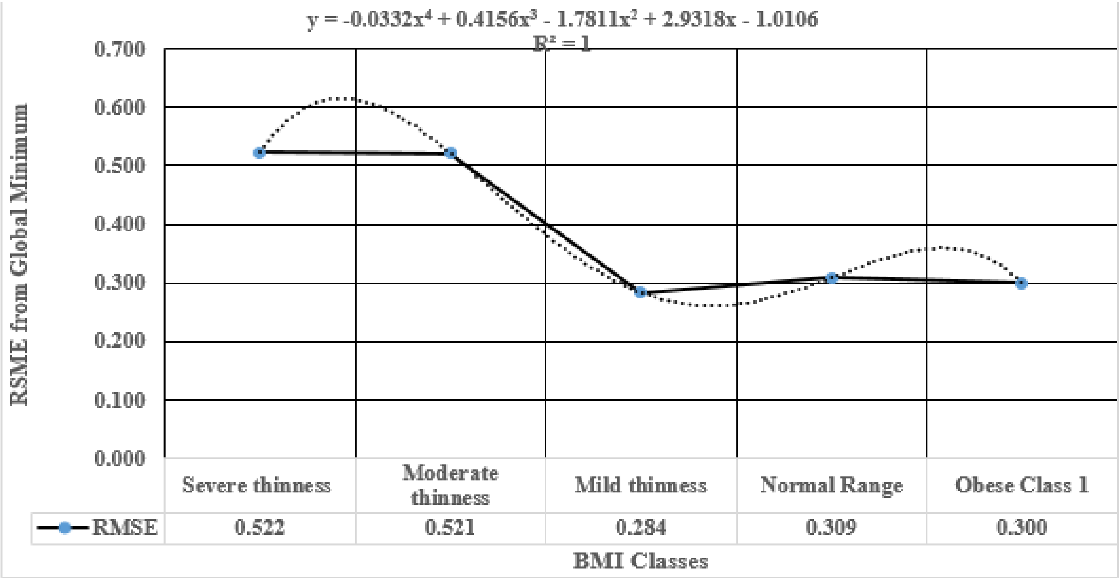

Figure 6: RMSE of hybrid evaluation functional values with BMI

Table 12: Anthropometric measures based on design for extreme, average (hybrid) and RMSE (hybrid) criteria

	ANTHROPOMETRIC MEASURES									
	FFR	**BKD**	**BPD**	**PH**	**TC**	**SELH**	**SEYH**	**SH**	**HB**	**EEB**
EXTREME	64.4	57.9	48.9	50.6	18.4	27.3	83.4	88.2	36.7	41.6
AVERAGE	73.2	57.1	48.7	48	17	24.4	68	76.4	31.2	43
MIN. RMSE	76.1	54	41.2	46	15	25	72.3	82	38	33

It was established (using a single-factor Analysis of Variance at a level of significance of $\alpha=0.05$) that there was no statistical significance between the means of the three groups with a calculated F-value of 0.099887 compared to an F-Critical value of 3.3541 corresponding to the degrees of freedom of 2 and 27 between and within the groups respectively. Thus, each of the three is good to be a basis for design of the cane chair based on quantitative method employed here. However, further scrutiny using cross-correlation analysis performed aimed at testing the level of significance of difference in each pair of measures using the CHISQ.TEST function in Microsoft Excel are as depicted in Table 13.

Again, just as in the case of Qualitative Evaluation Function alone, the Minimum RMSE Criterion correlates higher with the Average Criterion with cross-correlation coefficients 0.71348 and 0.6468 and very poorly with the Design for Extreme Criterion. This is a vindication of the Average Criterion as a stopgap design criterion and since the Minimum RMSE in this case is deduced from the Design for Extreme Criterion, the RMSE can be used as a better option than the prescribed Design for Extreme.

Table 14 summarises the comparative design features of the chair as constructed and based on RMSE Criterion (Qualitative and Hybrid).

Table 13: Cross-correlation coefficients for chair criteria design with anthropometric measures (hybrid)

	EXTREME	**AVERAGE**	**MIN. RMSE**
EXTREME		0.53454	0.3994
AVERAGE	0.6313		0.6468
MIN. RMSE	0.4771	0.71348	

Table 14: The cane feature-design parameters compared

Seat Feature	Anthropometric Measurement Basis	As Constructed (cm)	RMSE Criterion (cm)	
			Quantitative only	Hybrid
Seat Surface Height	Popliteal Height (PH) + Shoe Heel Allowance (0.45cm)	47.5	42.96	46.45
Seat Depth	Buttock-Popliteal Depth (BPD)	37.5	47.61	41.2
Seat Width	Hip breadth Sitting (HP)	41.00	38.66	38.0
Back Rest Width	Hip breadth Sitting (HP)	41.00	38.66	38.00
Back Rest Height	Sitting Shoulder Height (SEYH – TC)	57.5	53.32	57.3

Correlation test performed on the three streams of chair parameters reveals that Hybrid RMSE Criterion has the higher correlation coefficient of 0.9412 with the parameters of the cane chair as constructed as against the Quantitative RMSE Criterion's correlation of 0.6521. The cane chair thus has ergonomic merit as constructed. This may not be attributable to any scientific or artistic design attribute but to construction experience garnered over several years.

3.2 Redesigning

As earlier indicated, the redesign of the chair was based on incorporating two of the major features absent in the construction of the chair (back/neck rest and leg rest) based on anthropometrical measurements and various combinations of the added backrest and leg rest as well as qualitative measurements of comfort and liking rated by the respondents.

3.2.1 Quantitative Redesign with Weight and Height variation.

Evaluation of the quantitative anthropometrical measures based on different positioning of the leg rest and back rest are as depicted in Table 15.

Table 15: Redesigning with combinations of Back Rest (BR)/Leg Rest (LR) angles based on BMI

WHO Class/ BMI	LR	90	90	90	90	100	100	100	100	110	110	110	110
	BR	90	100	110	120	90	100	110	120	90	100	110	120
Severe thinness (< 16.00)	Max.	0.57	0.61	0.57	0.54	0.58	0.64	0.59	0.58	0.64	0.59	0.64	0.59
	Avg.	0.53	0.52	0.52	0.46	0.55	0.54	0.54	0.48	0.55	0.54	0.54	0.48
	Min.	0.46	0.44	0.44	0.40	0.51	0.45	0.49	0.40	0.46	0.48	0.48	0.43
Moderate thinness (16.00 - 16.99)	Max.	0.62	0.62	0.60	0.56	0.64	0.62	0.65	0.58	0.56	0.54	0.58	0.51
	Avg.	0.56	0.54	0.55	0.50	0.57	0.56	0.57	0.51	0.52	0.50	0.51	0.46
	Min.	0.49	0.49	0.47	0.44	0.51	0.51	0.46	0.44	0.48	0.46	0.42	0.41
Mild thinness (17.00 - 18.49)	Max.	0.69	0.66	0.68	0.66	0.71	0.68	0.67	0.67	0.66	0.66	0.66	0.63
	Avg.	0.58	0.57	0.58	0.51	0.57	0.56	0.58	0.51	0.55	0.54	0.55	0.48
	Min.	0.43	0.43	0.49	0.40	0.42	0.44	0.44	0.38	0.38	0.37	0.42	0.28
Normal Range (18.50 - 24.99)	Max.	0.81	0.81	0.81	0.78	0.83	0.83	0.82	0.76	0.83	0.80	0.82	0.77
	Avg.	0.61	0.59	0.61	0.54	0.61	0.60	0.61	0.55	0.59	0.58	0.59	0.53
	Min.	0.28	0.30	0.23	0.23	0.33	0.35	0.28	0.28	0.32	0.33	0.27	0.27
Obese Class1 (25.00 - 34.99)	Max.	0.78	0.74	0.76	0.69	0.75	0.72	0.79	0.71	0.78	0.72	0.77	0.69
	Avg.	0.59	0.58	0.59	0.53	0.59	0.58	0.58	0.52	0.57	0.56	0.56	0.50
	Min.	0.22	0.25	0.33	0.30	0.23	0.27	0.35	0.28	0.30	0.33	0.33	0.25
Maximum		0.81	0.81	0.81	0.78	0.83	0.82	0.82	0.76	0.83	0.80	0.82	0.77

Using Equation 9 and the result based on various classes of BMI in Table 15, it can be seen that the Footrest/Backrest combinations of 100/90 and 110/90 are the best-suited design. This coupled with the chair design parameters obtained for the hybrid case in Sub-Section 3.1 determine the best chair configuration determinable by the hybrid qualitative/quantitative experimental-based approach to the cane chair ergonomic evaluation. The redesigned cane chair configuration are thus as depicted in Figure 7.

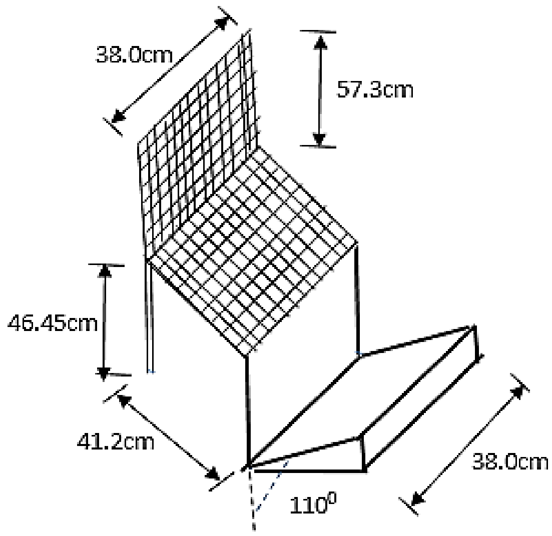

Figure 7: The re-designed Cane Chair with Hybrid RMSE Criterion

4. CONCLUSIONS

In this paper, critical evaluation of the anthropometrical quality of a local cane chair in Nigeria and redesign based on Body Mass Indices were undertaken. A multi-evaluation functional design approach and two novel design criteria were used to propose alternative designs to optimize anthropometrical measures. The results were analyzed in relation to human body mass indices, which are health indicators for various health issues including those occasioned by seating. The work demonstrated a balanced approach using both qualitative and quantitative parameters to assess and influence the design of a chair in an experimental setting.

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