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INNOVATIVE DESIGN DEVELOPMENT OF ERGONOMIC ABLUTION STATION FOR WHEELCHAIR USER

R. Rohimi[1], W.O.A.S. Wan Ismail[2], A.F. Ireana Yusra[2], M.Y.Nur Haizal[3], Sharizal Ahmad Sobri[4], SaifulBahri Mohamed[5]*

[1]Faculty of Innovative Design and Technology, Universiti Sultan Zainal Abidin, Gong Badak Campus, Kuala Nerus, Terengganu, Malaysia

[2]Adcanced Material Research Cluster, Faculty of Bioengineering & Technology, Universiti Malaysia Kelantan, Jeli Campus, Kelantan, Malaysia

[3]Green Design and Manufacture Research Group, Centre of Excellence Geopolymer and Green Technology (CEGeoGTech), Universiti Malaysia Perlis, Kangar, Perlis, Malaysia

[4]Global Entrepreneurship Research and Innovation Centre (GERIC), Universiti Malaysia

[5]Kelantan, Kota Campus, Pengkalan Chepa, Kota Bharu, Kelantan, Malaysia

Email: [2*]woasaifuddin@unisza.edu.my

R. Rohimi, W.O.A.S. Wan Ismail, A.F. Ireana Yusra, M.Y.Nur Haizal, Sharizal Ahmad Sobri, Saifulbahri Mohamed. Innovative Design Development Of Ergonomic Ablution Station For Wheelchair User-- Palarch's Journal Of Archaeology Of Egypt/Egyptology 17(10), 1-15. ISSN 1567-214x

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ABSTRACT

Mosque is an essential civic building because it functions as a community space and fulfils the spiritual need of the normal people including special population. The registered physical disabilities recorded are increasing annually and indicate that accessible facilities are widely provided in the public buildings, especially the ablution area. However, the ablution area design is still lacking, and most mosques in Malaysia do not fulfil these requirements in terms of providing facilities specifically for wheelchair users. Therefore, this research aims to come out with a new design of wheelchair ablution station with an adaption of universal design principles that extends the accessibility and efficiently cater to the need of all range of the wheelchair users. The accessible, comfort and ergonomic of ablution design are influenced by the type of wheelchair and the different of wheelchair user's anthropometry. The QUAL-quan method is used in the analysis, while the observation of accessible facilities was made at several mosques, malls, and highway rest areas in Terengganu. Fifteen questionnaires were

distributed to the wheelchair user randomly to identify the customer requirements, and the data is used for Quality-Function-Deployment (QFD) method before designing a universal ablution station design for a wheelchair user. This study showed the 3D design development of a new design ablution station with consideration of the ablution size, work surface adjustability, easy to use or user-friendly, safety, aesthetic, and water-saving.

INTRODUCTION

Malaysia experiences a two-fold increase in a decade of registered Persons with Disabilities (PWDs) by the Department of Social Welfare. 497,390 PWDs registered in 2018 compared to 248,858 PWDs recorded in 2008. The physical category is the largest group, followed by learning disabilities, hearing, mental, others disabilities, visually impaired, and speech disabilities (Department of Social Welfare Malaysia, 2018). According to the Persons with Disabilities Act 2008, people with disabilities include those with long term physical, mental, intellectual, or sensory disabilities, which in interaction with various barriers may restrict full and active participation in society (Department of Social Welfare Malaysia, 2016). The Malaysian Standard 1184:2002, Code of Practice on Access for Disabled Persons to Public Building (First Revision) describes the basic requirements of buildings and related facilities to permit access for PWDs. It covers standard design and specification for accessible facilities among wheelchair users include vehicle parking, pathways, ramps, main entrances, lifts, toilet, and others.

LITERATURE REVIEW

PWDs have less opportunity to join community because of the inaccessible environment, and there are cases that facilities and access provided are not accessible and reachable by PWDs (Kamarudin et al., 2019; Abdullah et al., 2018). This is in-line with Isa et al.(2016) stated that inaccessibility is found in some public places due to poor design, poor planning, poor maintenance, and lack of enforcement on guidelines provided. Lack of awareness among developers to this accessible requirement is the common problem why the existing facilities in the public places and mosques are inaccessible. The Muslim's PWDs population has increased annually, and the praying facilities are compulsory to be developed towards free barriers. The ablution area is the common inaccessible facilities, and most mosques in Malaysia do not fulfil these requirements for PWDs (Mohd Shobri et al., 2018). The ablution area design is still lacking, especially for disabled or elderly because the Malaysian standard guideline is not fully adapted by the developer and designer to provide accessible facilities.

Therefore, the adaption of universal design principles in Malaysia helps accessibility systems, especially facilities design of wheelchair ablution area. It brings this country in line with other developed countries which provide accessible technologies that efficiently cater to the need of all range of users (Kadir & Jamaludin, 2012). The anthropometry data and the way designing a product influence the ergonomic factor due to incorrect body size, posture, and workplace design. Knowing the variations in the anthropometric dimensions enables the designers to anticipate required modification to their design for

other population groups (Abd Rahman et al., 2018). Anthropometric data are applied to specific design problems to maximize accessible facility considering three basic principles; Design for the Average, Design for Extreme Individuals, and Designing for Adjustable Range.

In this study, the wheelchair user requirements to the current ablution design are identified to develop the Quality Function Deployment Method (QFD) and the house of quality. The results from Dawal et al. (2017) and Amanet al.(2017) stated that the significant body parts that need to be improved are arms, neck, trunk, and leg. The results highlighted that the design of the wheelchair ablution station might be the reason for discomfort postures, and further research may be conducted for wheelchair users with other limitations (Wicaksono & Indonesia, 2008). Therefore, this study focused on designing wheelchair ablution station with technological applications to extend accessibility and ergonomics for different anthropometry groups. It will also comply with the Malaysia Standard (MS) Coded MS1184:2002 titled Code of Practice on Access for Disabled Persons to Public Building.

MATERIALS AND METHODS

Observation

The observation has been conducted to inspect the accessible facilities provided by the public buildings in Terengganu and the aspect of inspection cover from the parking space, ramps, ablution area, prayer hall and toilet. The accessibility level is used to indicate the facilities at each selected place are accessible and reachable by the wheelchair users. The public buildings being assessed in this study are eight mosques, two highway rest area, and two malls and each place chosen in this study is according to their significance to the public, and the regularity of public visiting in a daily basis.

The data will simply be analyzed into level of accessibility using color-coded and score is added to observe the total marks for each facility provided. The accessible (green-4 scores), fairly accessible (yellow-2 scores) and not accessible (red-0 score). These approaches have been used by previous study to audit facilities provided in the public building (Asiah Abdul Rahim& Nur Amirah Abd Samad, 2018).

Questionnaire

Fifteen questionnaire forms have been distributed to the wheelchair user at several rehabilitation centres in Terengganu and students from Universiti Sultan Zainal Abidin randomly. The subjects were selected either from a permanent injury such as spinal cord injury (SCI) or temporary injury that cause them to use a wheelchair as their mobility to move around. The subjects comprised of 11 males and 4 females between 23 to 50 years old. They had willingly volunteered to participate in this survey to elaborate their requirements on wheelchair ablution station.

Quality Function Deployment method (QFD)

QFD is a planning process for products and services that starts with the voice of the customer. This method allows the charting of customer requirements or wants and the technical "how" which results in a better understanding of design relationships of wheelchair ablution station. The mapping process using House of Quality consisted of six steps which are, identify customer's needs (What's), evaluate customer criteria, determine technical measures (How's), determine matrix between customer need and technical requirements, determine technical correlation, and determine target specification of design (Soewardi & Afgani, 2019). The customer requirement includes, ablution station compact size, work surface adjustability, easy to use, aesthetic, safety and water saving.

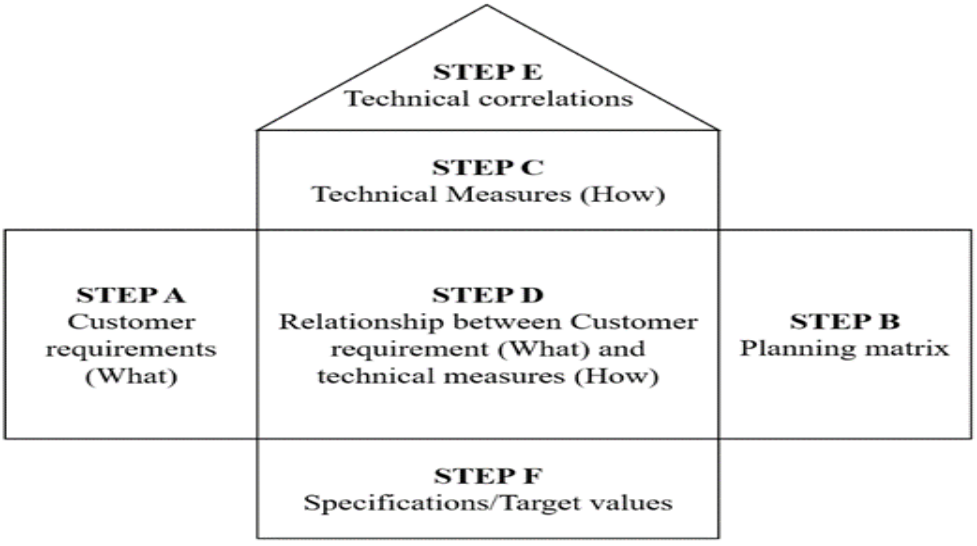

Figure 1: Conceptual map of house of quality (Soewardi & Afgani, 2019)

Design development

The conceptual design of wheelchair ablution station is developed by Autodesk Inventor Professional 2018 (Jalal Abdullah & Shaikh Mohammed, 2019) with 1:1 ratio scale. Several requirements should be considered in the designing of ergonomic ablution station that maximizes accessibility for all range of wheelchair user. It is including, the type of wheelchair, anthropometry of wheelchair user, foot washer feature, safety and the range height of ablution work surface. The results on QFD analysis will be considered in the design development process to ensure all the customer requirement can be applied on the new design of ablution station for wheelchair user.

RESULTS AND DISCUSSION

Observation

From the site observation checklists, the accessible facilities provided in eight mosques, two highway rest area, and two malls in Terengganu were evaluated and summarized in Table 1. The study found that the ablution area is the lowest facility scores (20) of accessibilities among the wheelchair users. The step of stairs is the most substantial barrier faced to access the facilities, and most mosques that provide outdoor ablution area is fairly accessible because of the improper design for these groups. It coincides with the previous study, where most large states mosque in Malaysia have stairs design for accessing the ablution area (Asiah Abdul Rahim et al., 2014). The highest scores recorded were 38 for parking space and ramps facilities followed by the toilet (34) and prayer hall (30). The small step stair is the factor of fairly accessible scores in some buildings requiring some effort to access the prayer hall independently. Overall, mosque 7 records the highest building score of accessible facilities, and mosque 6 is the lowest building scores of accessible facilities for the wheelchair user. One of the reasons, the mosque 7 is a tourist attraction place that influences the result scores compared to the mosque 6 due to it was a historical mosque in this state and constructed between the years 1793 and 1808. However, a small modification can contribute to large improvement of overall accessibility for those buildings.

Table 1: The checklist of evaluated buildings of accessible facilities for wheelchair user

Type of Buildings	Wheelchair User Facilities					**Building Scores**
	Parking Space	Ramps	Ablution Area	Prayer Hall	Toilet	
Mosque 1	4	4	2	4	2	16
Mosque 2	2	4	2	4	2	14
Mosque 3	2	4	4	4	2	16
Mosque 4	4	0	0	0	4	8
Mosque 5	2	2	0	2	2	8
Mosque 6	2	0	0	0	0	2
Mosque 7	4	4	2	4	4	18
Mosque 8	2	4	2	4	2	14
RnR1	4	4	2	2	4	16
RnR2	4	4	2	2	4	16
Mall 1	4	4	2	2	4	16
Mall 2	4	4	2	2	4	16
Facility Scores	38	38	20	30	34	-

Questionnaire analysis

Questionnaires were initially distributed and use quantitative methods (Wan Ismail, 2018) involving wheelchair users. There are six questions to be

answered to identify the rating of six requirements in designing the universal design of ablution station for wheelchair users. The range of rating format used is 1 (Not required) until 5 (Very required), and each question must be rated based on their opinions or experiences while performing ablution as a wheelchair user. It includes the compact size of the ablution station (Q1), work surface adjustability (Q2), easy to use (Q3), safety (Q4), aesthetic (Q5), and water-saving (Q6).

Q2, Q3, and Q4 are the most rated essential criteria for designing the ablution station's universal design. Five ratings were given on these requirements to ensure the accessibility for all range of the wheelchair user, and the design safety is compulsory to prevent any potential hazard to the user. Same as easy to use question (Q3), the product should be designed user-friendly to ease the ablution process. Four rates were given to Q1, Q5, and Q6, where the design should be compact, full of features without compromising the aesthetic design, and water-saving is a priority in the design development process.

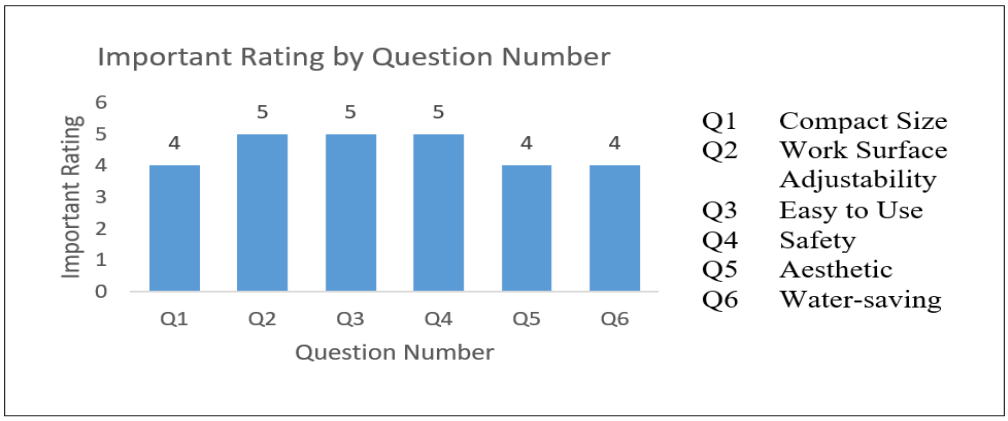

Figure 2: Important Rating of Customer Requirement Based on Question Number

Quality Function Deployment analysis (QFD)

House of Quality in Figure 3 presents several information of developed design such as customer requirements, technical requirements, important rating, relative weight, customer competitive evaluation, and target specification. Other than that, the House of Quality expresses the result in determining the relative weight of functional requirements by which parts need to be emphasized more to achieve the desired target. Using this tool, the customer wants, and needs are transformed to technical requirements by formulating initial specifications of the product and possible materials to be used. But these requirements are still subject to the changes as the progress to the study is made (Gumasing et al., 2019).

Based on the results, the most important requirement to be emphasized is a microcontroller that has strong relations in which 4 out of 6 customer requirements are related include work surface adjustability, easy to use, safety,

and water-saving. It is the largest relative weight of technical important rating, which is (22%) compared to other technical requirements. It followed by ergonomic design (15%), dimension of work surface height (12%), energy system operation (9%), (8%) for linear actuator, (7%) for material of ablution structure, material of work surface, dimension of foot washer and (6%) recorded for foot washer system.

The target values or specifications in the material selection of the ablution station should be glass for the work surface, design structure made from mild steel, and covered by stainless steel for aesthetic purpose. Direct current (DC) is a primary source for power supply used to execute the system in order to maximize the product safety. The dual directions of the foot washer feature are important to ensure the foot is fully covered by water for both up and the bottom side of the foot surface. The benchmark is made to observe the new design of the ablution station compare to the existing competitors.

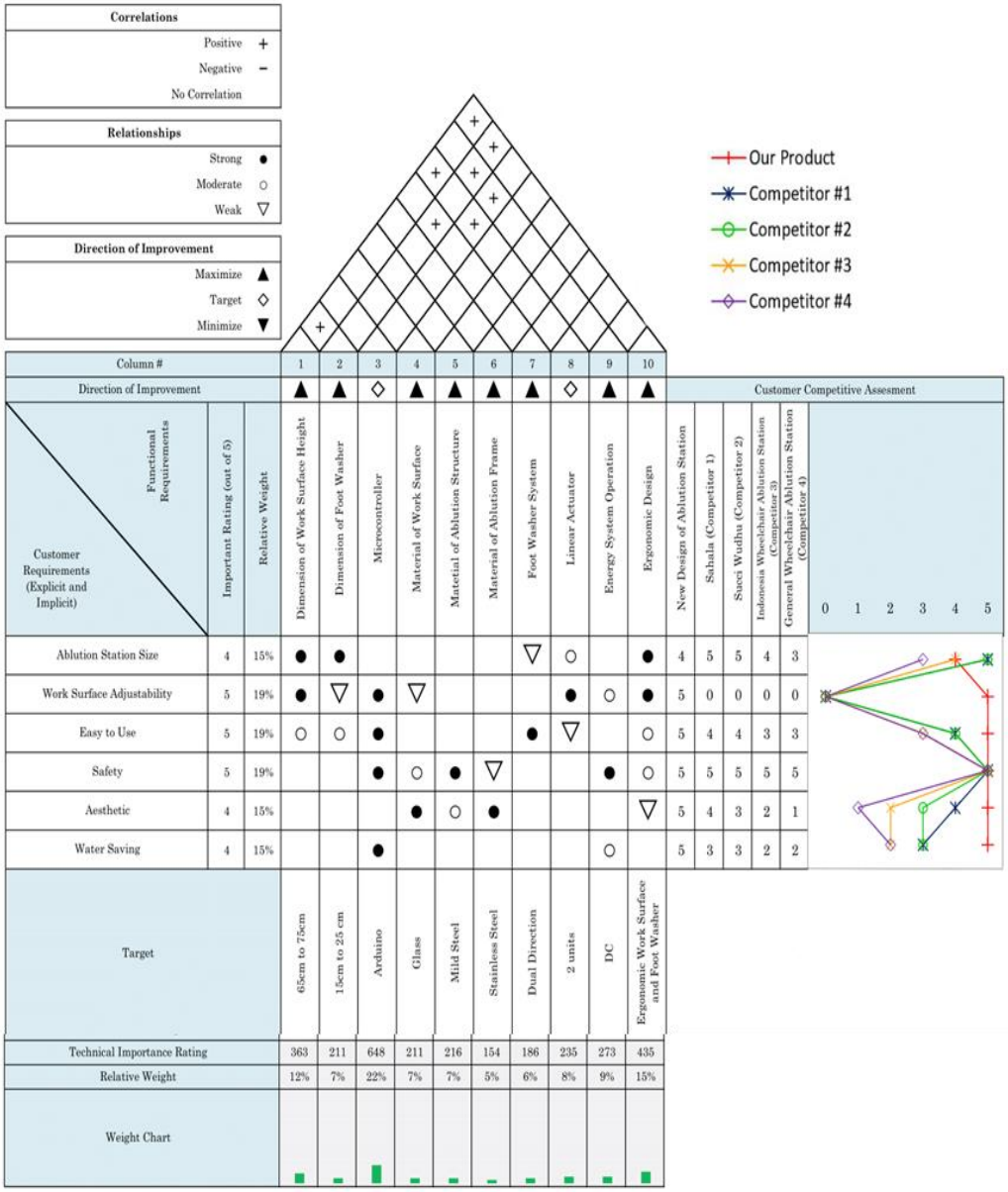

Figure 3: House of Quality new wheelchair ablution station

Design development

Design development process discusses the requirements and consideration in designing the universal design ablution station for wheelchair users that fit almost all user ranges. Other than determining the ablution process is easy and comfortable to be performed, leaving no body parts involved dry should be considered for proper ablution process. The ablution process starts from wash both hands, wash mouth, face, lower arms from wrists to the elbow, wash head, wipe ears inside and out, and wash both feet. Each step was repeated three times before continuing to wash other body parts.

Wheelchair ablution work surface height

The estimation of the ablution work surface height (WSH) can be adapted by the calculation from the previous studies on developing an ergonomic table for a wheelchair user. The height is influenced by several factors including the type of wheelchair used and the anthropometry data of wheelchair users. Based on MS, the recommended height for wheelchair work surface with armrest should be 75cm compare to 65cm for wheelchair without armrest equipped. Therefore, design for the adjustable range is a suitable method of determining a desk height considering the 5th percentile female to the 95th percentile male of the relevant population characteristics (Hoque et al., 2014) to maximize the accessibility of ablution station. The data of popliteal height (P), sitting elbow height (E), and sitting shoulder height (S) are required to determine the height of the ablution work surface for wheelchair user and the calculation of WSH is taken from the equation by Gouvali and Boudolus (2006).

$$E + [(P + 2)\cos 30°] \leq WSH \leq [(P + 2)\cos 5°] + (E0.8517) + (S0.1483) \quad (1)$$

Notes: E = Sitting elbow height, P = Popliteal height, S = Sitting shoulder height

Table 2 highlights the data comparison from previous researchers that come out with the recommended ergonomic wheelchair WSH from different perspectives. The wheelchair user's anthropometry for E, P, and S are taken from the previous researcher (Adnan & Dawal, 2019) and the 95th percentile value of the data is used in the calculation of ablution station WSH. From the Eq. (1) calculation, the adjustability range of WSH should be 71 to 89cm taking the minimum female and maximum male value. However, consider the wheelchair type without armrest equipped, the WSH is recommended to be adjustable from 65cm to 89cm taking the maximum value from the Eq. (1) and minimum value from MS. The adjustability range of WSH is planned to fit almost all range of users include the type of wheelchair used and the anthropometry of the wheelchair user.

Table 2: Anthropometry Data of Wheelchair User and Recommended Ablution WSH

Anthropometry of Wheelchair User										
Measurement	Male Wheelchair User (cm)					Female Wheelchair User (cm)				
	Mean	SD	Percentile			Mean	SD	Percentile		
			5th	50th	95th			5th	50th	95th
Sitting elbow height	20.1	4.6	13.8	20.1	24.4	17.0	4.9	9.7	17.2	22.9
Sitting shoulder height	53.3	6.4	44.3	53.2	62.2	47.4	6.3	39.0	47.5	55.9
Knee Height	51.6	5.6	42.3	50.3	61.0	50.6	9.2	41.1	46.1	66.0
Popliteal height	44.4	11.3	34.3	42.4	59.3	40.7	9.1	30.9	39.2	55.7
Arm reach forward	80.9	6.8	70.2	80.6	90.7	75.4	4.4	70.3	74.6	81.8

Recommended WSH for Wheelchair User			
Reference	Calculation	Specification (cm)	
-	Eq. (1)	Male	$76 \leq WSH \leq 89$
		Female	$71 \leq WSH \leq 83$
(Adnan & Dawal, 2019)	Sitting elbow height + knee height	Male / Female	70
(Department of Standards Malaysia, 2002)	MS 1184:2002	With Arm Rest	75
		Without Arm Rest	65

Adjustable water tap and WSH

The minimum and maximum distance for arm reach forward (A) recorded in Table 2 are 70.2cm to 90.7cm. The ablution work surface area is 58cm × 67cm to ensure user accessibility and comfortability. Hand detection by range sensor (B) facilitates the automatic activation of the water tap and maximize water-saving to prevent water flows directly to the drain without any contamination while performing ablution,refer to Figure 4. (30.3%) water is wasted during performing ablution using automatic tap compare to mechanical knobs-tap (47%), mixing short neck-tap (42%), mixing high neck-tap (38%), and mechanical push button tap 37% (Zaied, 2017). Automatic tap helps PWDs with different hand disabilities to perform ablution even not as a wheelchair user. The curved shape and adjustable work surface angle prevent water from splashing and overflowing when the water tap is brought closer to the user for comfort purposes.

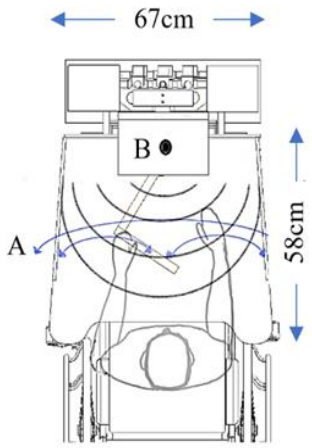

Figure 4: Automatic Tap Accessibility

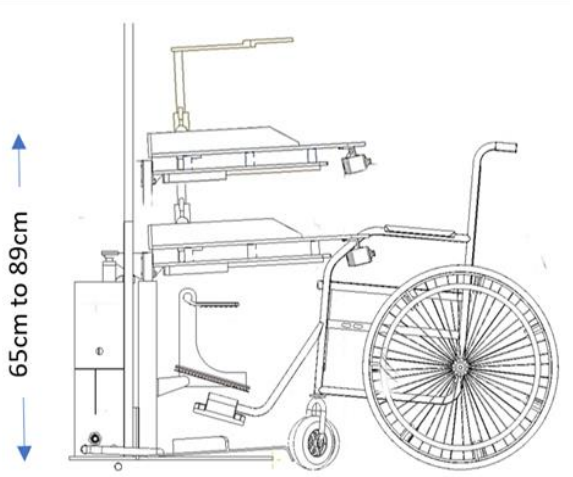

Figure 5: Adjustable Work Surface Height

Foot washer design development

Difficulties of performing ablution especially the lower body side make foot washer are the most highlighted issue among the wheelchair user. Other than preventing the body parts involved dry, minimizing the user steps and efforts in performing ablution is required for comfort and ergonomic purpose. The foot washer platform of existing ablution located below the wheelchair footrest causes them to fold the footrest first then place the feet onto the washer platform. Several steps involved and a new design of foot washer minimizes those steps, and it designed for comfort ability.

Figure 6 shows the position of the new foot washer system is then lifted above the wheelchair footrest and it was designed to fit almost all type of wheelchair footrest. It has two directional fountains, the bottom and the top side that wash the entire surface of the foot by pushing the joystick controller, and the system will activate automatically starting the right side and then the left side of the foot washer for 15 seconds each. The user only needs to slightly lift both of the legs then place it onto the washing platform without the footrest is folded. The wheelchair user does not need to bow during the last step of the ablution process that effects the user's comfortability. Surface finish, sharp edges, functionality, size, surface area of water faucet and aesthetic were considered in designing a new foot washer system of ablution station for wheelchair user.

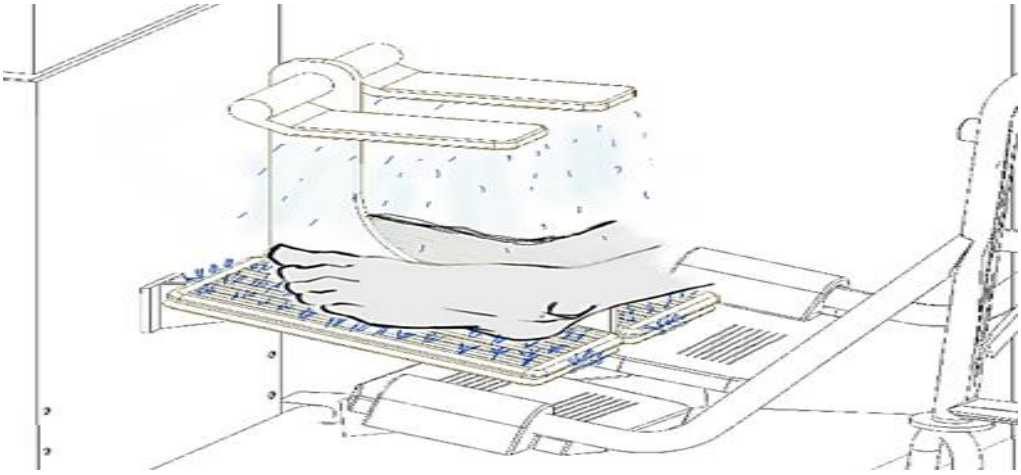

Figure 6: Two-way Foot Washer System

Ablution station drawing and specification

Wheelchair ablution stations are often located in areas that are not exposed to full light. The use of LED lamp can illuminate during ablution process day and night. The back stand's design is to stabilize the structure where it acts as the main supporter when the ablution work surface is adjusted to the maximum value, which is 89cm. Microcontroller is applied to control the whole system and activities, including the sensors, solenoid valves, and linear actuators that adjust the height of the work surface. The design of exhaust pipe, base platform, and foot washer expected to reduce water spilled while performing ablution and ensuring the foot is fully covered by clean water. Adjustable water tap with 45cm in length helps the user to adjust the most appropriate and comfortable position while performing ablution by using new design of ablution station for wheelchair user

Table 3: Wheelchair Ablution Station Features and Specification

New Wheelchair Ablution Station Features		
No.	Item	Description
1	LED light	Emits light in dark environment
2	Back Stand	Structure Support
3	Housing for Piping and Wiring System	Micro controller System
4	Exhaust Pipe	Channel used water to the drain
5	Foot Washer	Wash foot at dual direction (top and bottom) side
6	Base Platform	Reduce water spilled
7	Wheelchair	Standard Foldable Light-Weight Wheelchair
8	System Controller	Adjust the height work surface and toggle switch for foot washer activation
9	Work Surface	Thick glass material (10mm)

10	Water Tap	Adjustable and rotatable water tap
New Wheelchair Ablution Station Specification		
Dimension		90cm (L) × 80cm (W) ×172(H)
Material		Mild steel, stainless steel, glass
Power Supply		Direct Current (DC)
Work Surface Adjustability		65cm ≤ WSH ≤ 89cm

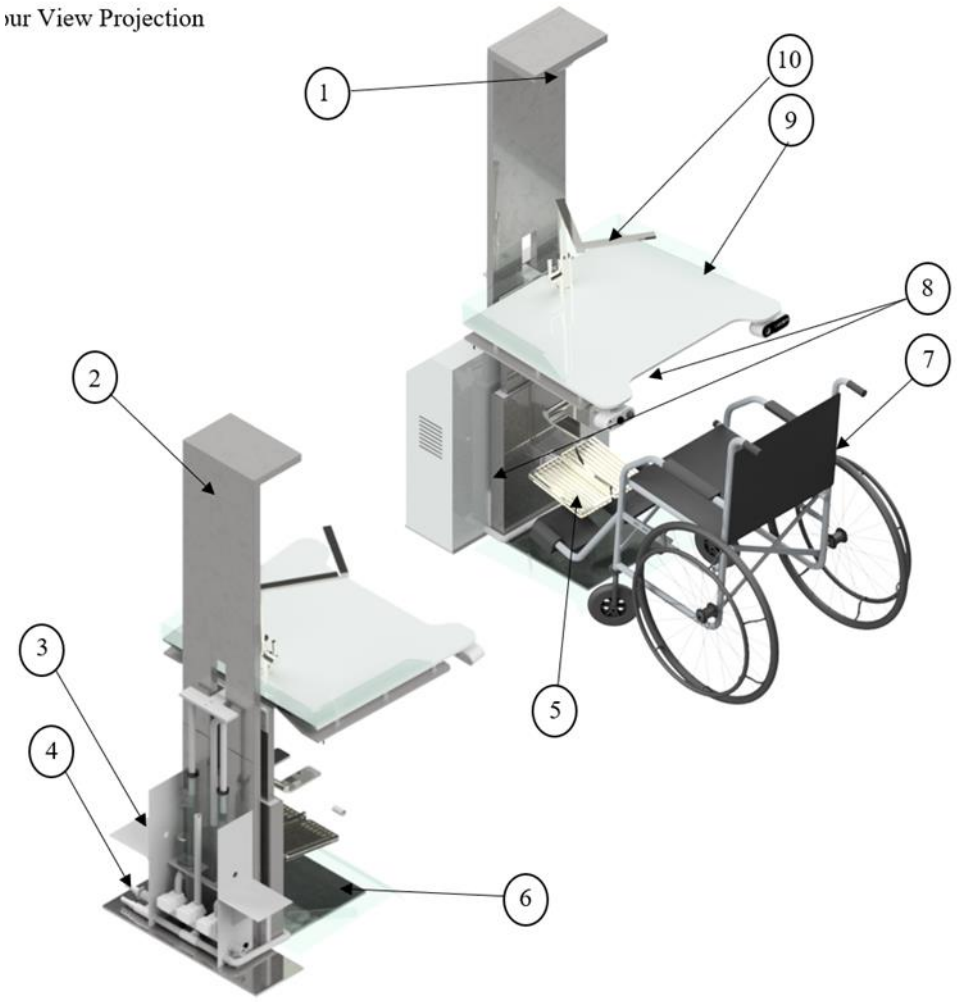

Figure 7: Wheelchair Ablution Station 3D Rendering Image

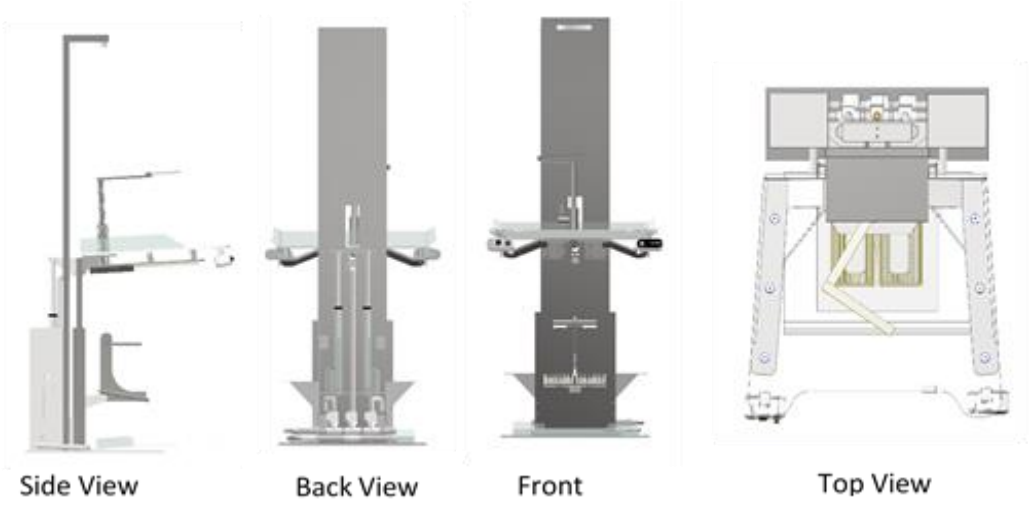

Figure 8: Four-view Projection Wheelchair Ablution Station

CONCLUSION

This study is to develop the new universal design of the ablution station for a wheelchair user by investigating the customer requirements and determining the final design and specifications through QFD method in the design development process. The results of the observation shown the ablution area is the most inaccessible facilities in the selected research area. The questionnaire analysis found from 15 respondents, the customer most requirements of designing a wheelchair ablution station were work surface adjustability, easy to use, safety, aesthetic, water saving, and the size of ablution station. Based on the QFD results, the most important requirement to be emphasized is a microcontroller that has strong relations and it was the largest relative weight of technical important rating followed by ergonomic design, work surface height, energy system operation, linear actuator, material of ablution structure, material of work surface, dimension of foot washer and foot washer system. Considering the universal design principles and designing for adjustable range, the WSH was calculated to extend the accessibility and ergonomic for different type of wheelchair used and wheelchair user's anthropometry. The use of automatic tap with range sensor allows the accessible and reachable for 5^{th} percentile group taking the arm reach forward measurement and minimize the amount of water consumed during ablution process. Future work of this study is to run RULA analysis of proposed design and to simulate the effectiveness of the new foot washer system compare to traditional method. Therefore, this research is expected to be one of the social contributions in developing our country towards a free barrier environment.

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