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Design and Development of an Automated Shoe Rack

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ABSTRACT

Background: Due to usability issues in existing shoe rack designs, many designers have looked into the development of ergonomic shoe racks. However, there appear to be a number of possible flaws that still exist in these ergonomic shoe rack designs. **Objective:** This paper aims to design and develop an automated shoe rack for improved usability. **Results:** After conducting market research on available shoe rack designs, two stages of conceptualisations with selection matrices were done to select the most feasible design to be worked upon. Based on the concept selection matrices, the automated shoe lift bench concept was chosen and designed using the Autodesk Inventor Professional 2013 software. After the fabrication of the shoe rack, the Rapid Entire Body Assessment (REBA) usability test was used as validation for improved usability. A REBA score of 1 (negligible risk) was obtained for the new shoe rack while a REBA score of 6 (medium risk) was obtained for the conventional shoe rack. The improvement came from the minimisation of neutral deviation from the neck, trunk and leg regions where users did not require to bend, squat or stretch to obtain shoes from the lowest rack. **Conclusion:** Overall, the automated shoe bench lift system proves to be extremely beneficial in improving the usability of storage systems and could be implemented in other furniture/storage products in future.

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INTRODUCTION

The shoe rack is a common household storage unit and can be categorised as a type of furniture. Shoe racks come in many different shapes, designs and materials for its purpose of storing and organising shoes. With the technological advancement and the convenient assistance from computer assisted design (CAD) programs in today's age, a new world of possibilities has been opened for furniture product designers as many past design limitations have been eliminated. This growth of new products is very much evident as the

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market is flooded with all kinds of shoe storage solutions; e.g. basic shoe rack, shoe cabinet, over-the-door shoe rack, shoe rack bench and automated shoe carousel. However, the ever-evolving trends and the growing demand for ergonomic products have created a gap in today's market for the development of a shoe rack for improved usability; namely an ergonomic automated shoe rack.

With the present ease of obtaining knowledge, customer awareness has grown tremendously and industries can no longer rely on pass laurels and afford to think that anything it produces will be accepted by the consumers. Consumers are much more aware on the importance of an ergonomically sound product design to prevent the risk of musculoskeletal disorders. In addition, safety, occupational hazard and product liability related regulations are gradually but surely being implemented and enforced across all workplaces which will in turn force all furniture manufacturers to include ergonomic, eco-friendly and energy saving evaluations as a priority in the designing of future products. This slow rise in emphasis on ergonomic and higher usability furniture/storage designs can clearly be witnessed in today's trends as furniture shops offer more choices of ergonomic products such as ergonomic office chairs and multipurpose workstations.

Shoe racks are not excluded from this trend. Ergonomic researchers and designers have seen to this higher demand of higher usability products and have developed ergonomic and/or automated shoe racks that are readily available in today's market. However, there remains room for improvement to fix some gaps/flaws/deficiencies in these existing ergonomic shoe rack designs. This paper aims to address these deficiencies.

Based on a study on Malaysia's wooden furniture industry, Malaysia's exports have grown significantly starting from year 2000 with large expansion into the overseas markets; Malaysia's exports surged from RM317 million in 1990 to RM8.7 billion in 2008 (Malaysian Timber Industry Board, 2015). In 2008, Malaysia was the 10th largest exporter of furniture in the world and 3rd in Asia (Ng and Thiruchelvam, 2012).

According to the Malaysian timber industry board (MITB), in January 2015, wooden furniture products exported 34% of a total of RM1.81 billion worth of exported timber products (Malaysian Timber Industry Board, 2015). This number shows that Malaysia is one of the frontrunners in the world in the wooden furniture business, and with good resources of timber it should not be an unrealistic target for Malaysia to also be considered as the World's leader in wooden furniture design.

Looking into the furniture and storage market, there is much room for improvement on the ergonomics and usability aspects of design. This paper aims to address these gaps/flaws/deficiencies and to design and develop an ergonomic automated shoe rack for improved usability that incorporates the solutions to the gaps/flaws/deficiencies in the existing ergonomic and/or automated designs. The scope of this shoe rack design is to incorporate an automated aspect into the final design to improve usability and in turn lower the risk of injuries that are associated with the deficiencies of current shoe rack designs in the market.

Malaysian anthropometric and biomechanical characteristics were critically researched in this paper to find the most suitable ergonomic design to fit this intended market. All features that can attribute to the improvement of this shoe rack's usability were also critically discussed such that it can be a feasible marketable product.

TYPES OF SHOE RACKS

A poll in America was conducted in 2006, and it was found that affluent American woman own an average of 27 pairs of shoes and American man own an average of 12 pairs of shoes (Trippet et al., 2006). With this staggering numbers, it is no surprise that the demand for convenient shoe storage solutions is on the rise.

Furthermore, the need for ergonomic shoe rack designs will grow tremendously as users with more shoe options will spend a greater time viewing/picking/trying on shoes from the shoe rack and in turn increases the risk of developing musculoskeletal injuries if the design is not ergonomically made. Generally shoe storage units are independent units made of wood, plastic or metal.

In recent times, designers and researchers have taken more attention towards the ergonomics of a product to improve its usability such that it limits occurrence of repetitive strain injuries. According to a paper by the National Physical Laboratory, there are two complementary but distinctly distinguishable approaches to usability in products (Bevan, 1995):

1. Product oriented "bottom up" view which identifies usability with ease of use.
2. "Top-down" approach which interprets usability as the ability to use a product for

its intended purpose that originates from human factors.

Usability has both of these roles in product design. It acts as a feature and attribute that must be incorporated into the designing of a product, and as the main objective of the design. Current designers and researchers have taken both these approaches to develop shoe storage solutions of improved usability. However, there may still be some possible deficiencies or flaws in these existing ergonomic shoe storage solutions.

Shoe Bench (Preutz, 2015). This shoe storage bench design by IKEA makes it extremely suitable to be put by an entryway as it serves as a shoe storage solution and also a multipurpose bench to be used mainly for putting on/taking off shoes. The shoe bench can be described by the following points:

- Main part: Solid hardwood, Acrylic paint
- Tube: Galvanised steel, Stainless steel
- Top panel: Particleboard, ABS plastic, Acrylic paint, Foil
- Holds a minimum of 8 pairs of shoes
- Cost: 59.99USD = (RM 222)
- Width: 108cm
- Depth: 34cm
- Height: 50cm

Possible deficiencies in shoe bench design. The open storage can be deemed to look messy and unorganised to a few target consumers. Furthermore, it requires bending and kneeling over to view/pick/store shoes which risks its user to musculoskeletal disorders.

Shoe storage bench (Improvements, 2015). This shoe bench design by IMPROVEMENTS addresses the problem with the open storage and also slightly improves its usability with the easier reach flip-down door. The following points are descriptions of the shoe storage bench design:

- Material: MDF and Veneer
- Holds up to 9 pairs of shoes
- Price: $169.99 – (RM628)
- Width: 76.2cm
- Depth: 40.6cm
- Height: 61cm
- Weight: 17.2kg

Possible deficiencies in shoe storage bench design: Though this design improves its easy access to shoes, it still may be too difficult for some, especially ageing users to retrieve shoes from the lowest rack.

Automated Shoe Storage (Storage Motion, 2015). This automated shoe storage is an electric, motor driven, vertical carousel that addresses the problem of needing to bend over to view/pick/store shoes. This design can be customised to have a floor to ceiling storage that is space efficient as this motor driven shoe storage solution rotates and revolves all shelves to a reachable and viewable level with a push of a button. The automated shoe storage can be described by the following points:

- Automatic revolving shelves that are motor driven, a vertical carousel/conveyor
- columns of shoe shelves, one behind the other
- Customisable units to fit storage space and type of shoes

Possible deficiencies in automated shoe storage design. As with all customised designs, the cost is comparatively high. Also, this design is not suitable near the entry way as it extremely space consuming, which is not a design suitable for Asian countries where it is culture to remove shoes before entering the house. Shoe wearing provisions are also not provided in this design.

Shoe wheel (Torro, 2010). The shoe wheel design by RAKKU design is an ingenious designed mobile storage unit with expandable pockets to hold a variety of shoes. Easy rotation of the wheel to make a selection and can be easily stored in a confined area such as a cupboard or underneath the staircase. The following points are descriptions of the shoe wheel bench design:

- 20 expandable pockets that can hold up to 30 pairs of shoes
- Locking, swivel wheels for mobility
- Injected polymer frame (moduled ABS resin)
- Super clean vinyl side panels and pockets
- Elastic polyester cords
- Chrome plated steel base
- Price: $71 – (RM262)

Possible deficiencies in shoe wheel design. Though this fresh and new design is able to store many shoes in such a small space, it still has its drawbacks. One drawback is that it can be unhygienic to store so many shoes in a wheel were close proximity between the sole and the top of the shoe can be grounds for breeding bacteria. Also, it requires some time and effort in storing/retrieving the shoes from the shoe wheel, needing to expand the pockets to store/retrieve shoes can prove to be difficult for some.

Automated carousel shoe cabinet (Ashley and Ashley, 2000). The upper compartment consists of an electrical motor powered carousel that rotates the shoe compartment, while the lower compartment consists of a drawer for storing socks. This design can be described with the following points:

- Carousel shoe cabinet system for shoe storing in an organised manner
- Optional for an electrical motor to be installed to rotate the carousel

Possible deficiencies in automated shoe cabinet design. Relatively wider than the conventional shoe rack making it not suitable to be placed near the doorway. Lower end of shoe carousel still requires bending over to pick/store shoes. Table 1 summarises all the possible deficiencies of the current ergonomic shoe rack designs in the market.

Table 1: Possible Deficiencies in Ergonomic Shoe Rack Design

Designs	Possible Deficiencies
Shoe bench	• User still required to bend to retrieve/store shoes on the lower rack
Automated shoe storage	• Requires customisation • Expensive • Space consuming
Shoe cabinet with flip down door	• User still required to bend to retrieve/store shoes on the lower rack
Shoe Wheel	• Unhygienic as shoes are confined together in a small area • Requires more time and effort in retrieving/storing shoes
Carousel shoe cabinet	• Relatively wider than the other designs, making it unsuitable for placement by the door way • Lower shoe pockets still difficult to reach

DESIGN CONCEPTUALISATION (PHASE 1)

A total of 4 concepts were created in order to address the deficiencies of the identified designs in the preceding sections. The concepts include the ¼ circle automated shoe storage bench (Concept 1), dual wheel kick-in shoe storage bench (Concept 2), ergonomic shoe cabinet with swivel out seat (Concept 3) and automated rotating lift ottoman with shoe enclosure (Concept 4).

These concept designs were considered preliminary designs and were hand-drawn before the finalised concept was decided. Figure 1 shows an overview of concept 1 and concept 2, while Figure 2 shows the overview for concept 3 and 4. Table 2 presents the concept selection matrix for all 4 concept designs. The point system used for concept selection was defined as:

1- Weak Justification
2- Average Justification
3- Advantageous Justification
4- Strongest Justification

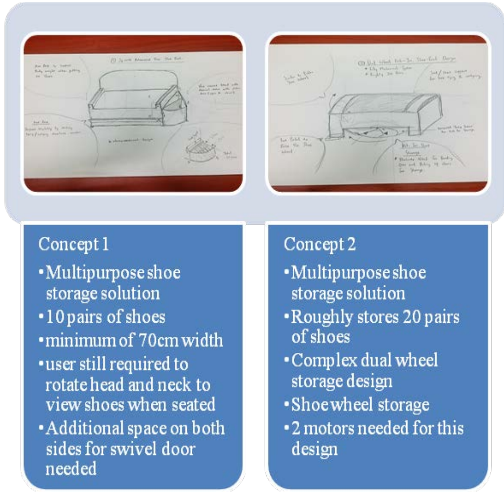


Figure 1: Overview of Concept 1 and 2

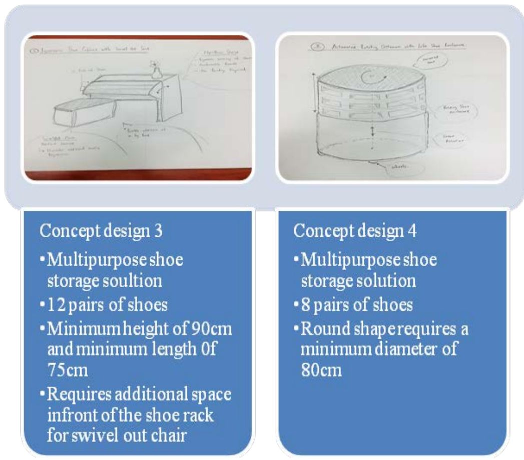


Figure 2: Concept Design 3 and 4 Overview

Table 2: Concept Selection Matrix for Conceptualisation Phase 1

Criteria/Concept	1	2	3	4
Usability improvement	1	4	4	4
Cost	4	1	2	3
Suitable to place near entry way	4	4	1	2
Space efficiency	2	2	1	4
Complexity of design	3	1	2	2
Multipurpose	2	2	2	2
Transportability	2	2	1	4
Total	**18**	**16**	**13**	**21**

Based on the selection matrix table in table 2, concept 4 was selected as the most viable option for this study. Its 3 main advantages of improved usability, space efficiency and transportability make it the most suitable concept for this study. Though being the most suitable concept design, this concept still had room for improvement and this was investigated further in phase 2.

The simple lift system of the ottoman using a linear actuator to lift the shoe rack to a more comfortable easy reach height for its users makes this automated aspect the most attractive compared to the other concept designs.

According to the design scope and design targets mentioned earlier in the study, this shoe rack design must be suitable to be placed near the entry way.

The round design of the ottoman makes it less suitable to be placed anywhere near the entry way as it can be viewed as unorganised compared to a rectangular shaped shoe rack that is leaned against the entry way wall. Apart from that, additional sock storage should be introduced to the improved design to improve its multipurpose feature. Two main improvement features to concept design 4 include:

1. A rectangular shape design so that it is suitable to be backed up against the wall
2. Additional storage features for socks

DESIGN CONCEPTUALISATION (PHASE 2)

Based on the selection matrix, concept 4 was chosen as the ideal concept design to be further improved on. Based on the linear actuator lift system, 2 more concepts were generated in phase 2 based on the improved features of concept 4 in phase 1.

These concepts are also hand-drawn prior to the finalised design. Figure 3 presents concept A, which is known as the automated shoe cabinet lift with a foldable bench.

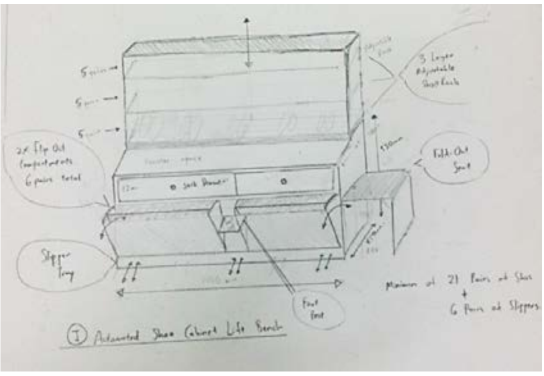


Figure 3: Concept A – Automated Shoe Cabinet Lift with Foldable Bench

Concept A features a rectangular shaped design suitable to be leaned against the wall by the entry way and also extra storage room for socks and other footwear items. Its larger design means it will be able to fit approximately 21 pairs of shoes in its 3 tier shoe lift rack and its front 2 flip down storage with an additional 6 pairs of slippers on the slipper tray.

A fold out seat will be attached to its side as a shoe lace tying provision. Its estimated dimension is 1500 x 700 x 800 mm (before extension). Figure 4 concept B which is known as the automated shoe lift bench.

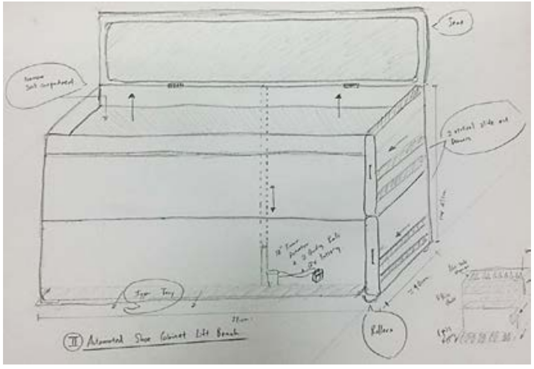


Figure 4: Concept B - Automated Shoe Lift Bench

Concept B is an automated shoe lift bench with rollers attached to one side for transportability. Concept B has a shape of a chest box, with 2 tier racks capable of storing a minimum of 8 pairs of shoes and 5 pairs of slippers on the slipper tray at the bottom.

Concept B features 2 pull out drawers on its side for additional storage for things like shoe polish and brush, it also has a flip open top seat, similar to a piano chair seat, suitable for storing socks. Its estimated dimension is 1000 x 600 x 450 mm (before extension).

Comparing both the designs in conceptualisation phase 2, it was decided that design concept B was a more suitable option to pursue as a prototype. Table 3 presents the justifications on the final selection for Design B.

Table 3: Conceptualisation Phase 2 Final Decision

Justification	Elaboration
Smaller dimension	Suitable for a larger percentage of households (apartment type house)
Less materials used	Keep cost low, increase marketability
Less complex design	Potential to sell as a self-assemble storage unit
Transportability	Chest box shape with rollers attached at one end making it easier to move around
Prototype	Better to experiment (construct) a smaller unit to identify improvements needed for design

DIMENSIONAL CONSTRAINTS

This study utilises Malaysian anthropometric data. Based on a study by Mohamad et al. (2010), mean data of various parameters from Malay, Chinese, Indian and other races were gathered based on a total of 1007 Malaysians.

To accommodate 90% of Malaysian population, all dimensions of the new design were based on data between the 5th percentile and 95th percentile and data closer to the 50th percentile. Based on this scope, the critical dimensional constraints for the automated shoe lift bench are listed in Table 4.

Table 4: Critical Dimension Constraints

Unit Part	Anthropometric Dimension
Bench height (max)	Popliteal height 425 mm
Rack Width (4 pairs) (min)	Foot Length 226 mm x 4
Rack Length (min)	Foot Breadth 102 mm
Extended Rack Height	Shoulder Height 1288 mm
Slipper Rack Height (min)	>100 mm
Load	180 kg x n (safety factor)

USABILITY TEST METHOD

Observations by video recording and snap shots are used to determine the strain or the angular deviation of a body segment from the neutral position by means of visual perception. Hence, this study adopts the observational technique as a method of assessment on the usability of the shoe rack.

For this study, since the main concern is more on the postural analysis and less on the loading of musculoskeletal system, the REBA assessment method is the most suitable method of choice to determine the design usability.

RAPID ENTIRE BODY ASSESSMENT (REBA)

REBA is the chosen method of assessment for this project as REBA provides a quick and systematic assessment of the complete body postural risks to a user. It is suitable for this paper in measuring the usability of the shoe rack. REBA was developed by Dr. Sue Hignett and Dr. Lynn McAtamney, both ergonomists from University of Nottingham in England (Hignett and McAtamney, 2000).

The REBA technique is a postural analysis system sensitive to musculoskeletal risks in a variety of tasks, especially for assessment of working postures, which includes the upper arms, lower arms, wrist, trunk, neck, and legs (Kee and Karwowski, 2007). The basis of REBA is to score the positions of individual body segments that deviate from the neutral posture. A larger deviation from the neutral position would score higher points.

The scoring is separated into two parts, namely Group A and Group B and provides five action levels for evaluating the level of corrective actions. Further elaboration of the REBA assessment method is shown in Figure 5. Table 5 shows the REBA scoring system.

Table 5: REBA Point System (Middlesworth, 2015)

Score	Risk Level of Musculoskeletal Disorders
1	Negligible risk, no action required
2-3	Low risk, change may be needed
4-7	Medium risk, further investigation, change soon
8-10	High risk, investigate and implement change
11+	Very high risk, implement change

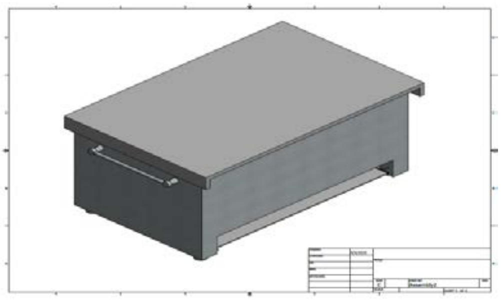
The REBA assessment is carried out to available shoe rack designs and the final automated shoe rack design to determine whether the usability issues of the older designs have been addressed. The selections of postures to be evaluated are as follows:

1. Most difficult posture and work task (bending to retrieve shoes from the lowest rack)
2. Posture sustained for the longest period of time (act of putting on a pair of shoes)
3. Posture where the highest force loads occur

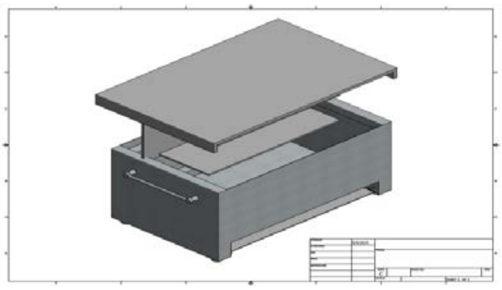
The total REBA score for each type of shoe rack including the new shoe rack design is tabulated and listed in the results table.

FINALISED DESIGN - 3D DRAWINGS

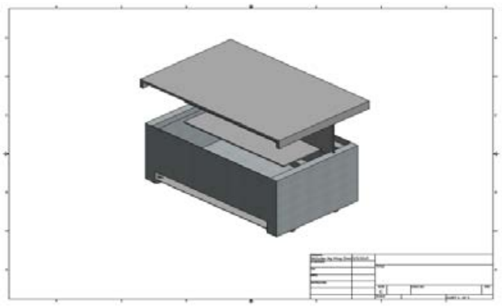
Figure 5 shows the CAD drawing for the automated shoe storage bench. Figure 5 (a) shows it in a closed position. Figure 5 (b) shows it in its first opened position while Figure 5 (c) shows it in its second opened position. Figure 5 (d) shows the exploded view of the product.



(a)



(b)



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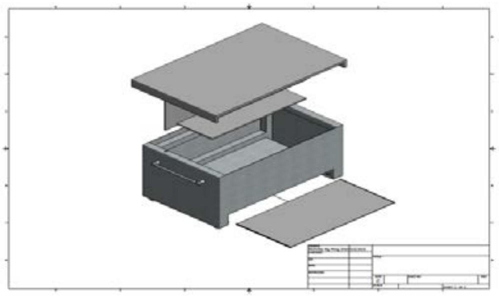


(d)

Figure 5: CAD Drawings of Automated Shoe Storage Bench

DIMENSIONS OF THE FINAL PROTOTYPE

Table 6 shows the final prototype dimensions. The prototype basically consists of 2 major parts namely the base structure and the seat cover attached to the shoe rack rail. The rectangular base structure was constructed with a combination of 2 x 3 and 3 x 3 Balau lumber along with 0.2-cm and 1.0-cm thick plywood using L-shaped halved joints and nails.

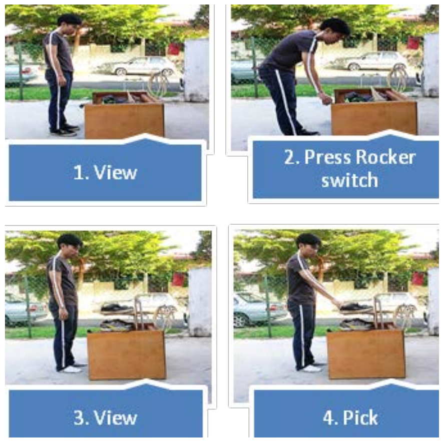
The second part which included the shoe rack support and the bench seat was constructed using grooves to fit the shoe rack backboard into the base structure and it is supported by Balau lumber. The bench seat was constructed using two 1.0-cm thick plywood nailed together.

Table 6: Final Prototype Dimensions

Model dimension	Descriptions
Length	Top length with seat: 120cm Bottom length: 105cm
Width	65cm
Height (Closed)	Without seat:50cm With seat: 57cm
Height (Open)	85.5cm
Feet rest height	11cm from base

USABILITY TEST RESULTS

Figure 6 shows a series of still shots of a user retrieving and putting on shoes from the automated shoe rack, where Figure 6 (a) involves viewing, picking and storing. Figure 6 (b) shows a series of still shots of a user retrieving slippers from the lower slipper rack. Figure 6 (c) shows a series of still shots of the neutral sitting position on the bench and two shoe lace tying positions, where position 1 includes a seated position on the bench and position 2 includes placing the feet on the bench top.



(a)

(b)

(c)

Figure 6: Retrieving and Putting on Shoes from the Automated Shoe Rack

After the aforementioned usability tests, similar tests were conducted using a conventional 3 tier shoe rack. Figure 7 shows a series of still shots of a user viewing, retrieving, putting on and storing the shoe from the lowest rack.

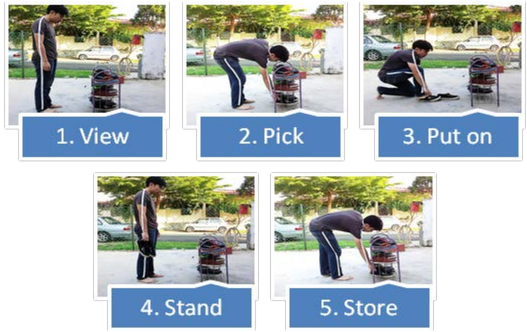


Figure 7: View, Pick, Put on and Store

OVERAL RESULTS

The test data covers the following sample criteria:

- 20 intended users (10 male, 10 female)
- Age ranges from 18 years old – 55 years olds
- Average Stature: 161.5cm

REBA Assessment score in Table 7 is based on 4 users with a stature of 160 cm and those who obtained the same REBA score.

Table 7: REBA assessment score (View-Pick-Store)

Viewing shoes - Picking shoes - Storing Shoes				
Automated Shoe Rack				
REBA steps	Body Part Analysis	Score		
Step 1	Neck	1		
Step 2	Trunk	3		
Step 3	Legs	1		
Step 4	Table A score		2	
Step 5	Upper Arm	2		
Step 6	Lower Arm	1		
Step 7	Wrist Score	1		
Step 8	Table B score		1	
Step 9	Table C score			1
	Activity Score			0
Total REBA score (Table C)				1 (Negligible Risk)
Conventional Shoe Rack				
REBA steps	Body Part Analysis	Score		
Step 1	Neck	2		
Step 2	Trunk	4		
Step 3	Legs	2		
Step 4	Table A score		6	
Step 5	Upper Arm	2		
Step 6	Lower Arm	1		
Step 7	Wrist Score	1		
Step 8	Table B score		1	
Step 9	Table C score			6
	Activity Score			0
Total REBA score (Table C)				6 (Medium Risk)

It was found that the automated shoe bench had a total REBA score of 1, which is of negligible risk. This is a considerable improvement from the conventional shoe rack which obtained a REBA score of 6, which is of medium risk.

Table 8 shows the REBA assessment score for 3 shoe lace tying/untying positions. It was found that the sitting on bench position and feet on the shoe bench position obtained a REBA score of 5 (medium risk), where both positions were found to be better than lacing/unlacing by squatting on the floor (REBA score of 8 - high risk).

Table 8: REBA assessment score (Shoe Lacing/Unlacing)

Shoe Lacing/Unlacing				
Squat over on the floor				
REBA steps	Body Part Analysis	Score		
Step 1	Neck	2		
Step 2	Trunk	3		
Step 3	Legs	4		
Step 4	Table A score		7	
Step 5	Upper Arm	2		
Step 6	Lower Arm	2		
Step 7	Wrist Score	1		
Step 8	Table B score		2	
Step 9	Table C score			7
	Activity Score			1
Total REBA score (Table C)				8 (High Risk)
Sitting on the Shoe Bench				
REBA steps	Body Part Analysis	Score		
Step 1	Neck	2		
Step 2	Trunk	4		
Step 3	Legs	1		
Step 4	Table A score		5	
Step 5	Upper Arm	1		
Step 6	Lower Arm	1		
Step 7	Wrist Score	1		
Step 8	Table B score		1	
Step 9	Table C score			4
	Activity Score			1
Total REBA score (Table C)				5 (Medium Risk)
Feet on the Shoe Bench				
REBA steps	Body Part Analysis	Score		
Step 1	Neck	2		
Step 2	Trunk	3		
Step 3	Legs	1		
Step 4	Table A score		4	
Step 5	Upper Arm	2		
Step 6	Lower Arm	2		
Step 7	Wrist Score	1		
Step 8	Table B score		2	
Step 9	Table C score			4
	Activity Score			1
Total REBA score (Table C)				5 (Medium Risk)

DISCUSSION

Based on the REBA visual assessment conducted on 20 individuals (10 males and 10 females) within the age group of 18 to 55 years and of various ethnicity, stature and weight, it was concluded that the new automated shoe rack prototype did improve its usability. An average REBA score of 1 (negligible risk) was obtained for the new prototype; a significant improvement from the average REBA score of 6 (medium risk) for the conventional normal shoe rack.

The improvements come from the minimisation of neutral deviation from the neck, trunk and leg region where the users do not need to bend, squat or stretch to obtain shoes from the lowest rack. The deviation score was obtained for each action that required the most deviation off the neutral position to complete as observed in the still shots. Apart from that, the slipper rack proved to be of great functionality, as users are able to slide the slipper rack in and out with ease, moving only their feet in the act of picking and putting on their slippers.

REBA assessment was also conducted for multiple positions for shoe lace tying/untying.

Both position 1 and position 2 obtained a REBA score of 5 (Medium Risk) compared to the bend and squat on the floor position which obtained a score of 8 (High risk). This result indicates that users can choose from either using position 1 or position 2 to tie/untie shoe lace as both provides better support and provision compared to the bend and squat position.

To conclude, the REBA assessment provided a good insight into how a simple automation can improve a product's usability and intended users are very much conducive to changes in furniture/storage designs if they find that the product is convenient and user friendly.

CONCLUSION AND IMPLICATIONS

The overall aim of designing a shoe rack for improved usability that incorporates all the solutions to the gaps/flaws/deficiencies in existing ergonomic and/or automated designs has been successfully justified through the usability testing results. The lift system proves to be extremely beneficial in improving the usability of storage systems and could be implemented in other furniture/storage products in the future.

Automation in the furniture and storage industry is slowly picking up pace as more people are aware of the benefits of having automation or automation control incorporated into the design of the furniture or storage unit as not only does automation help in terms of reducing human intervention (reduce risk of musculoskeletal injuries) and improving usability, it also opens up a wider possible range of multi-purpose design features which is extremely beneficial in this critical times where much effort is put into designing for a sustainable and resource cautious future. The results from this study can be made as a solid argument for implementing non complicated automation into items of regular human contact to improve its overall usability.

In a more specific context, apart from being a useful addition to a household, an automated shoe rack can also be implemented in workplaces where guest or workers are required to remove their shoes before entering the premise. In most cases, shoes are left on the floor in a disorganized fashion making it a safety hazard as it obstructs the entryway and also makes it difficult for one to retrieve his/her shoes when leaving.

An organized systematic automated shoe rack system will solve this disorganized fashion and also make the process of retrieving of shoes way easier. Other establishments such as factories, bowling alleys, ice skating/rollerblade rinks also require a similar shoe storing system to solve the aforementioned problems. And by incorporating an automatic and ergonomic feature intro a shoe storage system, it can improve the overall usability, image and the safety of the establishment.

FUTURE WORKS

This product has good potential in future markets as there only a handful of fully automated shoe storage solutions available in the market today, all of which have been researched in this paper. To make the product more marketable, one option is to cater for the higher income household category with custom build option to enhance its ergonomic feature and also to implement space saving features into the custom design.

In addition, Teak wood should be the material of choice for this option as Teak furniture has a high demand and it is the most suitable type of wood for storage units as it is strong, durable, lasts a lifetime in wide range of climates, low maintenance, aesthetically naturally beautiful and eco-friendly. Another option is to market this design as a self-assemble kit suitable for all intended users by minimizing construction parts and simplifying joints and latches. This product has the potential to be marketed as self-assembled storage units very much similar to products from IKEA.

REFERENCES

Ashley, C. H. and Ashley, J. P. (2000). USA Patent No. US006086171A. U. S. Patent.

Bevan, N. (1995). Measuring Usability as Quality of Use. *Software Quality Journal, 4*(2), 115-130.

Hignett, S. and McAtamney, L. (2000). Rapid Entire Body Assessment (REBA). *Applied Ergonomics, 31*(2), 201-205.

Improvements. (2015). Indoor Living. Retrieved 20 July 2015, from http://bit.ly/1Fxn0w8

Kee, D. and Karwowski, W. (2007). A Comparison of Three Observational Techniques for Assessing Posturing Loads in Industry. *International Journal of Occupational Safety and Ergonomics (JOSE), 13*(1), 3-14.

Malaysian Timber Industry Board. (2015). Mtib Export Statistics. Retrieved 29 April 2015, 2015, from http://www.mtib.gov.my/

Middlesworth, M. (2015). MSD Prevention. *How to Prevent Sprains and Strains in the Workplace.* Retrieved 24 April 2015, 2015, from http://bit.ly/1gGiYsu

Mohamad, D., Deros, B. M., Ismail, A. R. and Darius, D. D. I. (2010). *Development of a*

Malaysian Anthropometric Database. Paper presented at the Conference on Manufacturing Technology and Management, Kuching, Sarawak, Malaysia.

Ng, B.-K. and Thiruchelvam, K. (2012). The Dynamics of Innovation in Malaysia's Wooden Furniture Industry: Innovation Actors and Linkages. *Forest Policy and Economics, 14*(1), 107-118.

Preutz, H. (2015). Shoe, Coat and Hat Racks. Retrieved 20 July 2015, from http://bit.ly/Tu11lg

Storage Motion. (2015). Shoeselect - Automated Shoe Storage. Retrieved 29 April 2015, 2015, from http://bit.ly/1IghTjP

Torro, D. (2010). Japan Patent No. US7699181 B2. R. Inc.

Trippet, T., Noel, K. and Zawadzinski, J. (2006). Time Style and Design Poll. Retrieved 13 April 2015, 2015, from http://ti.me/1MFiRtZ