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Article

The Interaction of Ergonomic and Anthropometric Factors in Occasional Chair Design for Elderly Malaysians

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Abstract: This research focuses on furniture ergonomics, specifically the occasional chair for elderly Malaysian. An ergonomics study in furniture design is essential to ensure its full functionality meets user satisfaction. The design must comfort the end user and reduce the risk of injury. Additionally, different ergonomic requirements must be considered depending on the age and environment of the user. As a result, to avoid injury and provide comfort to users, this study prioritises ergonomics chair design for a group of users in Malaysia, the elderly aged 60 and above. This study proposes a new design to meet the ergonomics requirements of elderly users. The vital need to meet comfort and reduce injuries for the elderly can be met through the study of ergonomics for the elderly, which can be applied to products in the future. The researcher has set the design parameter according to the anthropometric data from the Business and Institutional Furniture Manufacturers Association (BIFMA) standards. The assessment outcomes determine the ergonomic dimension requirements to provide comfort and safety. The suggested dimensions when through the simulation ergonomics analysis. The result shows that the new recommended dimensions comply with the Rapid Upper Limb Assessment (RULA). In conclusion, ergonomic design needs for the elderly due to lacking physical and mental strength.

Keywords: ergonomics; anthropometry; elderly furniture

1. Introduction

The world's population is a matter of discussion for all researchers because it is one of the causes of the problems that may arise. United Nations Department of Economic and Social Affairs. Population Division (2015) reported that there is mounting evidence that population explosion, economic advancement, rising standards of living, and increased consumption have contributed to altered land use patterns, substantial energy use, and the loss of precious resources, with more obvious signs of global warming and degradation of the environment than ever before. The world's population is saturating every region of the globe. Researchers now have the chance to constantly acquire new findings that will benefit the advancement of civilization. Nevertheless, some issues must be resolved underlying the delight of assisting people. The researchers are responsible for investigating the issue to solve it and benefit humanity. United Nations Department of Economic and Social Affairs (2019) clarified that the demographic transition's effect on human longevity was the primary factor contributing to population worldwide growth. UN also concluded that the ensuing drop in fertility, however, was the catalyst for an increase in the proportion of elderly worldwide. In 2020, 727 million people worldwide were 65 or older. The generation of older people worldwide is predicted to rise by over twofold in the following three decades, reaching over 1.5 billion in 2050 (United Nations Department of Economic and Social Affairs, 2021). According to the data, the number of people 65 and older who were considered elderly will rise throughout the year. Most researchers must be aware of this and employ various strategies to assist this group in staying healthy in this hyper-increasingly competitive global economy. According to Amarya et al. (2018) they concluded that the elderly encounters a variety of issues that call for a multi-sectoral strategy that incorporates contributions from the fields of sociology, health, psychology, nutrition, and other social sciences.

Minetto et al. (2020) stated that musculoskeletal issues are severe conditions that seriously harm individual health, particularly in the elderly, as they are faced with pain, mobility problems, an elevated likelihood of falling and fractures, and a reduced capacity for or inability to carry out activities of daily living. Yoshikawa et al. (2021) determine that sacral sitting results from inconsistent sitting, which worsens the patient's posture while sitting with the trunk tilted and in a sacral position raises the possibility of aspiration, the systemic elevation of muscle stiffness, coughing, and difficulties in expectorating. Nazari et al. (2012) concluded that the nucleus pulposus and intervertebral disc's anterior and posterior heights and the nucleus's position inside the disc were all influenced by shifts in posture, along with three different types of morphological modifications.

Ergonomics (or human factors) is a scientific discipline concerned with the understanding of the interactions between humans and other system elements, as well as an area of expertise that relates theory, fundamentals, information, and strategies to design in order to optimize human well-being and better system performance (Dul & Weerdmeester, 2008). The improvement of human sitting posture satisfaction has long been an essential task in furniture design since ergonomics sitting can create discomfort or low levels of comfort and quickly lead to diseases such as lumbar muscle strain (Vink & Hallbeck 2012), as cited in Sun et al., 2018) Most researchers have found that one factor affecting this group is the physical health of the elderly. According to new research, the muscle groups functioning around the ankle, knee, and hip joints weaken (known as atrophy) as people age, and as a result, the sit-to-stand execution time rises because these muscle groups cannot contract efficiently and ensure the smoothness of movement (Sarvestan et al., 2020).

Deros et al. (2015) believes the capability and knowledge of humans to develop products must be tailored to human characteristics. Thus, when there is a mismatch between a product and human characteristics, product users will experience discomfort. Therefore, all products must be manufactured according to users' anthropometric data (Sagot et al., 2003, as cited in Deros et al., 2015). Dainoff et al. (2007) emphasized it is critical to design affordances with a dynamic character, in the sense of providing support while allowing for changes in posture. As a result, specific chair affordances will be better than others in terms of (a) physical characteristics that reduce biomechanical loading/minimize discomfort and (b) perceptual characteristics that increase the likelihood that users will perceive and execute the relevant chair affordances (Dainoff et al., 2007). Wibowo & Soni (2014) explained that ergonomics is sometimes defined as the study of adapting the work to the user rather than forcing the user to fit the work to the user. They indicated that anthropometric data might be employed to produce a satisfactory match.

Designers already have a variety of resources that predict both software and hardware efficiency; however, in deciding on human-machine interaction in the conceptual stages of a design, they need tools that forecast how the human will operate using task-based metrics attributed with the speed, actions, timing, and errors that may occur while performing a task (Demirel & Duffy, 2007). The enormous, sophisticated anthropometrics tool CATIA V5 enables the researchers to generate an excellent user-specified human model. (Gao et al., 2009). People have now thoroughly investigated the requirements for human posture and proposed a series of evaluation standards, including Rapid Upper Limb Assessment (RULA) (Zhang et al., 2008). This study used the results of previous findings to support the appropriate measurements to increase comfort and lower injuries in achieving the goal of designing an ergonomic chair complying with International Standards.

2. Research Propositions

An anthropometric study is vital when designing a chair that emphasises comfort and safety: Therefore, suitable dimensions of size and measurement are needed to ensure the design has met the demand of the end-users. Anthropometric studies for Malaysians aged 60 and above were used and examined to match researchers' proposed chair dimensions. Many Malaysian anthropometric studies have been published but do not focus on participants with age 60 years and older.

Table 1. Literatures of elderly anthropometric studies in Malaysia

Case Study	Title of paper	Age	Dimension
1.	The relationship between anthropometry and hand grip strength among elderly Malaysians. International Journal of Industrial Ergonomics (Nurul Shahida, 2016)	60 years old and above	Anthropometric dimensions
2.	Development of Malaysian anthropometric database. (Mohamad et al., 2010)	15-80 years old	40 standing and sitting.
			Anthropometric dimensions

The prior research on the anthropometrics of Malaysians who are the same age as the study subjects is summarised in Table 1. Accuracies can be made in the research outcome when applying the appropriate anthropometric data. The researchers employed secondary data because of the high validity. One of the challenges with this study's limitations is the dearth of information on anthropometrics for the elderly. Lacking enthusiasm and awareness from higher officials on the value of anthropometric data in the design of living spaces and products created a significant challenge for Malaysian researchers in raising funds (Yusuf et al., 2016).

2.1. BIFMA guidelines for ergonomics chairs

BIFMA is a non-profit trade association for manufacturers of commercial and institutional furniture. BIFMA has been the representative of the business furniture industry since 1973. The industry's customer service - providing healthy, comfortable, and productive workspaces - is built on an architecture of material and technical standards (BIFMA organization, n.d.). Most BIFMA scientific furniture dimension and standards were not available for free, thus the researchers had to find from furniture company report available online to obtain the information.

Table 2. Literature of BIFMA guidelines

Data	Title of Reports	Source	Website URL
Data 1	Ergonomics and Design a Reference Guide.	(Openshaw et al., 2006).	https://www.researchgate.net/publication/349336642_Ergonomics_and_Design_A_Reference_Guide
Data 2	Office Chairs Overview of Ergonomic Standards. EWI Works.	(Ritchie, 2018).	https://www.ewiworks.com/wp-content/uploads/2019/10/Updated-Chair-Standards-Overview.pdf

Data 1 in Table 2 was obtained from a report published by the office furniture maker Allsteel Inc. and Study 2 report produced by the EWI Work Company, a business that offers services to give its clients good ergonomic consulting. BIFMA standards were employed as guidelines for both companies' reports. This indicates how crucial the BIFMA standard is as a reference for corporations seeking to develop ergonomic products.

2.2. (CAD)Drawing

Computer-assisted design (CAD) software was used to assist in the development of concept design for this project. A design with proper dimensions and measurements can be constructed with this software. The necessity of size and measurement accuracy can lead to an appropriate dimension recommendation for an ergonomic chair for the elderly. Drawing and idea development were created and evaluated with peers determining the best design for this study.

2.3. CAD Simulation validation test

The structure of this product was verified via CAD software simulation to achieve the ergonomics required for the study. Yogasara (2004) stated CATIA V5 provides simulation features that can be used to determine a product's ergonomics. The Ergonomics Design and Analysis workbench in CATIA V5 R8 is an intelligent human modelling and ergonomics evaluation tool with many advanced functions and features. Yet, it is an extension feature of the CAD system. It has some limitations compared to independent ergonomics programs intended for analysis, examination, and assessment in ergonomics fields (Yogasara, 2004).

2.4. Rapid upper limbs assessment (RULA) posture analysis in CAD simulation

RULA is a way to evaluate the posture, style, and movement of performing activities requiring an upper body (Yusuf et al., 2016). Rapid Upper Limbs Assessment (RULA) is one of the features used to assess ergonomics. This instrument was utilized in this study to generate data regarding the ergonomics of this chair. This analysis was implemented in the CATIA V5 simulation program to record the ergonomic decision findings. The exposure scores, according to RULA were divided into four 0, 1, 2, and 3 exposure categories: negligible, low, medium and high, respectively. Medium and high-risk actions should be addressed to reduce the level of exposure of risk factors (Ansari & Sheikh, 2014).

Table 3. Categories of the risks level using RULA assessment

RULA Level	RULA Score	Risk Level	Required Action
0	1-Feb	Negligible	Acceptable
1	3-Apr	Low	Investigate further
2	5-Jun	Medium	Investigate further and change soon
3	7	High	Investigate and change immediately

Source: Ansari & Sheikh (2014)

Table 4. Color associated to the score in CATIA V5 simulation software for RULA analysis.

Segment	Score range	Color associated to the score					
		1	2	3	4	5	6
Upper arm	1 to 6						
Forearm	1 to 3						
Wrist	1 to 4						
Wrist twist	1 to 2						
Neck	1 to 6						
Trunk	1 to 6						

Source: Paul et al. (2019)

Table 3 and 4 illustrate the RULA score for ergonomic analysis. Green indicates the score is acceptable while yellow shows its needs to be investigated further and minor changes if possible. The red colour means it should be investigated further and changed.

3. Results and Discussion

The BIFMA standards are referred to analyses the findings. The proposed design's size and dimension have followed the guidelines from existing Malaysian anthropometric data. The guidelines are essential to ensure that the chair's design must meet its needs for the best ergonomic standard.

3.1. Analyzed the relationship of BIFMA guidelines and Malaysian elderly anthropometrics in Malaysia.

Figure 1. Size and dimension guidelines from BIFMA and Allsteel Sum chair (Openshaw et al.,2006)

Table 5. Size and dimension specifications guidelines from BIFMA **(**Data 1)

Seat properties		**Specification**	
		Measurement	**BIFMA guidelines (Inch)**
Seat Height	A	Popliteal height + Shoe allowance	15.0” – 19.9”
Seat Depth	B	Buttock-popliteal length - Clearance allowance	No deeper than 16.9” (fixed) 16.9” included (adjustable)
Seat Width	C	Hip breadth, sitting + Clothing allowance	No less than 18”
Backrest Height	D	None	At least 12.2”
Backrest Width	E	Waist breadth	14.2”
Backrest Lumbar	F	None	Most prominent point 5.9” – 9.8” from seat pan, in and out one
Armrest Height	G	Elbow rest height	6.9”– 10.8” 7.9” – 9.8
Armrest Length	H	None	None
Distance Between Armrests	I	Hip breadth, sitting + Clothing allowance	18”(fixed) 18” included adjustable

Source: Openshaw et al. (2006)

Data 1 in Figure 1 and Table 5 follows the guidelines suggested by Openshaw et al. (2006). The tabulated number of standards in accordance with BIFMA to satisfy the ergonomic demands. The authors then use the outcomes of this data analysis as a guideline to develop an occasional chair item. Meanwhile, the second data in Table 6 by Ritchie et al. (2018) has been employed to complement data 1. Having more than one source of information can provide the researcher with more data to examine to choose the best anthropometric measurement for the elderly. Table 5 and 6 there are a few data additions, for example the seat pan angle and torso-thigh angle are two of the new data in table 6. This indicates how changes in anthropometric measurements always affect adding and updating dimensional measurement data and ranges for office chairs.

Table 6. Measurement guidelines from BIFMA (Data 2**)**

Seat properties	**Specification**	
	Measurement unit	**BIFMA guidelines**
Seat Height	Centimetres (cm)	37.6-51.2
	Inches (in)	14.8-20.2
Seat Depth	Centimetres	Fixed: Max. 41.5
	(cm)	Adjustable: should include
		a depth of 41.5 or less
	Inches (in)	Fixed: Max. 16.3
		Adjustable: should include
		a depth of 16.3 or less
Seat Width	Centimetres (cm)	Min. 48.9**
	Inches (in)	Min. 19.2**
Backrest Height	Centimetres (cm)	Min. 35.4 from compressed seat height
	Inches (in)	Min. 13.9 from compressed seat height
Backrest Width	Centimetres (cm)	Min. 36.0
	Inches (in)	Min. 14.2
Armrest Height	Centimetres	Fixed: N/A
	(cm)	Adjustable: 19.5-28.9
	Inches (in)	Fixed: N/A
		Adjustable: 7.7-11.4
Armrest Length	Centimetres (cm)	None
	Inches (in)	None
Distance Between Armrests	Centimetres	Fixed:49.3
	(cm)	Adjustable Min: 49.3
	Inches (in)	Fixed:19.4
		Adjustable Min: 19.4
Torso-Thigh Angle	Degrees (°)	Fixed: Min. 90° (vertical)
		Adjustable: range of ≥15° of
		which at least 15° falls
		between 90°-120°

Source: Ritchie (2018)

In this study, the BIFMA standard is necessary for the researchers to propose a design that can facilitate the user's ergonomics. Researchers have examined the suitability of the recommendations using the anthropometry measurements of the elderly in Malaysia, even though the dimension and range recommendations made by BIFMA are requirements that must be followed. As a result, research on the

BIFMA-recommended measurements and the anthropometric measurements of Malaysian seniors must be examined to determine the appropriate suggested measurements to satisfy ergonomic criteria.

3.2. Dimensions and Ranges Recommendations based on Anthropometrics study and BIFMA guidelines

To determine the proper measurements for the elderly; the anthropometric research of the selected case studies and BIFMA standards were employed and analysed. Figure 2 shows the sitting posture anthropometry that the researcher analysed.

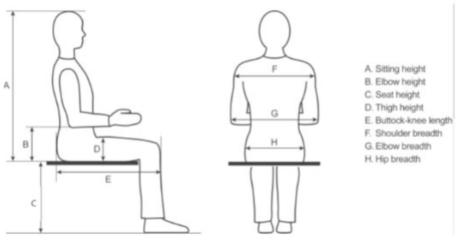


Figure 2. Sitting anthropometry

Source: Molenbroek et al. (2017)

Table 7. Collection of previous data for dimension and ranges including recommended dimension for this study

Measurements	Dimension and ranges(mm)				
	Malaysian elderly anthropometrics 5^{th}-95^{th} percentile data(mm)		BIFMA guidelines		Recommendations
	Study 1	Study 2	Data 1	Data 2	
Popliteal Height/seat height	Male: none Female: none	354.38 - 495.21	381 - 505.46	376.00-512.00	Adjustable height with 380.00 – 478.00 ranges
Buttock Popliteal Length	Male: none Female: none	367.87 - 529.33	No deeper than 429.26 (fixed) 429.26 included (adjustable)	Fixed: Max. 415 Adjustable: should include a depth of 415 or less	397
Hip breadth, sitting	Male: 288 - 405	261.22 - 495.45	No less than 457.2	Min. 489	552

	Female: 272 - 386				
Sitting height	Male: 746 - 865 Female: 706 - 818	667.12 - 918.59	At least 309.88	Min. 354 from compressed seat height	758.00 not included headrest. 880.00 included headrest
Shoulder breadth, standing	Male: 342 - 453 Female: 322 - 400	346.77 - 531.17	360.68	Min. 360	528
Shoulder-elbow length	Male: 300 - 357 Female: 275 - 346	256.99 - 424.03	175.26 - 274.32 200.66 - 248.92	Fixed: N/A Adjustable: 195-289	Adjustable arm rest height: 249.00-287
Forearm-hand length	Male: 416 - 480 Female: 357 - 466	366.99 - 476.06	None	none	283
Elbow to elbow breadth	Male: 346-529 Female: 306-516	none	457 (fixed) 457 included (adjustable	Fixed:493 Adjustable Min: 493	543

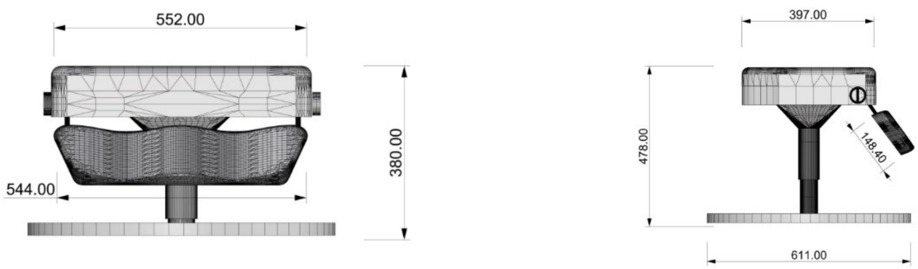
3.3. Computer-Aided Design (CAD) for design analysis.

The Rhino V6 was applied in this research to assist in developing an ergonomic chair design. Based on analysis done by comparing the BIFMA standard and anthropometrics of the elderly in Malaysia, this tool enables researchers to obtain precise dimensions. The backrest, seat, and armrest images illustrate in Figures 3,4 and 5

(a) (b)

Figure 3. illustrates the measurements and several views of the backrest: (a) A front view showing the backrest width.

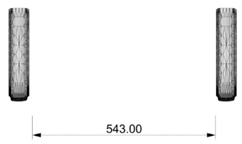
In anthropometric studies 1 and 2, the measurement for the backrest width was obtained from the shoulder width while standing. Refer to Data 2 in Table 7 BIFMA recommendation that the backrest width must be more excellent than 360.00 mm. According to studies 1 and 2 in Table 7, the maximum shoulder width while standing is 531.17mm, while the smallest is 322.00mm. Therefore, 528.00 mm is the recommended width for the backrest; (b) a side view with the recommended dimension. The dimension was determined by measuring the sitting height in anthropometric studies 1 and 2 in Table 7. According to the anthropometric study, the highest measurement for sitting height was 918.59 mm, and the lowest was 667.12 mm, including the headrest. Refer to Data 2 in Table 7 BIFMA recommendation that the backrest height must be greater than 354.00 mm. The recommended backrest height was 752.25 mm.



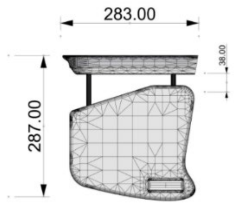
(a) (b)

Figure 4. varied views of the seat, including recommendations for measurement

Figure 4 (a) Front view with width and minimum adjustable height dimension. The width dimension was gained from the hip breadth, while the height was gained from the popliteal height from anthropometric studies 1 and 2 in Table 7. The maximum length of the hip breadth was 495.45 mm, and the minimum was 272.00 mm. Refer to Data 2 in Table 7 BIFMA recommendation that the backrest seat width must be greater than 489.00 mm. The recommended dimension for the seat width was 552.00 mm. Having a seat width 50 mm greater than the maximum hip breadth will give the user more space and suit the comfortability aspect;(b) Side view and the length and height dimensions of the seat. In previous anthropometric studies in Table 7, the seat length was determined by measuring the popliteal buttock. The maximum measurement was 529.33 mm, and the lowest was 367.87 mm. Refer to Data 2 in Table 7 BIFMA recommendation that the seat depth must be smaller than 415.00 mm. The suitable dimension for the seat depth is 397 mm, which is lower than the anthropometric measurement because there must be a space between the front of the seat and the back of the knee. The popliteal height in the anthropometric studies determined the height of the chair. Refer to Data 2 in Table 7 BIFMA recommendation that the adjustable seat height range between 376.00 mm- 512.00 mm. The highest anthropometric measurement was 495.21 mm, and the lowest was 354.38 mm. The recommended ranges for the adjustable seat height are 380 mm to 478 mm.



(**a**)



(**b**)

(c)

Figure 5. diverse view of the armrest design, including the suggested dimension

Figure 5(a) Top view for the armrest part comprise the distance between armrest. The distance between arm rest by BIFMA guidelines in Table 7 claim 457 mm (Data 1) and 493.00 mm (Data 2). The suggested dimension for the distance between the arm was 543.00 mm. The dimension for this chair was slightly greater than the BIFMA guidelines because it depends on the width of the seat; (b) Side view with adjustable height and length dimension. Refer to Data 2 in Table 7 BIFMA recommendation that the adjustable seat height range between 195.00 mm- 289.00 mm. The recommended armrest height ranges for the chair design were 249.00mm-287.00mm. (c) Front view with armrest width dimension. The recommended armrest width was 66.00mm and no data was available from BIFMA.

3.4. CATIA V5 simulation for ergonomics using RULA analysis

This research used a simulation tool called CATIA V5 to produce ergonomic results. The RULA assessment feature is used to simulate the ergonomic score of the proposed chair. In this simulation, the anthropometric of the Malaysian elderly is manually input to ensure that precise data will be obtained.

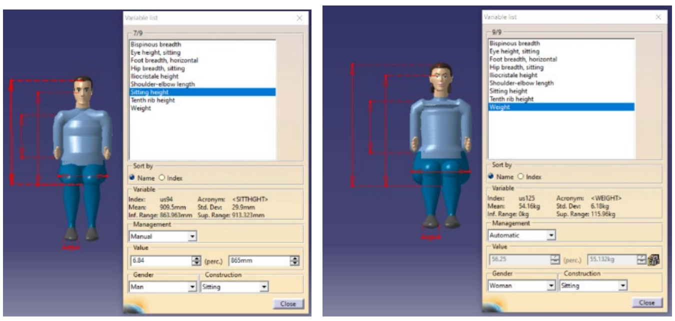


Figure 6. Dimension for 95th percentile of male(left) and female(right) elderly in Malaysia.

Figure 6 shows examples of dimensions that were manually entered for each manikin. Most of the critical dimension was entered manually, and some dimensions could not be key-in due to no data from previous studies. The dimensions missing from the previous studies are bispinous breadth, lliocristale height, tenth rib height and weight. The simulation system automatically entered the dimension.

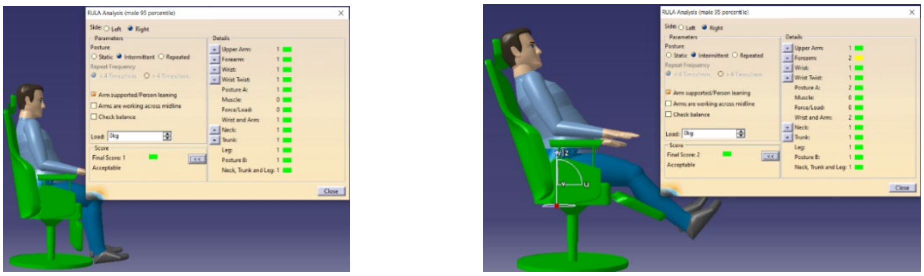


Figure 7. RULA analysis of elderly 95th percentile normal sitting position(left) and recline sitting position(right)

Table 8. RULA analysis with associated color score result

Segment	Elderly male and female RULA analysis color associated score result											
	Male 95th percentile(normal)		Male 95th percentile(recline)		Female 95thpercentile(normal)		Female 95thpercentile(recline)		Male 5th percentile(normal)		Female 5th percentile(normal)	
Upper arm	1		1		1		1		1		1	
Forearm	1		2		1		2		1		1	
Wrist	1		1		1		1		1		1	
Wrist twist	1		1		1		1		1		1	
Neck	1		1		1		1		1		1	
Trunk	1		1		1		1		1		1	
Final score	1		2		1		2		1		1	

Table 8 demonstrates the result of the RULA analysis for the elderly with different percentile and sitting positions. Based on the final score, elderly male and female 95th percentile (normal position) they achieved acceptable requirements for RULA analysis in ergonomics. In contrast, elderly male and female 95th percentile (recline position) acquired a final score 2 but still achieved acceptable requirements. The forearm score for male and female reclining positions score in Yellow might have a negligible effect on the final RULA analysis score. It shows that the 95th percentile elderly male and female required the highest setting for both Sitting height and arm rest height. The height for the adjustable armrest has the highest setting 287.00 mm, while the sitting height of the chair is also adjusted to the highest setting is 478.00 mm. 5th percentile male and female, the height for adjustable arm rest, has the highest setting 287.00 mm, while the sitting height of the chair adjusted to the lowest setting which is 380 mm. This shows that the 5th percentile elderly male required the highest setting for armrest height and the lowest for sitting height. Elderly male and female 5th percentile (normal position) achieved acceptable requirements for RULA analysis based on the final score. The recommended ranges recline angle for the chair was 100° - 112°degree. According to Mohamaddan et al. (2022) study, the result shows that the muscle activity human leaning backwards for 100° chair compared to 80° chair varies, and extra effort is needed for a more leaned chair. Thus, the recommended reclining ranges for the chair should not be exceeded.

3.5. Designer impression of the final design proposed

The final chair design had been rendered in Keyshot to produce a realistic image for viewer remark.

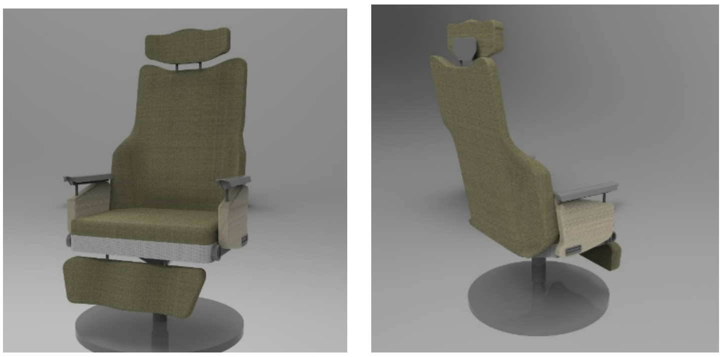


Figure 8. Front and rear view of chair design.

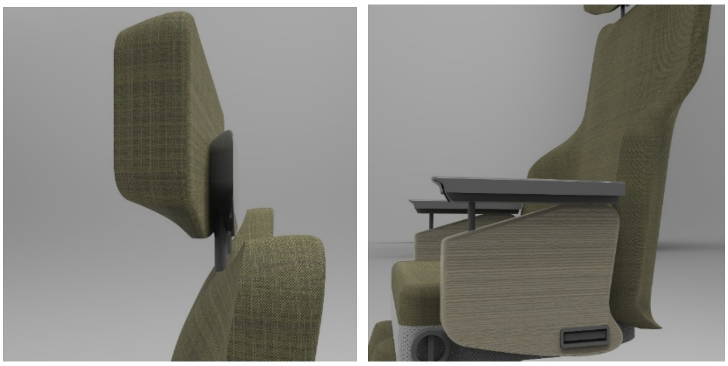


Figure 9. Head rest and arm rest with adjustable height function

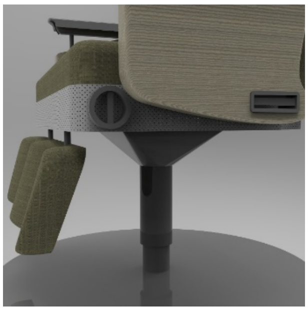


Figure 10. Adjustable seat height and 360°swivel functions

4. Conclusions

The study's primary goal is to produce a chair design that is acceptable and fulfils the ergonomics need of the elderly in Malaysia. The researchers hope that the proposed anthropometrics and ergonomics chair can increase the comfort level and safety of end-users. The simulation ergonomics analysis by CATIA V5 is the best tool to assist this study in achieving its objectives. The overall ergonomic results are acceptable, comply with the RULA ergonomics analysis, and can be recommended for future use. The anthropometric data are based on four groups of participants, namely 95th percentile male, 95th percentile female, 5th percentile male and 5th percentile female. Table 8 confirmed that 95th percentile male final score for RULA analysis was 1 and acceptable for ergonomics requirement. Table 8 similarly confirmed 95th percentile female final score for RULA analysis was 1 and acceptable for ergonomics requirement. Table 8 show 5th percentile male and 5th percentile female results had a final score 1 and were acceptable for ergonomics requirements.

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