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Ergonomical Evaluation for the Design of EMU Library Furniture and Proposing a Better Design

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***Abstract*—The point of the article is proposed better design of EMU Library by assessing its furniture and its impact on the understudy stance, execution and consideration. One hundred and fifty four undergraduate and postgraduate were measured. They were between 16 to 45 years old. Twelve information of anthropometry of the subjects were measures including: Stature, Shoulder Elbow Height, Shoulder Height, Popliteal Height, Knee Height, Forearm Length, Buttock-to-Popliteal Length, Elbow Sitting Height, Hip Width, Sitting Height, Sitting, Overhead Stretch Height, and Eye Height. Standard deviation, mean, percentiles, least and greatest estimation of measurements were figured**

Ergonomic design criteria, Anthropometric data, Mismatch, Dimension, Percentile

I. INTRODUCTION

The academic library was, and always will be an integral part of learning. Even in this digital age, the library has a lot to offer by managing online data, weaving and sorting electronic sources, and providing support to users who are constantly bombarded by electronic information. While it is true that students live, breath, socialize and interact in the digital environment they still need the library's support to help them organize, structure and prioritize electronic information [2].

The library can still function under its traditional setting it is evident that there has to be a shift of the library's priorities from investing in physical and analogue items to electronics ones [3]. Therefor; it is necessary to focus in workstation area and design of university library where a lot of students spend a considerable part of their daily life, using library furniture; not surprisingly, due to lack of proper anthropometric database, these products have typically been ill fitted for the intended user populations. The library environment can be defined as a system which includes the following components:

- Furniture such as bookshelf, tables, seat and other work surface.
- Computer equipment such as screen, keyboard, CPU and mouse device.
- Environment factors such as illumination, glare, temperature, noise and humidity.

We know the student's bodies are facing many significant stresses, without being aware of them, from extending their wrists; or slouching, or sitting without armchair and feet support or also straining to look at poorly placed monitor [3]. We know the aim of ergonomics as a science is to reduce strain, fatigue, and injuries of human by improving the product design and workspace arrangement. It has always claimed a comfortable design and relaxed posture. Therefore, in the library workstation design, it is important to use anthropometric measures.

In the design, we need dimensions such a sitting elbow height, shoulder height, knee height, upper arm length, sitting height, popliteal height and buttock-to-popliteal length. Moreover, to assess the degree of success in product design we can determine the degree of fitness to human body dimensions which we called "mismatch ratio" [3]. This mismatch might affect the studying process, even during the most interesting and stimulating interactions and can produce some musculoskeletal disorders, such as neck and low-back pain.

The existing library furniture at Eastern Mediterranean University, Famagusta, Turkish Republic of Northern Cyprus had fixed dimensions for all the students and served as a reference. We hypothesized that this would give uncomfortable and tiring sitting positions to majority of students. The main objective of this study was to perform an anthropometric survey and to define the optimal dimensions and characteristics of library furniture through the application of validated and valuable anthropometric criteria.

The students spend many hours each day in library either in front of computer screen or just reading or studying by sitting on chair with table without thinking about the health impact of the related human posture. A physical stress may result on human bodies from sitting incorrectly at workstation; the symptoms from such postures may be strain fatigue, and cumulative trauma and repetitive stress injuries that affect negatively the performance. This project focuses on optimize the proper furniture design to reduce musculoskeletal discomfort [3].

II. WORKSTATION DESIGN

Evaluations of a desk-seat set are used at Chulalongkorn University. By using applied statistics

with optimization, it was found as a result that 9% of users are matching with seat height and 36.3% of users are matching for desk height. Additionally, the conclusion was that the most convenient heights both for seat and desk were (40.5 cm and 62 cm) instead of (47.7 cm and 75 cm) which were currently used. The percentage of matching was increased by proposing these new dimensions to 63.4% for seat height and 98% for desk height [1].

When users are sitting, tilting forward on a seat, a higher loading of the intervertebral occurred. This was occurring due to decreasing of the hip angle and would influence the breathing ability and blood circulation [4]. Backrests should be adjustable in tilting at least 85 degrees to 100 degrees while still it is possible to maintain at least a 90 degree sitting angle and have the adjustability for height between 16 to 20 inches from the seat pan. Additionally, it should be at least 13 inches wide [5].

The rest of workers feet on the floor or on a footrest should be allowed by the chair height. Additionally, the chair height should allow the worker to use a suitable keyboard while keeping his/her forearm parallel to the floor and his/her wrists at the same plane of the forearm, and his/her legs should have enough clearance [6], and the optimal adjustability range for seat height be 37cm to 55cm [7].

III. Mismatch between Anthropometric Measures and Laibrary Furniture

The mismatch can be defined as the incompatibility between student's body dimensions and the dimensions of library furniture. A mismatch between popliteal height and seat height when the current seat height is less than the cosine of thirty degree or greater than the cosine of five degree of popliteal height [8], and the mismatch between seat width and hip breadth occurs when the seat width is less than 1.1 or greater than 1.3 of hip width, and the backrest height as recommended to keep the backrest lesser than scapula height, or at the upper edge of the scapula 60-80% of shoulder height. Hence, the mismatch appears when the backrest is greater than 0.8 or less than 0.6 of sitting shoulder height [8]. The mismatch between seat depth and buttock-to-popliteal length when the seat depth is less than 80% or greater than 95% of buttock-to-popliteal length [9].

The table clearance should be at least 20 mm: this space allows the knees to be more comfortable under the table, Therefore the lowest table height we will get it when shoulders are not in flexion or abduction. When the shoulders are at 25° flexion and 20° abduction the table height will be at the maximum elevation as shown in Fig.1.

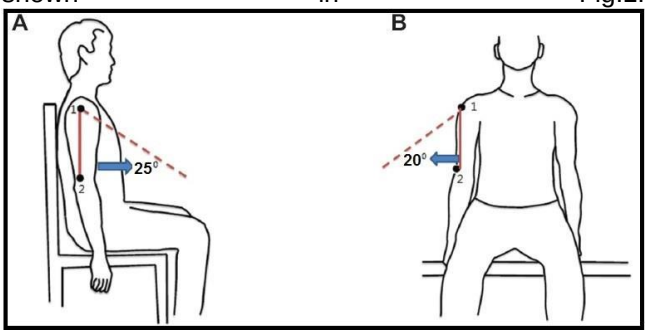

Fig1. The Shoulder at 25° Flexion and 20° Abduction

In our project we evaluated nine anthropometric measures of the participants which were made from the right side of their body, by adopting proper landmark definitions and standard measuring techniques. During measurements, the participants were barefooted, wearing light cloths, and instructed to sit in such a way that their thighs were in full contact with the seat, their lower and up- per legs were at right angles (knee bent at 90°), their feet were placed on the floor, and the trunk was upright. The anthropometric dimensions were the followings:

- Stature (S): The vertical distance from the floor to the top of the head, while the person stands erect, looking straight ahead.
- Sitting Elbow Height (EH): The vertical distance from the bottom of the tip of the elbow (olecranon) to the person's seated surface, taken with the elbow flexed at 90°.
- Sitting Shoulder Height (SSH): The vertical distance from the top of the shoulder at the acromion process, to the person's seated surface.
- Knee Height (KH): The vertical distance from the foot resting surface to the top of the kneecap just in back and above the patella, measured with knee flexed at 90°.
- Popliteal Height (PH): The vertical distance from the foot resting surface to the popliteal angle, where the back of the lower leg meets the underside of the thigh, measured with a 90° knee flexion.
- Sitting Height (SH): The vertical distance from the seat surface, to the crown of the head (vertex).
- Buttock-Popliteal Length (BP): The horizontal distance from the back of the uncompressed buttock to the popliteal angle.
- Hip Breadth (HB): The maximum horizontal distance across the hips in the sitting position.

In addition, the following TABLE I, shows the formulas used to measure the library furniture [9].

TABLE I. Library furniture dimension combination formulas

Dimension Combination	Formula
Chair Seat Height (SH) and Popliteal Height (PH)	$(PH + 2)\cos 30 \leq SH \leq (PH + 2)\cos 5$
Chair Seat Depth (SD) and Buttock-Popliteal Length (BP)	$0.80BP \leq SD \leq 0.99BP$
Chair Seat Width (SW) and Hip Breadth (HB)	$1.1HB \leq SW \leq 1.3HB$
Chair Backrest Height (BH) and Shoulder Height (SDH)	$0.60SDH \leq BH \leq 0.80SDH$
Table Height (TH) and Elbow-Height (EH)	$(PH + 2)\cos 30 + EH \leq TH \leq (PH + 2)\cos 30 + 0.85EH + 0.14SH$
Underneath Table Height (UTH)	$(KH + 2) + 2 \leq UTH \leq (PH + 2)\cos 5 + 0.85EH + 0.14SH - 4$

Thus, We can conclude the lowest table height:

Min Table Height (TH) = Elbow sitting height (EH) + Low seat height (LSH)

$$\text{Min (TH)} = \text{EH} + \cos 30° \text{PH} \quad (1)$$

The maximum table height can be calculate from

$$\text{Max TH} = \cos 5° \text{PH} + \text{Max EH} \quad (2)$$

Let AL is arm length then,

$$\text{AL} = \text{Sitting Shoulder Height (SDH)} - \text{EH} \quad (3)$$

Max EH= EH+ (1-cos20°) AL+ (1-cos25°)*cos20°AL

$$\text{Max EH} = \text{EH} + 0.0605\,\text{AL} + 0.0881 \quad (4)$$

From (2) and (4)

$$\text{Max TH} = \cos 5° \text{PH} + 0.852\,\text{EH} + 0.148\,\text{SDH} \quad (5)$$

Therefore, from (1) and (5), formula to determine TH is

$$\text{EH} + \cos 30° \text{PH} < \text{TH} < \cos 5° \text{PH} + 0.852\text{EH} + 0.148\text{SDH} \quad (6)$$

IV. METHODOLOGY

A. *Subjects*

A total one hundred-fifty-four undergraduate and postgraduate students, ninety-seven males and fifty-seven females were participated in this study. Their ages ranged from sixteen to forty-five years old. All subjects were students from Eastern Mediterranean University (EMU).

B. *Anthropometric Method*

In this research, twelve anthropometry dimensions were measured and directly used in designing chairs and tables for students' library furniture. All anthropometric measurements were collected using the students of Eastern Mediterranean University. During measurement each student was asked to keep two different postures; sitting up right where knees and elbow bent ninety degrees as in Fig. 2, and standing erect without shoes.

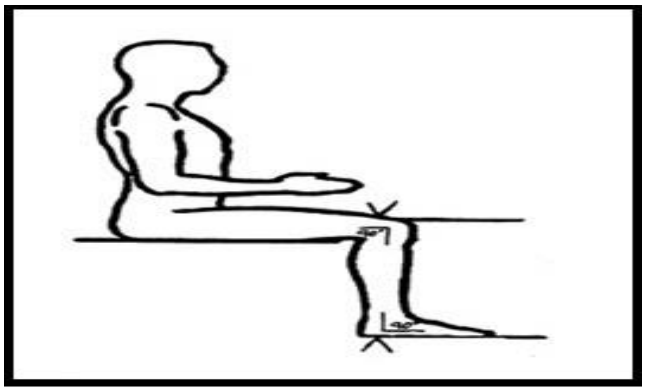

Fig. 2. Position of student in during measures

The measured dimensions were stature, shoulder height, shoulder elbow height, buttock-to-popliteal length, popliteal height, forearm hand length, hip width, elbow sitting height, sitting height, eye sitting height and overhead stretch Fig. 3, shows all these dimensions. On the average, it took around 12 minutes to complete all the measurements require per one student.

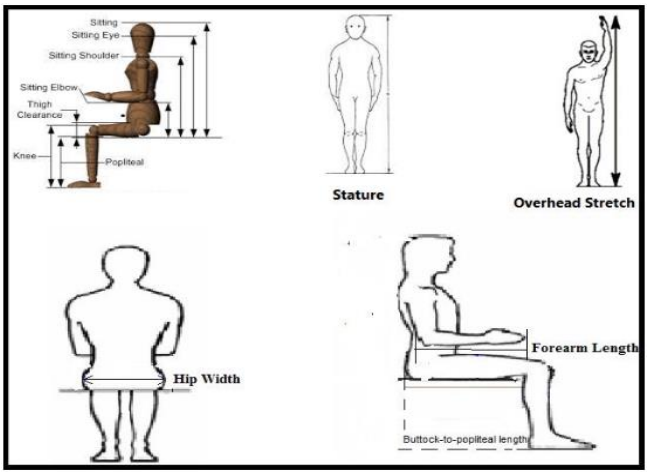

Fig. 3. Measured Anthropometric Dimensions

V. EXPERIMENTAL DESIGN

Experimental design is a statistical procedure used to improve processes, where the process variables are studies and its final result shows to experimenter which variables are most important and which are insignificant. In this project we can consider the experiment to compare between two conditions that usually are named treatments. For example, the popliteal height of student is an important characteristic of the seat height design. Therefore, the

designer is interested in comparing the popliteal height of males and females. An experiment was designed and performed as follows. First, 154 students were randomly selected. Then we use anthropometric set to measure the dimensions of students' body. Subjects were randomly scheduled to measurement. Additionally, the order of measurement of specific dimensions was randomized.

A completely randomized design was used in this research. The average of all anthropometric measurements, male and female was calculated.

A. The Normality Assumption

Before applying statistical method that supposes normality, it is necessary to perform normality test on anthropometric body dimensions. The normality assumptions are easy to check by using a normal probability plot. Generally, we can perform it quickly by Minitab15. Minitab 16 gives a p-value so; we can compare this value with our stated alpha level which is equal to 0.05.

The null hypothesis states that, the anthropometric data of male and female students follows a normal distribution. We will reject the null hypothesis when the p-value is less than alpha level. As can be seen from Minitab output, the p-value is larger than 0.05, this implies there is no sufficient evidence to reject the null hypothesis and it is concluded the data distribution is normal. Additionally, as illustrated in Fig. 4, and Fig. 5, all observation are close to the straight line on the graphs. Hence, the null hypothesis about normality is verified.

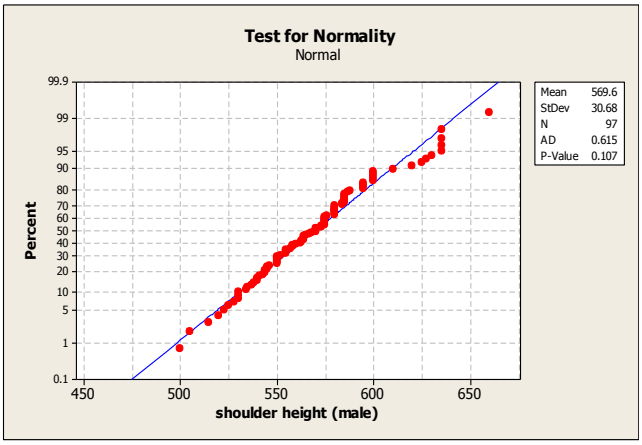

Fig. 4.Normal Probability Plot of Shoulder Height (male)

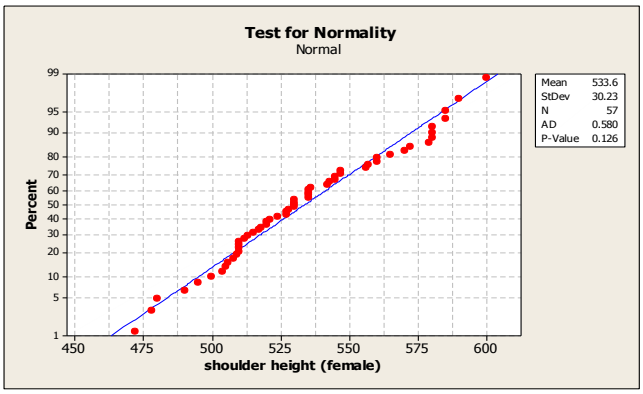

Fig. 5.Normal Probability Plot of Shoulder Elbow Height (female)

B. Percentile Calculation

Template The formula below is used to compare percentiles of a normal distribution.

$$\text{Kth percentile} = \mu \pm Z * \sigma \quad (7)$$

Where μ is the mean of anthropometric dimensions which are (stature, shoulder height, shoulder elbow height, buttock-to-popliteal length, popliteal height, knee height, forearm hand length, hip width, elbow sitting height, sitting height and eye sitting height figure) and σ is their standard deviation and Z is the value from the standard normal distribution for the wanted percentile. If we take any human body dimension such as elbow sitting height, we will find the 10th and 90th percentiles as follows:

$$10^{th}\ P_{\text{sitting height}} = \mu_{\text{sitting height}} - 1.28 * \sigma_{\text{sitting height}}$$

$$90^{th}\ P_{\text{sitting height}} = \mu_{\text{sitting height}} + 1.28 * \sigma_{\text{sitting height}}$$

The average (μ) and the standard deviation (σ) of a human body dimension can be taken from TABLE II and TABLE III.

TABLE II. Anthropometric Data for Male Students

Item	μ	median	σ	min	max	10th	90th
Weight (kg)	76.5	75.0	12.9	55.0	115.0	59.9	93.2
Stature (cm)	176.8	176.0	5.6	160.0	194.0	169.6	184.0
Shoulder Height (mm)	569.6	570.0	30.7	500.0	660.0	530.1	609.2
Shoulder Elbow Height (mm)	372.4	375.0	32.7	308.0	440.0	330.2	414.6
Buttock-to-Popliteal Height (mm)	502.5	501.0	40.7	425.0	600.0	449.9	555.0
Popliteal Height (mm)	470.3	465.0	32.7	408.0	580.0	428.1	512.5
Knee Height (mm)	563.1	565.0	33.5	485.0	650.0	519.9	606.4
Forearm Length (mm)	492.2	492.0	29.2	420.0	570.0	454.4	529.9
Hip Width (mm)	397.6	394.0	40.9	290.0	520.0	344.8	450.4
Elbow Sitting Height (mm)	226.4	225.0	28.2	155.0	290.0	190.0	262.8
Sitting Height (mm)	839.6	840.0	38.7	720.0	930.0	789.7	889.5
Siting Eye Height (mm)	742.8	740.0	38.4	648.0	825.0	693.3	792.2
Overhead stretch (mm)	2218.1	2210.0	84.8	2000.0	2460.0	2108.7	2327.5

TABLE III. Anthropometric Data for Female Students

Item	μ	median	σ	min	max	10th	90th
Weight (kg)	61.23	59	11.831	35	98	45.97	76.49
Stature (cm)	163.65	163	7.359	148	182	154.16	173.14
Shoulder Height (mm)	533.56	530	30.232	472	600	494.56	572.56
Shoulder Elbow Height (mm)	336.18	335	37.808	250	415	287.40	384.95
Buttock-to-Popliteal Height (mm)	475.32	475	37.001	400	559	427.58	523.05
Popliteal Height (mm)	447.07	451	30.488	385	510	407.74	486.40
Knee Height (mm)	516.60	511	31.778	448	590	475.60	557.59
Forearm Length (mm)	451.37	450	22.559	390	500	422.27	480.47
Hip Width (mm)	404.25	400	44.513	310	505	346.82	461.67
Elbow Sitting Height (mm)	228.18	225	29.561	170	301	190.04	266.31
Sitting Height (mm)	779.91	780	41.189	680	874	726.78	833.05
Siting Eye Height (mm)	688.32	685	39.160	591	794	637.80	738.83
Overhead stretch (mm)	2004	1995	104.077	1790	2242	1869.92	2138.44

VI. RESULTS AND DISCUSSION

A. Library Furniture

The EMU Library second floor contains about one hundred and forty three tables, three hundred and twenty four chairs and fifty nine bookshelves. Three types of tables and only one type of chairs exists in second floor of library and there dimensions are shown in TABLE IV below.

TABLE IV. Dimensions of Furniture Used in EMU Library (Second Floor)

Dimension	Measurement (cm)
Seat Height	40
Seat Depth	43.5
Seat Angle	4°
Seat width	44.5
Backrest angle	10°
Maximum Height of backrest	41.5
Maximum Height to bottom of backrest	28.5
Individual Table	
Table Height	73
Table Clearance	71
Table Slop	0
Table Width	86.5
Table Length	60
Long Table	
Table Height	76
Table Clearance	67
Table Slop	0
Table Width	180
Table Length	90
Computer Table	
Table Height	74
Table Clearance	71
Table Slop	0
Table Width	80
Table Length	80

B. Anthropometric Measurement

The measurements of the students' bodies are listed in tables 1 and 2. Analysis of data was done by Minitab 16 and Excel 2010. Basic descriptive statistics were used to compute both mean, median, standard deviation, maximum and minimum value for anthropometric data for males and females. As you can see in TABLE I and TABLE II, most of the mean and medians are very close to each, indicating symmetrical distributions.

We can calculate the 10th and 90th percentile by using formula (6). If we take any dimension form TABLE I and TABLE II such as shoulder elbow height, we can see the average for males and females are 372.4 mm and 336.2 mm with standard deviation of 32.71 mm and 37.81mm respectively, where the standard deviation value is directly proportional to the difference between each data and the mean.

Let: mean = μ and standard deviation = σ

10^{th} percentile (male) = μ-1.29σ = 372.4 –(1.29*32.71) = 330.2 mm.

10^{th} percentile (female) = μ-1.29σ = 336.2 –(1.29*37.81) = 287.4 mm.

90^{th} percentile (male) = μ+1.29σ =372.4 –(1.29*32.71) = 414.6 mm.

90^{th} percentile (female) = μ+1.29σ = 336.2 –(1.29*37.81) = 384.9 mm.

These distributions of shoulder elbow heights for male and female seems to be normally distributed as we can see from Fig. 5 and Fig. 6.

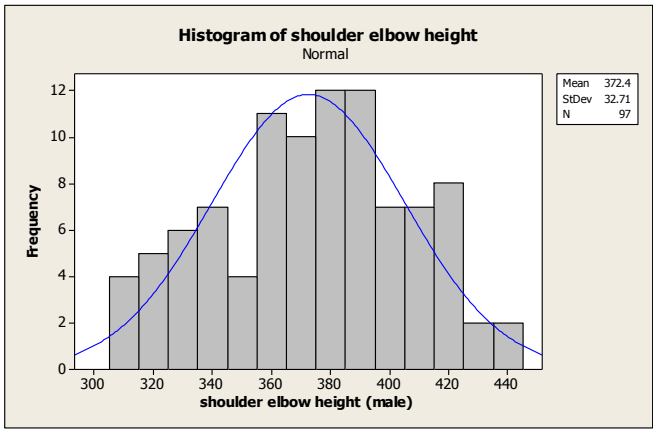

Fig. 5. Histogram for Shoulder Elbow Height (male)

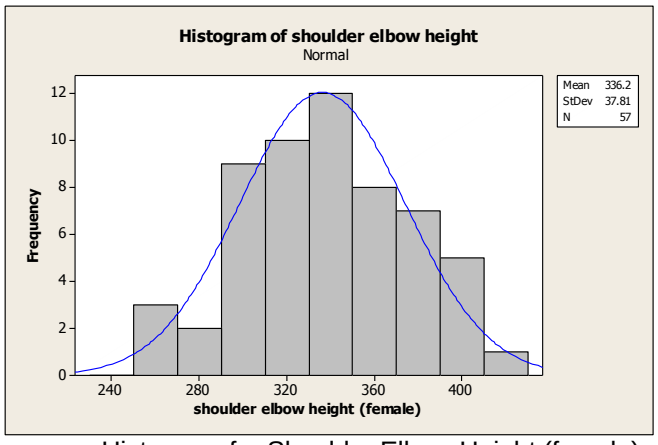

Fig. 6. Histogram for Shoulder Elbow Height (female).

C. Evaluate the Current Furniture of EMU Library

For evaluation and redesign for library furniture, it is important to consider the applied of anthropometry and ergonomics principles, and use equations to calculate the limitations of furniture dimensions to determine the mismatch. We can see the mismatch between male and female students and current dimension of library furniture shown in the TABLE V and TABLE VI below.

TABLE V. Mismatch between Furniture and Body Dimensions for 57 Female Students

Mismatch Between	Percentage %
PH and SH	40.4
BPL and SD	47.4
HW and SW	57.9
SDH and BH	35.1
EH and TH (Individual)	84.2
UT (Individual Table Clearance)	0.0
EH and TH (Long)	96.5
UT (Long Table Clearance)	0.0
EH and TH (Computer)	89.5
UT (Computer Table Clearance)	0.0

TABLE VI. Mismatch between Furniture and Body Dimensions for 97 male Students

Mismatch Between	Percentage
PH and SH	55.7
BPL and SD	45.4
HW and SW	45.4
SDH and BH	3.1
EH and TH (Individual)	73.2
UT (Individual Table Clearance)	0.0
EH and TH (Long)	89.7
UT (Long Table Clearance)	0.0
EH and TH (Computer)	80.4
UT (Computer Table Clearance)	0.0

The objective of this study is to evaluate the design of EMU library by using the mismatch ratio. So, we proposed Combination of Statistics and Optimization techniques to design the tables and chairs of workstations. In this technique the design is based on the optimal proportion of matching.

D. Combination of Statistics and Optimization

The aim of this technique is to design the chair and table with respect to the maximum percentage of matching between target population's body dimensions and the furniture set.

1) Chair Design

The chair is the most important piece of furniture used in library where the student spend one hour or more of their time sitting, studying and reading. Therefore, it is necessary to select a properly designed chair to enable the student to sit comfortably, work efficiently, and provide proper support for the human body to minimize fatigue.

a) Seat Height (SH)

After many years of investigation a number of recommendations and guidelines are offered so that it can be used in the design of a seat. From formulas before.

SH > 0.866PH & SH < 0.996PH

Then, SH/0.996≤PH≤SH/0.866

Thus, the population whose body dimension matches with current seat height of (400 mm) is

400/0.996≤PH≤400/0.866

Thus,

401.6≤PH≤461.9

When we refer to TABLE II and TABLE III, we can see the mean value of popliteal height for 97 male and 57 female students are 470.3 mm and 447.07 mm and the standard deviations are 32.70 mm and 30.48 mm respectively.

Proportion match of male population = $P(\frac{401.6-470.3}{32.7} \leq \frac{PH-\mu}{6} \leq \frac{461.9-470.3}{32.7})$

Proportion match of female population = $P(\frac{401.6-447.07}{30.48} \leq \frac{PH-\mu}{6} \leq \frac{461.9-447.07}{30.48})$

Proportion match of male population match = P (-2.1≤ Z ≤ -0.26) = 0.38

Proportion match of male population match = P (-1.49≤ Z ≤ 0.49) = 0.62

As a result the current seat height is fitting for male and female by 38% and 62% respectively of the students.

To optimize this percentage we will calculate this proportion for different seat heights.

The proportion of students match are shown in the TABLE VII and TABLE VIII at different seat heights:

$$P_{male} = \left(\frac{\left(\frac{SH}{0.996}\right)-470.3}{32.7} \leq \frac{PH-\mu}{6} \leq \frac{\left(\frac{SH}{0.866}\right)-470.3}{32.7}\right).$$

$$P_{female} = \left(\frac{\left(\frac{SH}{0.996}\right)-447.07}{30.48} \leq \frac{PH-\mu}{6} \leq \frac{\left(\frac{SH}{0.886}\right)-447.07}{30.48}\right).$$

TABLE VII. Proportion of Male Students Match at Different Seat Height

SH	SH/0.996	SH/0.866	Prob1	Prob2	Probability
320	321.2851	369.515	0.00	0.00	0.00
330	331.3253	381.0624	0.00	0.00	0.00
340	341.3655	392.6097	0.00	0.01	0.01
350	351.4056	404.157	0.00	0.02	0.02
360	361.4458	415.7044	0.00	0.05	0.05
365	366.4659	421.4781	0.00	0.07	0.07
370	371.4859	427.2517	0.00	0.09	0.09
375	376.506	433.0254	0.00	0.13	0.12
380	381.5261	438.7991	0.00	0.17	0.16
385	386.5462	444.5727	0.01	0.22	0.21
390	391.5663	450.3464	0.01	0.27	0.26
400	401.6064	461.8938	0.02	0.40	0.38
410	411.6466	473.4411	0.04	0.54	0.50
420	421.6867	484.9885	0.07	0.67	0.60
425	426.7068	490.7621	0.09	0.73	0.64
430	431.7269	496.5358	0.12	0.79	0.67
440	441.7671	508.0831	0.19	0.88	0.68
460	461.8474	531.1778	0.40	0.97	0.57
470	471.8876	542.7252	0.52	0.99	0.47
480	481.9277	554.2725	0.64	0.99	0.36
490	491.9679	565.8199	0.75	1.00	0.25
500	502.008	577.3672	0.83	1.00	0.17
510	512.0482	588.9145	0.90	1.00	0.10
520	522.0884	600.4619	0.94	1.00	0.06
530	532.1285	612.0092	0.97	1.00	0.03
540	542.1687	623.5566	0.99	1.00	0.01
550	552.2088	635.1039	0.99	1.00	0.01
560	562.249	646.6513	1.00	1.00	0.00
570	572.2892	658.1986	1.00	1.00	0.00

TABLE VIII. Proportion of Female Students Match at Different Seat Height

SH	SH/0.996	SH/0.866	Prob 1	Prob2	Probability
320	321.2851	369.515	0.00	0.01	0.01
330	331.3253	381.0624	0.00	0.02	0.02
340	341.3655	392.6097	0.00	0.04	0.04
350	351.4056	404.157	0.00	0.08	0.08
360	361.4458	415.7044	0.00	0.15	0.15
365	366.4659	421.4781	0.00	0.20	0.20
370	371.4859	427.2517	0.01	0.26	0.25
375	376.506	433.0254	0.01	0.32	0.31
380	381.5261	438.7991	0.02	0.39	0.38
385	386.5462	444.5727	0.02	0.47	0.44
390	391.5663	450.3464	0.03	0.54	0.51
400	401.6064	461.8938	0.07	0.69	0.62
410	411.6466	473.4411	0.12	0.81	0.68
420	421.6867	484.9885	0.20	0.89	0.69
425	426.7068	490.7621	0.25	0.92	0.67
430	431.7269	496.5358	0.31	0.95	0.64
435	436.747	502.3095	0.37	0.96	0.60
440	441.7671	508.0831	0.43	0.98	0.55
460	461.8474	531.1778	0.69	1.00	0.31
470	471.8876	542.7252	0.79	1.00	0.21
480	481.9277	554.2725	0.87	1.00	0.13
490	491.9679	565.8199	0.93	1.00	0.07
500	502.008	577.3672	0.96	1.00	0.04
510	512.0482	588.9145	0.98	1.00	0.02
520	522.0884	600.4619	0.99	1.00	0.01
530	532.1285	612.0092	1.00	1.00	0.00
540	542.1687	623.5566	1.00	1.00	0.00
550	552.2088	635.1039	1.00	1.00	0.00
560	562.249	646.6513	1.00	1.00	0.00
570	572.2892	658.1986	1.00	1.00	0.00

Through varying the seat height from 400 mm to the different values between 320 and 570 mm, the proportion of male match is increased when the seat height reduced from 570 to 435 mm. Then this proportion starts decreasing and gets closer to zero when the seat height approximately 320 mm. also the proportion of female match increased when the seat height reduced from 570 to 420 mm, then it starts decreasing and gets closer to zero when the seat height approximately 320 mm. With the optimization method, the maximum proportion of match population for male and female is found at 68% and 69% when the seat height is 440 and 420 mm respectively, therefore; the current seat is not convenient for the most students and should change it to range between 420 to 440 mm. This is obvious from looking at Fig. 9, and Fig. 10.

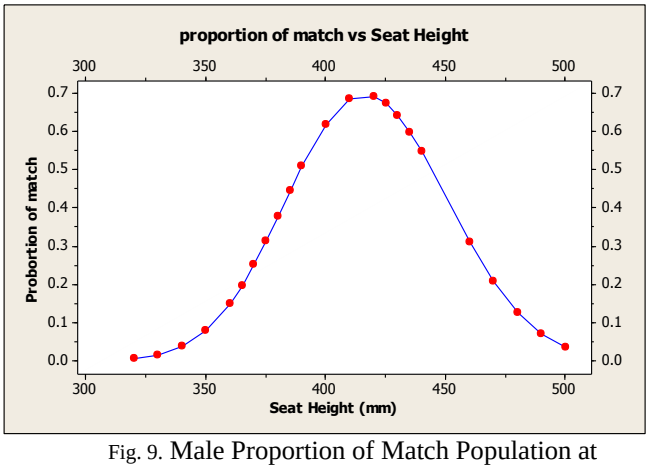

Fig. 9. Male Proportion of Match Population at Different Seat Height

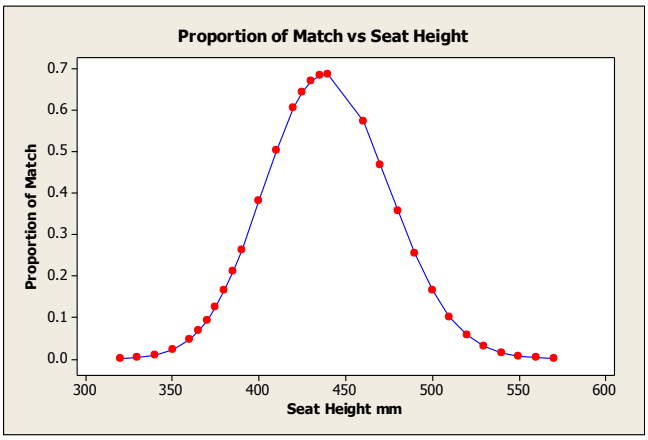

Fig. 10. Female Proportion of Match Population at Different Seat Height

b) Seat Depth (SD)

1) The seat depth should be designed for the tenth percentile [8],and the mismatch in th case when the depth is less than 80% or greater than 95% of the buttock-to-popliteal length as in the following formula [9].

0.80 BP ≤SD≤ 0.95 BP

We can calculate the proportion of the matching male and female students for the seat depth by using the same procedures that are explained above.

Then, $\frac{\text{SD}}{0.95} \leq \text{BP} \leq \frac{\text{SD}}{0.80}$

Thus, students whose body dimension of BP are between 457.9 and 543.8 mm they matching the current seat depth with 70.8% of male students and 65% of female students. If we compute the proportion at different seat depth as shown in Fig. 11, and Fig. 12, we see that, the maximum proportion of match population is 71.1% of male students when the seat depth is 440 mm and 73% of female students when the seat depth is 420 mm.

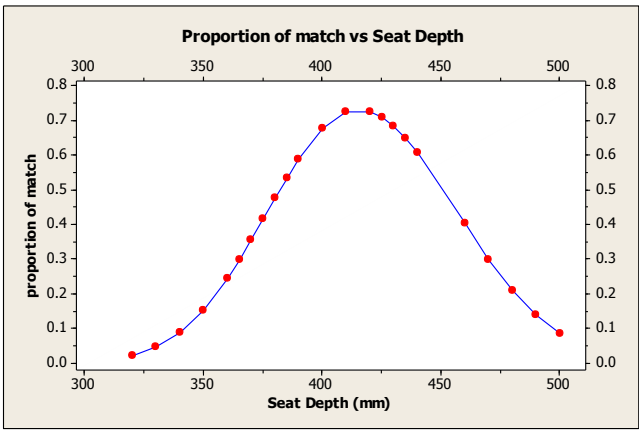

Fig .11. Proportion of Male Match Population at Different Seat Depth

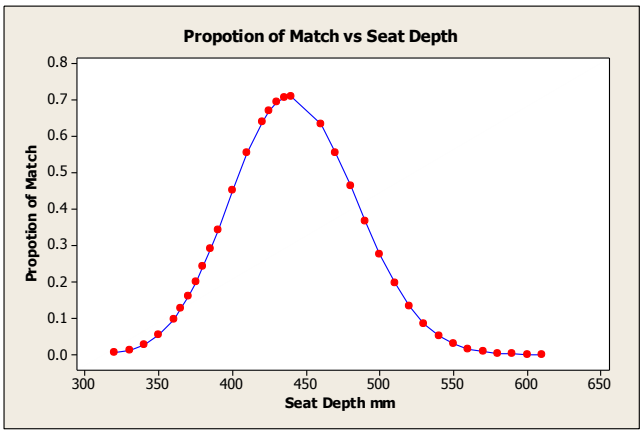

Fig .12. Proportion of Female Match Population at Different Seat Depth

c) Seat Width (SW)

The seat width should be large enough to allow space for side movement [8]. Then,

1.1HW≤ SW≤ 1.3HW

The proportion of match for any different seat width =

$$P\left(\frac{(\frac{SW}{1.3})-\mu}{6} \leq \frac{PH-\mu}{6} \leq \frac{(\frac{SW}{1.1})-\mu}{6}\right)$$

Once again we used the same procedures to find the proportion of matching the seat width so, we found the maximum percentage of matching for male is 58.4 % when seat width is 480mm and maximum percentage of matching for female is 55.3% when seat width is 490mm.

d) Backrest Height (BH)

The backrest has to be lower than the scapula or at most on the upper edge of the scapula (60-80% of shoulder height) [8]. From formula

0.6 SDH ≤ BH ≤ 0.8SDH

So, BH ≥ 0.6SDH and BH ≤ 0.8SDH

Thus, $\frac{\text{BH}}{0.8} \leq \text{SDH} \leq \frac{\text{BH}}{0.6}$

We found the maximum proportion of match population is 99.2% when the backrest height is 390mm for male and maximum proportion of match population is 98.8% when backrest height is 365mm for female.

2) Table Height (TH) Design

As people with different heights perform different tasks, the three types of table should be designed to minimize stressful posture. To estimate the proportion of students matching the current table height, we can apply the same procedures which we used earlier to determine the proportion of matching of students for seat height. The current table height for individual table, long table and computer table are 730,760 and

740mm respectively. From equation (6) ,the limitations of the table height is:

EH + cos30° PH < TH < cos5° PH + 0.852 EH + 0.148 SDH

$$Let\ ES = 0.853EH + 0.148SDH \quad (8)$$

$$\mathrm{EH} < \mathrm{TH} - 0.866\mathrm{PH} \quad (9)$$

By Substituting (8) in (7) we got:

$$\mathrm{ES} > \mathrm{TH} - 0.996\mathrm{PH} \quad (10)$$

So, When PH is current Seat Height which is 400mm,

- Individual Table

EH< 730-(0.866*400)
EH< 383.6mm.
TH< 0.996PH+ES,
ES > 730-(0.996*400)
ES > 331.6mm

- Long Table

EH < 413.6mm.
ES > 361.6mm.

- Computer Table

EH < 393.6mm.
ES > 341.6mm.

The equations above showed us the matching proportion of students with current TH (individual, long, and computer) are 100% for male and female students (for sitting elbow height under 383.6, 413.6 and 393.6 mm separately, in any case, the rate of students who fit to the present table height (individual, long and computer table) are 0% for all students as we can see Fig.13, and Fig. 14.

Equations (8) and (9) gave us the matching ratio at various TH.

The proportion of the EH at different table height (male) = $p(z \leq \frac{(TH-346.4)-226.37}{28.20})$
and the proportion of ES at different table height (male) = $p(z \geq \frac{(TH-398.4)-277.4}{27.27})$.
The proportion of the EH at different table height (female) = $p(z \leq \frac{(TH-346.4)-228.18}{29.56})$
and the proportion of ES at different table height (female) = $p(z \geq \frac{(TH-398.4)-273.6}{28.28})$.

When we changed the table height from 730,760 and 740 to 630mm for male students, we found the proportion of match is 97.9% when EH is less than 283.6mm. The proportion of match is 95.4% when ES is greater than 231.6mm. When we change the table height from 730, 760 and 740mm to 630mm for female students, we found the proportion of match is 96.9% when EH is less than 283.6mm. The proportion of match is 93.1% when ES is greater than 231.6mm. As a result we recorded the maximum point of the percentage of matching as 99% at the intersection point between two curves of EH and ES shown in Fig. 13, and Fig. 14, when table height is 630mm for male and female students.

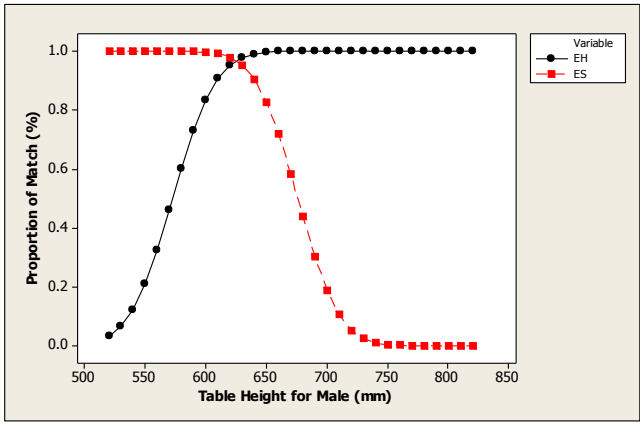

Fig. 13. The Optimal Proportion of Match Population at Different Table Height (male).

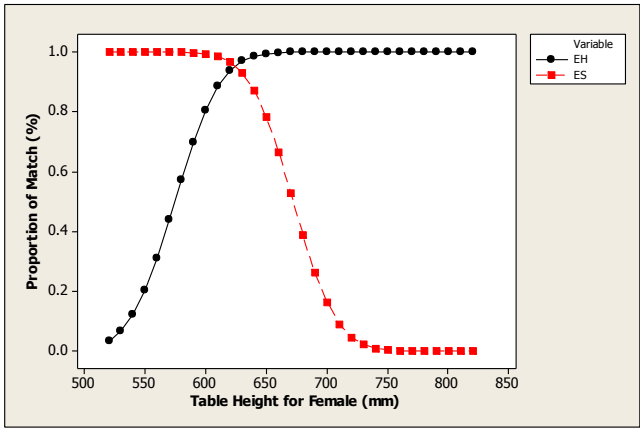

Fig. 14. The Optimal Proportion of Match Population at Different Table Height (female).

As a result, the chair and table dimensions for male students, by this technique, should be as following TABLE IX.

TABLE IX. Optimal Dimensions of Library Furniture for Male Students

Item	Dimension (mm)
Seat Height	440
Seat Depth	440
Seat Width	480
Backrest Height	390
Table Height	630

On the other hand, the chair and table dimension for female students, by this technique, should be as following TABLE X.

TABLE X. Optimal Dimensions of Library Furniture for Female Students

Item	Dimension (mm)
Seat Height	420
Seat Depth	420
Seat Width	490
Backrest Height	365
Table Height	630

The mismatch for male and female students from this method was recorded as following TABLE XI.

TABLE XI. Mismatch Result after Optimization Technique

Mismatch Between	Male	Female
Popliteal Height and Seat Height	35%	35%
Buttock-to-Popliteal Length and Seat depth	32.9%	28%
Hip Width and Seat Width	43.3%	49%
Sitting Elbow Height and Table Height	1%	0%

We also cinsedered adjustuble chair dimension to see the optimal mismatch ratio.

E. Percentage of Mismatch for New Adjustable Chair

- Seat Height (SH)

The new seat height of the chair can be designed adjustable from 407.74mm to 512.55mm. This data was taken from 10th percentile of female students' popliteal height and 90th percentile of male students' popliteal height. This allows the students to place their feet on the floor. This new seat height will reduce the mismatch from 35% to 2% for male students and from 35% to 10% for female students; TABLE XII, shows the mismatch between Popliteal Height (PH) and Seat Height (SH).

TABLE XII. Mismatch between Popliteal Height and Seat Height of Old and New Chair.

Mismatch Between	Male	Female
PH and SH for current chair	35%	35%
PH and for new chair	2%	10%

- Seat Depth (SD)

Seat depth could be designed as recommended as the tenth percentile of buttock-to-popliteal length of female. This would include the shorter users. So, from equation (2), when the 10th percentile for buttock-to-popliteal of female students is 427.58.

Max seating depth = 0.95 * BP = 0.95 * 427.58 = 406.2 mm.

TABLE XIII. Mismatch between Buttock-to-Popliteal Height and Seat Depth

Mismatch Between	Male	Female
BP and SD of current chair	32.9%	28%
BP and SD of New chair	11.3%	22.8%

As a result, the mismatch will be reduced from 32.9% to 11.3% for male and from 28% to 22.8% for female students. In addition, we will get the same results if we are designed according to average as follows. Therefore the seat depth is 406.2mm is the best value, where it is compatible with the most students and the mismatch is reduced.

- Seat Width (SW)

The seat width should be large enough to accommodate the users with the largest hip width therefore, it is designed at 520 mm this dimension was taken from for the maximum value of hip width for all students so, the mismatch will be eliminated but, the optimization method reduced it for male and female to 4% and 5.2% respectively.

TABLE XIV. Mismatch between Hip Width and Seat Width

Mismatch Between	Male	Female
HW and current SW	43.3%	49%
HW and new SW	4%	5.2%

VII. CONCLUSION

We know that there are statistically significant differences between body dimensions of female and male students. This result helped us to specify in the design which principles of anthropometry parts should be used (e.g. design for adjustable range, or design for extreme or design for average). In this way, we were able to improve the proportion of matching method and obtain the best matching rate for males and females students.

The current tables in library are very high so that, the students' posture is not good because the angle upper and lower arm was greater than 90 degrees. This can increase the tension in muscles and cause a decrease in the ability of students reading and concentration during the study or read and can cause serious health problems.

The mismatch ratio between female's sitting elbow height and each type of tables was higher than male

mismatch ratio. Therefore, we decide to design the three type of tables (individual, long, and computer) with unique height 630mm to reduce the mismatch from 84.2%, 96.5% and 89.5% to 2.1% for female students and 73.2%, 89.7% and 80.4% to 1.5% for male students. The result showed us that no need for table adjustability.

We proposed chair adjustability to get an optimal mismatch reduction, therefore, when we suggest the chair height range from 407mm to 512mm, we found the mismatch was reduced from 35% and 35% to 10% and 2% for female and male students respectively.

VIII. Further Study can be done

- Assessing the safety factors of fire system and electricity installation.
- A study to provide the comfortable environmental conditions in library for students, and to motivate them to study and work efficiently. For instance, temperature, noise, humidity and audio effects, to increase motivation of student to focus and pay more attention to the reading or studying, according to Ergonomic Principles of Design.
- Extending this to consider other floors and sections of EMU Library.

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