UNIVERSITI PUTRA MALAYSIA

CONCEPTUAL DESIGN OF BIO-COMPOSITE CHAIR AND DESK BASED ON ANTHROPOMETRIC DATA

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy

April 2019

DEDICATION

This thesis is dedicated to my family who has continually supported and stood by me during this busy years

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in partial fulfilment of the requirement for the degree of Degree of Doctor of Philosophy

CONCEPTUAL DESIGN OF BIO-COMPOSITE CHAIR AND DESK BASED ON ANTHROPOMETRIC DATA

By

MAHMOOD ALI

April 2019

Chairman	**:**	**Professor Ir. Mohd Sapuan Salit, PhD**
Faculty	**:**	**Institute of Tropical Forestry and Forest Product**

This study is undertaken to design an anthropometrically enhanced Bio-Composite Chair and Desk to be used by students of Polytechnics in Malaysia . The Pugh total design method was used for this conceptual design and. There are 4 important stages in this study. First, evaluation of the anthropometric data (AD) of chair and desk currently used by polytechnics students was done. Second, generation design concepts of bio-composite desk and chair with and without anthropometric data using brainstorming, mind mapping and morphological chart was completed. Third, evaluation of the best design concept using weighted objectives method with inputs from Anthropometric data was completed. Finally, validation is carried out to validate the durability and comfortability of the new chair and desk under normal working conditions. Overall, the final proposed conceptual designed chair and desk provides an anthropometric interaction between the users and their workstation (chair and desk). This newly proposed chair and desk intends to enhance the teaching and learning process in the polytechnics and other institutions of higher learning.
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i

Abstrak tesis ini dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian keperluan untuk ijazah Doktor Falsafah

REKA BENTUK KONSEPTUAL KERUSI DAN MEJA BIO-KOMPOSIT MENGGUNAKAN DATA ANTROPOMETRI

Oleh

MAHMOOD ALI

April 2019

Pengerusi	**:**	**Profesor Ir. Mohd Sapuan Salit, PhD**
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Kajian ini dijalankan untuk merekabentuk kerusi dan meja bio-komposit antropometrik yang bakal digunakan oleh pelajar politeknik di Malaysia. Kaedah reka bentuk keseluruhan Pugh telah digunakan untuk reka bentuk konsep meja dan kerusi Politeknik. Terdapat 4 peringkat penting dalam kajian ini. Peringkat pertama, penilaian data antropometrik (AD) dilakukan untuk kerusi dan meja yang digunakan kini oleh pelajar politeknik. Peringkat kedua, konsep reka bentuk generasi untuk meja dan kerusi bio-komposit dengan dan tanpa data antropometrik menggunakan kaedah generasi idea baru, pemetaan minda dan carta morfologi telah dilakukan. Peringkat ketiga, penilaian konsep reka bentuk terbaik dilakukan menggunakan kaedah objektif berwajaran dengan input dari data Anthropometric. Akhirnya peringkat keempat, analisis data antroprometrik pelajar dengan kerusi dan meja baru dijalankan untuk mengesahkan keselesaan dan keteguhan struktur kerusi dan meja baru di bawah keadaan kerja biasa. Secara keseluruhannya, kerusi dan meja yang direka bentuk secara konseptual akhir menyediakan interaksi antropometrik antara pengguna dan stesen kerja mereka (kerusi dan meja). Pencadangan kerusi dan meja yang baru ini bertujuan untuk meningkatkan proses pengajaran dan pembelajaran di politeknik dan institusi pengajian tinggi lain.

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To all other friends, family and colleagues from that have contributed directly or indirectly to the writing of this thesis, I would like to thank them for their contribution

MAHMOOD ALI

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy.

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v

Declaration by graduate student

I hereby confirm that:

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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TABLE OF CONTENTS

xi

LIST OF TABLES

LIST OF FIGURES

xvi

xvii

LIST OF APPENDICES

LIST OF ABBREVIATIONS

AD	Anthropometric Data
BOM	Bill of Material
BC	Boundary conditions
CO_2	Carbon Dioxide
cm	centimeter
CV	Coefficient of Variation
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CE	Concurrent Engineering
DCS	Design Concept Selection
DFA	Design for Assembly
DFM	Design for Manufacturing
DFPP	Design for Piece-part Producibility
E	Young's modulus
EMG	Electromyogram
FEA	Finite Element Analysis
FEM	Finite Element Method
NF	Natural Fibres
NFC	Natural Fiber-reinforced Polymer Composites
MSD	Musculoskeletal Disorders
PCL	PATRAN Command Language
PDS	Product design specifications
PP	Polypropylene
PVC	Polyvinyl Chloride
QFD	Quality Function Deployment
SES	Socioeconomic Status
SD	standard deviation
SEM	standard error of mean

CHAPTER 1

INTRODUCTION

1.1   Background

Anthropometry is defined as "the science of measurement and the art of application that establishes the physical geometry, mass properties, and strength capabilities of the human body". In simple terms, Anthropometry can be defined as the study which deals with body dimensions i.e. body size, shape, strength and working capacity for design purposes and body composition. Anthropometry is also defined as a technique of expressing the quantitative form of human body. It is recognised as the single most universally applicable, inexpensive and non-invasive technique for assessing the size and proportions of the human body. This technique has been used by anthropologists worldwide to estimate body size and stature for many years. Thus, developing a correct anthropometric profile in stature is an important step for during the design of user friendly products. (Nor et al., 2013, Taifa and Desai, 2017)

The ability and capability of human to design a product must be adapted to human features. When there is a mismatch between a product and human features, automatically the feeling of discomfort will arise in users of the product. Therefore, all products must be designed according to users' anthropometric data. Comfort assessment can then be evaluated objectively and subjectively. Objective evaluation is usually carried out based on the existing parameters of the products (Deros et al., 2015).

Polytechnics, colleges, institutes or universities work requires students to spend long hours sitting down. Considering this, as well as the potential inadequate use of polytechnics furniture, it is likely that some anatomical-functional changes and problems in the learning process may occur. This situation causes an increased concern about the polytechnics classrooms, particularly about the study and design of polytechnics furniture suitable to the needs of the students and the appropriate dimensions according to the students' anthropometrics characteristics. Worldwide (Castellucci et al., 2015a), it is possible to observe a great number of studies regarding the students' anthropometric characteristics, with the aim of generating safer school furniture. Anthropometric information for chair and desk design is mainly concerned with providing data on the stature of the people for whom the chairs and desks are designed. Furthermore, most of the standards that are published worldwide for furniture selection tend to use, as a reference (Castellucci et al., 2015a) The function of all chairs and desks are commonly same. But the differences are its anthropometrically suitable for all users (Dejnozka, 1996, Hoekstra, 2009). Examples of among current used chairs and desks in polytechnic are shown in Figure 1.1.

Figure 1.1: Chair and desks in classroom

In institutions of learning, students' sitting posture are influenced by their activities performed in classroom, lecture hall and workshops so the anthropometrics dimensions of polytechnic student and the measures are design features of polytechnic furniture (Jung, 2005). Uncomfortable postures could be causing distress to students due to the long periods of time that the student spends at these institutions of learning and previous studies have already reported posture-related syndromes affecting students (Gouvali and Boudolos, 2006).

Anthropometry is playing a main role in the design development to create well designed product. Measurement size reference is inseparable from the human body based on furniture design, in order for the user to meet the people's requirements for the size of furniture (Wang and Yang, 2012). There is a conflict between the natural tendency to unrestricted physical movement and the need to maintain a sitting posture for a longer period of time in polytechnic student (Troussier, 1999). This study is of particular interest as it concerns polytechnic students rather than younger children reported in most previous studies in Politeknik Kuching Sarawak, Malaysia and elsewhere.

Concept generation is the most creative and an indispensable step of innovation design. Many researchers have stated that there is a significant correlation between the quality of design concepts and success of final products. However, improving the quality of design concepts is not easy, since it largely depends on designers' design thinking process, which is often limited by designers' knowledge and design thinking fixation. Therefore, using external knowledge and assistance tools becomes one of the ways to improve the quality of design concepts. Conceptual generation with input from anthropometric data should be considered in the initial stage of designing

concepts in order to achieve the best design concepts from start of design (Hao et al., 2017).

Concept evaluation is an important stage in the design process as it helps to assess the overall utility of design alternatives against the design objectives. Early concept evaluation can save both time and cost as 80% of overall product quality and 70–80% of product development cost is committed in the early stages of the design process. The importance of design concept evaluation is obvious because the poor selection of a design concept can hardly ever be compensated at later stages of design process and may lead to large redesign costs. Concept evaluation is a complex multi-criteria decision making problem inherent with a number of difficulties. The main design objectives that helps to determine the success of the final design concept (design solution) are customers' satisfaction, product development time and product cost. The need to incorporate highly subjective customer preferences in evaluation process, evaluation of trade-offs between conflicting design criteria, subjective judgments of experienced designers (or decision makers), calculating degree of satisfaction level of customers against the generated design alternatives and performance capabilities of design alternatives in terms of meeting the final technical specifications introduces various degree of uncertainty in the concept evaluation process. Conceptual evaluation with input from anthropometric data in the initial stage of designing concepts will help alleviate these potential issues in order to achieve the best design concepts from early stages of design (Tiwari et al., 2016).

Composites materials which involves natural fibers are referred to as bio-composite materials and these bio-composite materials have some additional advantages such as being environmentally friendly, reducing cost and renewability. Applications of natural fiber-reinforced polymer composites (NFCs) or bio-composites are being considered for various items like furniture and consumer goods (such as packing cases, ironing boards, tables, helmets, chairs, and urns), construction and infrastructure (such as roof panels, beams and bridges), sports and leisure (such as tennis rackets, bicycle frames and canoes), in accumulation to others like aerospace, wind energy, marine, environmental and bio-engineering applications (Al-Oqla and Sapuan, 2015). Previous design utilising bio-composites was used to fabricate a household multipurpose table using an epoxy composite reinforced with banana fiber woven fabric and natural woven fabric reinforced epoxy composite for household telephone stand (Sapuan et al., 2008, Sapuan and Maleque, 2005). Product development requires the design of component as well as manufacturing process by nature of composite at the early stage of design process to makes it fits within the definition of concurrent engineering (CE) (Sapuan and Mansor, 2014).

3

1.2   Problem Statement

Studying in a comfortable environment is important in the knowledge acquiring domain. In Polytechnic classrooms, comfortability is an important issue. Students can develop musculoskeletal disorders during a prolonged period of class. Their physical health and performance in the classroom can be improved by designing school furniture that match the body. In Malaysia, the comfortability assessment of the school environment, particularly in urban areas, is lacking. The comfort, physical health, and well-being of students during learning lessons in classroom depend partially on the work spaces, furniture and equipment that they use in Polytechnics which should conform to the anthropometric and biomechanical characteristics of the students. Classroom features such as workspace and personal space play an important role in the development and performance of students. In addition, their attention and motivation are all related to the comfortability of the classroom, which is critical for the healthy development of students (Yusoff et al., 2015).

In the polytechnics, institutes or universities that have classrooms furniture, most of these furnitures are considered to have low comfort level for the students since anthropometric data were not usually considered in the initial stage of ordering the furniture. Anthropometric data should be considered for designing as it will help students in achieving comfortability level, reduce Musculoskeletal disorders (MSDs), and improve performance of students in terms of attentiveness while professors or instructors are teaching them. The matching of body dimensions and classroom furniture is vital to promote proper sitting posture (Aminian and Romli, 2012; Taifa and Desai, 2017).

It is very essential for Asian population to have their own anthropometric measurements regarding students so as it can be easy for designers who are intending to make a furniture which can have comfortability, safety and increase satisfaction level and ultimately reduce Musculoskeletal disorders (MSDs). MSDs are said to be an injuries or pain in the joints of the body, muscles, ligaments, tendons, nerves, and structures that support limbs, back and neck. Previous studies have suggested that, anthropometric measurements needs to be used during designing activities of furniture. In case students continue to use poorly designed furniture, such furniture can result to other ailments also. Due variation of anthropometric measurements currently being used, there is need of having good database of anthropometric measurements in Malaysia if possible, so as such data can be used for current time and future time in designing school furniture. The presence of less survey regarding anthropometric data has been due to that majority of polytechnics or universities administration's procure ready-made furniture which only fit a few users (students). Continuation of such habit of procuring ready manufactured furniture without giving attention to anthropometric measurements of students can results to uncomfortability. Musculoskeletal disorders (MSDs), and can also reduce the performance of students who use such furniture for more number of hours per day while sitting on such furniture (Taifa and Desai, 2017)

4

A previous study was carried out to highlight possible mismatch between the student's body dimensions and the dimensions of classroom furniture used in most Malaysian institutions of higher learning. Data obtained from anthropometric dimensions indicates that there are a lot of differences even between people of the same and different races who make up the population of students in polytechnics across Malaysia. The purpose of this previous study was to find the mismatch between the anthropometric dimensions and the current furniture used in classrooms of polytechnics in Malaysia. From the comparison result, several mismatches are found and this leads to the conclusion that the design of furniture used in the classroom needs to be improved to better accommodate the studying process of the students (Aminian and Romli, 2012).

Conceptual generation with input from anthropometric data should be considered in the initial stage of designing concepts in order to achieve the best design concepts from start of design (Hao et al., 2017). Together with conceptual generation with input from anthropometric data, conceptual evaluation with input from anthropometric data in the initial stage of designing concepts will help alleviate these potential issues in order to achieve the best design concepts from early stages of design (Tiwari et al., 2016).

There is currently no published data on chair and desks anthropometric database for polytechnic students. Currently the chair and desk's user are subjected to unsupported back-leaning posture and feet height during sitting and writing (Figure 1.2 & 1.3) as the current design for desks and chair does not accommodate for such features. This happens because the side for back posture and side portions of the chair are not comfortable for some students in the polytechnic. Metal and plastic are used to fabricate and produced furniture such as chair and desk. This material is not suitable because it is hardened and has a high cost to manufacture.

Politeknik Kuching has also carried previous research showing that is a need for a detailed study of the suitability of the furniture currently in use in their classrooms (Appendix 1). According to the study, the feedback of more than 90% of the students showed that they were uncomfortable using the existing furniture for long periods of time, they did not like the use of plastics in the furniture as it bends at the wrong areas causing discomfort, the size of the existing furniture does not fit their size. Almost 100% of the students have requested that any future furniture should use more durable materials and that conform to the body's curvature. More than 90% of the feedback from the lecturer's observations (who teach in the lecture room) were that students often feel uncomfortable with being seated in the plastic made furniture during learning sessions for long periods of time and the student's size that does not fit the use of the furniture in the classrooms. The information obtained from the storage units of the polytechnic was that there is often damage to the furniture and it is difficult to repair, the worst damage is often in seating area, there were no guidelines (specification) when booking furnitures for classrooms, there

could be a need to use eco-friendly materials for future purchase of furniture to avert the high cost to repair furniture damage.

Figure 1.2:   The incorrect position when sitting
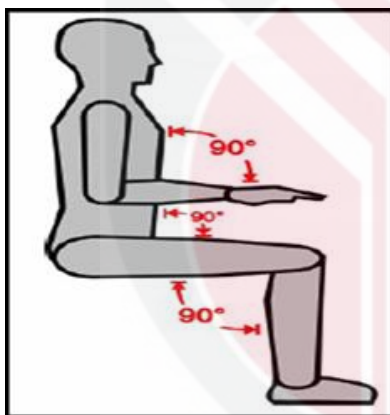
Figure 1.3:   The correct position when sitting

1.3   Research Need

The central idea for this research had been inspired by the fact that the chairs and desks represent as of the important equipment in the field of education in classrooms for every institution in world. The previous study carried out has highlighted that several mismatches were found and this leads to the need that the design of furniture used in the Malaysian institutions of higher learning classroom needs to be improved to better accommodate the studying process of the students (Aminian and Romli, 2012). Therefore this research is valuable in providing scientific baseline information not available in Malaysia currently about the anthropometry database and seating posture among the users using that equipment as well at the same time to design and develop of new chairs

and desks utilising bio composite materials with input from anthropometric data.

The aim of this research is to design and developed a new Polytechnic classroom chair and desk using bio- composites with input from anthropometric data to replace the existing plastic-based top part of the desk in order to reduce the desk's top part weight as well the backrest and seat of the chairs while maintaining the required structural strength for safety and functionality performances. Based on the project requirements, a new concurrent engineering approach with input from anthropometric data utilizing the total design process, morphological chart and weighted objective methods approach was applied in the design and development of this new chair and desk.

1.4 Objective of Study

1.4.1 General Objective

The general objective of this study is to design and develop an anthropometrically enhanced Bio- Composite Chair and Desk to be used by students of Polytechnics.

1.4.2 Specific Objectives

I. To evaluate the anthropometric data (AD) of chair and desk currently used by polytechnics students
II. To generate design concepts of bio-composite desk and chair with and without anthropometric data using brainstorming, mind mapping and morphological chart.
III. To evaluate the best design concept using weighted objectives method with inputs from Anthropometric data in development of bio-composite chair and desk.
IV. To validate design through inputs from Anthropometric Data in development of bio-composite chair and desk.

1.5 Scope of the Study

This study is focused on anthropometric correct and comfort level for chairs and desks at polytechnics. The main scope of the study is the design, development, evaluation and validation with input from anthropometric data of a new set of chair and desk for Polytechnic students to enhance their comfort levels to enhance their studying experience.

1.6   Novelty of the Study

This study is of particular interest as it concerns polytechnic students rather than younger children as reported in most previous studies in Malaysia and elsewhere. However, there hasn't been any research that has been undertaken to evaluate the comfort and discomfort levels among students during their learning process by having an anthropometric compliant furniture for Malaysian students. The Product Design Specification (PDS) of the new products will be based on inputs from Anthropometric Data (AD). Hence this type of study is a new type of way towards designing chair and desk that are anthropometric compliant for Malaysian students. Therefore, this study was undertaken in order to design chair and desk that are anthropometric compliant for Malaysian students in Polytechnics.

1.7   Limitation of the Study

This study is for design and development with input from anthropometric data of a natural bio-composite Polytechnic chair and desk. The testing of the newly fabricated chair and desk utilised virtual testing and not realtime testing as prototyping and creating the actual chair and desk and destroying them during the testing process is consumes a lot of time and money.

1.8   Organisation of the Thesis

The thesis is organised as follows:
Chapter 1 – Introduction. This chapter covers some aspects of the general information about bio-composite Polytechnic chair and desk. An outline of the research problems, research needs, research objectives and scope of research are also presented.

Chapter 2 – Literature Review. This chapter highlights the literature review for the design and development with input from anthropometric data of natural bio-composite Polytechnic chair and desk .

Chapter 3 – Methodology. This chapter highlights the methodology needed to design with input from anthropometric data (using brainstorming, mind mapping and morphological chart) for a bio-composite Polytechnic chair and desk utilising Pugh Total Design with input from anthropometric data.

Chapter 4 – Results and Discussion. This chapter highlights the results and discussion evaluation of the anthropometric data (AD) of chair and desk currently used by polytechnics students. It also shows the generated design concepts of bio-composite desk and chair with and without anthropometric data using brainstorming, mind mapping and morphological chart. The evaluation the best design concept using analysis, weighted objectives method with inputs

from Anthropometric data in development of bio-composite chair and desk. Prior to release the final design of the bio-composite chair and desk, input from anthropometric data was carried out to virtually validate the structural strength of the developed product under normal working conditions

Chapter 5 - Summary, General Conclusions and Recommendations for Future Research. The summary of the entire works, conclusions and recommend.

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152

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1.   Mahmood, A., Mohd Sapuan, S., Karmegam, K. and Abu Saleh, A., 2017. Conceptual Design of Bio-composite Polytechnic Desk Using Combined Total Design-Morphological Chart-Weighted Objective Methods. *Annals of Tropical Medicine and Public Health*

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