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# Implementation of User-Centered Design (UCD) Method in Product Development of Traveling Wheelchair

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**Abstract.** Persons with disabilities often difficulties when traveling and mobility in daily activities, especially with movement disorders. Many tools have been developed for people with disabilities to support mobility. One of them is a traveling wheelchair. Based on preliminary studies, it is known that the dimensions of traveling wheelchairs tend to be smaller than wheelchairs in general and have limited features that affect the comfort of its users. This study tries to evaluate a traveling wheelchair using the user-centered design (UCD) method and usability testing and developing this product. The standard UCD method used is based on ISO 9241-210, which focuses on users' needs and interests by applying ergonomic criteria and knowledge of usability techniques. The evaluation results show that the overall usability level of the wheelchair product tested has excellent standards with usability values ranging from 89.12% - 94.56%. However, there are still several problems, especially in the usability satisfaction criteria. Based on the evaluation results and the user's thinking aloud, the development of this traveling wheelchair product was carried out. Development is based on several parameters such as stability, wheelchair dimensions, seat, postural support, and adjustable and ergonomic factors.

## 1. Introduction

Disability is an inability to do an activity as ordinary people, caused by conditions of loss or disability of psychological, physiological, and anatomical structural or functional abnormalities [1]. A person with disabilities often difficulties traveling and mobility in daily activities, especially with movement disorders (physical disabilities). Disabled people have movement disorders caused by abnormal neuromuscular and bone structure disorders, illness, or accident, including cerebral palsy, amputation, polio, and paralysis [2]. Physical disabilities can be in paralysis of the limbs and bones, incomplete upper or lower limbs, causing movement to become slow for normal daily activities.

There have been many tools developed for disabilities to support mobility, a traveling wheelchair. Based on its usefulness, the design of this wheelchair is more straightforward than other wheelchairs with a lightweight so that it is easy to carry everywhere and can be folded and placed in the bag provided [3]. However, from the results of direct observations on travel wheelchairs and the internet, one of them from medicalogy.com, it is recognized that



the dimensions of these wheelchairs tend to be smaller than other wheelchairs and have limited features that affect the comfort of their users.

This research tries to evaluate the current traveling wheelchair and develop this product. One evaluation method that can be done is using the user-centered design (UCD) method and usability testing. Evaluation is vital in product development so that products can be used safely, comfortably and following user wants and needs [4][5]. The purpose of using the UCD method in this study is to involve wheelchair users directly in the early stages of product development so that input is obtained about the product's features and uses [6]. Whereas usability testing in the evaluation stage is intended to assess the ability of a product to meet user needs and get problems when using the product and the shortcomings of the product itself [7][8]. Both methods are used based on ISO because they provide internationally standardized criteria and have been necessary for all systems/products to meet user needs.

One of the studies that discuss the use of the UCD method and usability is a research conducted by Mohd Nizam Sudin in 2013 with the title "User-Centered Design Approach in Designing Motorcycle Tire Dismounting Tool for One-Handed User" [9]. The study explained that there were problems or difficulties in opening the outer tires of motorbikes. The majority of existing tools are designed without consideration for one-handed users (disabilities), where most of the tools require two hands to operate by default. To solve the problem, a tool design was carried out using the UCD method by translating workers' participation in the design. The resulting solution is a design of a tool that can be used by one-handed workers that can adjust the user's position and posture when using it. Referring to this research, analysis, and development of a travel wheelchair's use was carried out. The manufacture of wheelchairs is based on UCD results and evaluation of ergonomic principles.

The aim study is to apply the UCD approach to determine users' needs for traveling wheelchairs and guide the preparation of testing activities to be carried out. Tests are carried out to choose a travel wheelchair's usability value through usability testing and user response. The end goal is to produce a design for a traveling wheelchair that suits user use and needs.

## 2. Research methods

This research uses descriptive research. The problem solving of the usability of existing wheelchair products is carried out systematically and factually regarding the test subjects' facts and characteristics for persons with disabilities and wheelchair pushers.

### 2.1. The Procedure of User-Centered Design (UCD)

The UCD research implementation procedure consists of several stages. The first stage is to specify the context of use, where this stage is used to identify the system and users of the system. At this stage, users and stakeholder groups are also described, the characteristics of users or user groups, the objectives and tasks of users, and the environment of the system [10]. The next stage is to specify user requirements to identify system users' requirements and other functional requirements. Based on the previous step, a solution was provided for the resulting needs analysis in the form of a product design and prototype included in the product design solution stage. This study develops existing products so that the product to be evaluated later is assumed to use a current traveling wheelchair. The next step is to consider design against user requirements to assess the creation or development of previously identified users' needs. ISO 9241-210: 2010 [10] explains that the evaluation is useful for gathering new information about user needs, providing feedback on the strengths and weaknesses of the design, and providing an assessment of the solutions given. The steps of the research procedure using UCD in this study are described in table 1. This Procedure is based on ISO 9241-210: 2010 regarding the output of human-centered design activity.

**Table 1.** UCD procedures in research

<b>Input</b>	<b>Process</b>	<b>Results</b>
<b><i>Plan the Human-Centered Design</i></b> Input: Interview and observation instruments	<ol style="list-style-type: none"> <li>1. Literature study to understand the UCD method</li> <li>2. Field studies to stakeholders (disabilities and wheelchair pushers)</li> </ol>	<ol style="list-style-type: none"> <li>1. Understanding of UCD method applications</li> <li>2. Observation and interview reports</li> </ol>
<b><i>Specify the Context of Use</i></b> Input: The results of the previous stage	<ol style="list-style-type: none"> <li>1. Discussions with users to identify: <ol style="list-style-type: none"> <li>a. Product use</li> <li>b. User goals and task</li> <li>c. User characteristics</li> <li>d. System environment</li> </ol> </li> </ol>	<ol style="list-style-type: none"> <li>1. Report on the results of discussions with users</li> </ol>
<b><i>Specify User Requirement</i></b> Input: Report of the discussions results with users	<ol style="list-style-type: none"> <li>1. Identify user needs as functional and non-functional product requirements</li> </ol>	<ol style="list-style-type: none"> <li>1. Report on the identification of user needs</li> </ol>
<b><i>Produce Design Solution</i></b> Input: User needs	<ol style="list-style-type: none"> <li>1. Identify wheelchair products that can be used as initial test objects</li> </ol>	<ol style="list-style-type: none"> <li>1. Traveling wheelchair</li> </ol>
<b><i>Evaluate Design against User Requirement</i></b> Input: The result of all previous stage	<ol style="list-style-type: none"> <li>1. Identify activity to use product</li> <li>2. Describe the product to the user</li> <li>3. Performing direct product testing activities by users (usability testing)</li> <li>4. Requesting suggestions and evaluations from users (giving USE questionnaires and thinking aloud)</li> <li>5. Improvements based on user evaluation and ergonomics factors</li> </ol>	<ol style="list-style-type: none"> <li>1. Unique wheelchair design for disabilities</li> </ol>

### 2.2. Evaluation procedure (Usability testing)

Product evaluation in this study was carried out through usability testing. Usability testing can be used as a UCD benchmark for developing an interactive system or product [8]. The research model in this study is to take quantitative and qualitative data. Quantitative data is obtained from usability testing on products that refer to ISO 9241-11 with three assessment criteria: efficiency, effectiveness, and satisfaction [11] [12]. Meanwhile, qualitative data in usability testing is obtained on the satisfaction criteria from the respondents' subjective intuition in filling out the USE questionnaire [13] and thinking aloud. Thinking aloud Procedure is a usability testing approach involving thinking aloud to collect information about design and system development. Verbalization result with this Procedure will generate insights into the mental models associated with why the usability issues may occur [14].

The testing activity was carried out on two groups of respondents, each consisting of wheelchair users (with disabilities) and wheelchair pushers. The disability chosen is a mild type of disabled (limited in doing the physical activity) aged 20-40 years and does not experience motor and sensory coordination disorders. Wheelchair pushers are a family of persons with disabilities or people who frequently perform these activities.

### 2.3. Data processing

Through usability testing, quantitative and qualitative data were obtained from testing and discussions with users at the evaluation stage. The usability data processing obtained from testing is as follows:

(i) Effectiveness

The adequate Level can be seen by looking at the level of success of the activities carried out.

(ii) Efficiency

**Table 2.** Usability level status

Point (%)	0-20	21-40	41-60	61-80	81-100
Usability Level	Bad	Poor	Moderate	Good	Excellent

Measuring the Level of efficiency in this study was carried out by measuring the time of the respondent when doing activities.

(iii) Satisfaction

Measurement of user satisfaction is carried out by conducting interviews using the USE questionnaire shortly after the respondent completes the activity. The USE satisfaction questionnaire results distributed to respondents were in the form of a Likert scale value from 1-7. This value needs to be converted into a percent so that the usability level value can be calculated in the following way [15]:

$$\text{Satisfaction}(\%) = \frac{\text{Total scores answered}}{\text{Maximum \% total score}} \quad (1)$$

Usability testing data are interpreted to show whether the design is included in the excellent category in terms of user usability. The results of the test will be a percentage and adjusted to the usability level according to table 2 [16].

After evaluation, a design proposal is based on the test results, thinking aloud data, and ergonomic principles. The design is designed with an adaptation to users' behavior in using the product so that the product being developed does not force users to change their behavior when using the product. In addition, anthropometric designs use data from potential users (Indonesian anthropometry) so that the design results can be used comfortably.

### 3. Results and discussion

The needs of users and wheelchair pushers should be identified by considering the context of use. The data needs are used to analyze the testing activities that will be carried out when using the traveling wheelchair. The test activity data is described in table 3.

**Table 3.** Testing activity to using wheelchairs

Category	No	Activity/task (T)
Preparation	1	Open the wheelchair
	2	User move to a wheelchair
Operation	3	Push the wheelchair
	4	Move the wheelchair to a higher place
	5	Move the wheelchair from a higher place
	6	Make a stop by braking
Comfort	7	Move the legs
	8	Resting the hands
	9	Sit in a wheelchair
	10	Leaning back in the wheelchair
Finished using	11	User move from the wheelchair
	12	Fold the wheelchair

3.1. Evaluation results and usability aspects

3.1.1. Level of effectiveness. The percentage of effectiveness is obtained by comparing the number of successful activities with the total number of trials (5 trials). Testing activities are related to effectiveness by users consist of moving to a wheelchair, moving legs, and moving from a wheelchair. The effectiveness value of the three testing activities by the user is shown in Figure 1. The 100% test value of the three activities shows that the tested travel wheelchair can be used easily by the user without error. This indicates that a wheelchair has good static stability to make it easier for users to move to and from the wheelchair. Also, users can easily and freely move their feet on the footrests, and the footrests can support the user’s feet properly. Meanwhile, on the pusher, one activity has failed, namely moving to a higher place. Based on discussions and observations made, this failure occurs because the rear tire, which has a relatively smaller size, has a chance to get stuck.

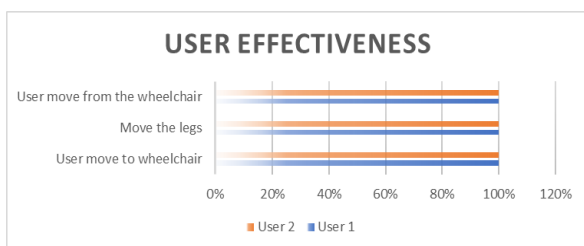


Figure 1. The level of effectiveness of testing by users

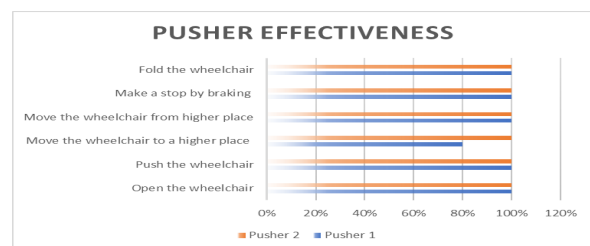


Figure 2. The effectiveness of the test by the pusher

3.1.2. Level of efficiency. For users, all testing activities can be done successfully by both user respondents, so the value of overall relative efficiency (ORE) is 100% for each test activity, as illustrated in Figure 3. This shows that users can do tasks efficiently and productively with a wheelchair. In other words, wheelchairs can meet functional needs in moving from and to a wheelchair and leg flexibility properly.

Whereas wheelchair for pushers, if it fails in one of the testing activities, then the efficiency value of that activity is also affected. The wheelchair displacement parameter shows an efficiency value of 100% except for moving to a higher place (69.74%). This is due to the driver failing the testing activity on the first try. Here, the pusher requires a third person/researcher’s assistance to climb onto the sidewalk that is against the predetermined task success criteria. This shows a 30.26% chance of the booster failing to rise to a higher place. However, other factors are also influenced, such as users who are still adjusting to a travel wheelchair. However, because the value of the ease of learning of the two pusher respondents is good, namely 78.57% (good), of course, it is not difficult to adjust to this wheelchair.

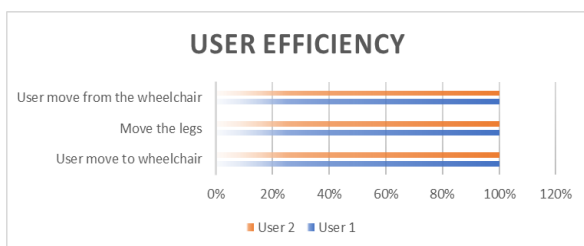


Figure 3. ORE diagram of the test by user

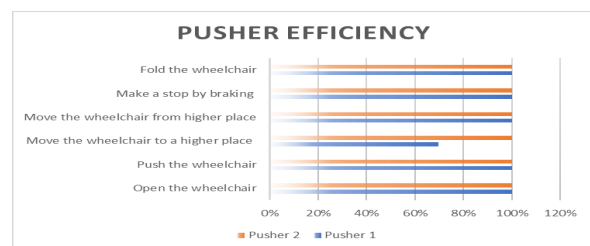


Figure 4. ORE diagram of the test by the pusher

*3.1.3. Level of satisfaction.* The measurement of the level of satisfaction in this study uses the USE questionnaire, which is the satisfaction aspect given by each user after completing testing activities. Based on the user satisfaction recap data described in table 4, the average satisfaction level is 77.97%, based on the usability level with good status. A good quality indicates that the user is entirely satisfied with what the product provides, especially when using it. The activity

**Table 4.** Recap of user satisfaction levels

Task	User 1 (%)	User 2 (%)	Average (%)
User move to wheelchair	82,63	79,59	81,11
Move the legs	91,84	71,43	81,64
Resting the hands	71,43	67,35	69,39
Sit in a wheelchair	67,35	85,71	76,53
Learning back in the wheelchair	73,47	85,71	79,59
User move from the wheelchair	75,51	83,67	79,59
Average	77,04	78,91	77,97

with the highest satisfaction score was related to moving to a wheelchair and moving the legs. Meanwhile, the lowest satisfaction value felt by users is related to hand resting activity. This activity is associated with the armrest's dimensions and shape where the user feels the armrest is too small and short, and the round shape makes the hand slip when it is rested. Besides, sitting in a wheelchair also gives the lowest score. This is related to the dimensions and material of the cushions. The user feels that the seat is not long enough and the material is not thick enough so that for long-term use, it can cause discomfort.

Meanwhile, for pushers (table 5), the average level of satisfaction is 86.40%, based on a usability level with an excellent status. Excellent status indicates that the pusher was very satisfied with what the product provides, especially when using it. The activity with the highest

**Table 5.** Recap of pusher satisfaction levels

Task	Pusher 1 (%)	Pusher (%) 2	Average (%)
Open the wheelchair	87,76	77,55	82,66
Push the wheelchair	89,80	71,43	80,62
Move the wheelchair to a higher place	85,71	79,59	82,65
Move the wheelchair from higher place	87,76	95,92	91,84
Make a stop by braking	93,88	95,92	94,90
Fold the wheelchair	89,80	81,63	85,72
Average	89,12	78,91	86,40

satisfaction score is the braking activity. The pusher feels helped by the handbrake in a travel wheelchair, wherein in a regular wheelchair, there is no brake for the pusher. While the lowest satisfaction value felt by pushers was the activity of pushing a wheelchair. However, this activity has a satisfaction score of 80.62% (excellent), where the pusher does not feel a problem when pushing a wheelchair.

*3.1.4. Usability level of USE questionnaire.* Based on the assessment results and recapitulation of usability values in table 6, the usability scores of users and drivers ranged from 89.12% - 94.56% with the excellent category. The special type indicates that the product being tested responds well to the user and can be useful in its use.

Based on the research conducted, it would be challenging to make the criteria of effectiveness and efficiency of testing objective measures. This is because almost all testing activities can be carried out successfully (effectiveness and efficiency are close to 100%). Therefore, subjective actions based on user perceptions can indicate the effectiveness and efficiency of using the product, using the USE questionnaire, and thinking aloud.

Based on the USE questionnaire results, users' most significant satisfaction value is the ease of learning criterion (87.50%). This means that users are delighted with the wheelchair being tested because it is easy to learn and adjust to its functional aspects. For the lowest value is the satisfaction criteria (77.98%). This score has the right standards, but users complain about several complaints when using a wheelchair in comfort with specific features. These problems are related to some parts of the wheelchair's dimensions and shapes, such as backrests, armrests, and cushions.


Whereas for the wheelchair pushers, the highest score was given on the satisfaction criteria (86.40%). Pusher is very satisfied with the features provided in wheelchairs because it can make it easier for them to help with disabilities. The elements referred to are the handbrake, wherein there is no handbrake in a standard wheelchair, a lever behind the wheelchair making it easier to climb to a higher place, and the overall physical aspect of the wheelchair. The lowest value is the criteria of usefulness (82.14%) and ease of learning (82.14%). This score has good criteria, or it can be said that the driving force is satisfied in terms of these two aspects. However, the pusher found no significant difference in benefits from the wheelchair tested with a regular wheelchair.

**Table 6.** Recapitulation of test results and usability level

Criteria	User (%)		Pusher (%)	
	User 1	User 2	Pusher 1	Pusher 2
Effectiveness	100	100	96,67	100
Efficiency	100	100	94,96	100
Satisfaction	77,04	78,91	89,12	83,67
Usability value	92,35	92,97	89,12	94,56
Usability level	Excellent	Excellent	Excellent	Excellent

*3.1.5. Thinking aloud.* The summary of the user's thinking aloud and pusher results is analyzed to know the causes and reasons for their impressions. Also, user needs are analyzed based on the results of the evaluation (usability testing) that has been done. The analysis results are shown, and the requirements based on the evaluation results are shown in Table 7.

Table 7: Think aloud analysis based on evaluation results

Category	Thinking aloud	Analysis
1. Design	Footrest is made not slit 	Based on observations and what the respondents felt, a slotted footrest has a risk of pinched feet. So that respondents tend to be careful when moving their feet on footrests. This travel wheelchair's footrest design is better than a regular wheelchair because the user can move his feet to the side freely. But it can still be improved by making a footrest without gaps.



Armrests are made wider and adjustable



Respondents felt that the cylindrical armrest would cause the hand to slip easily, and long-term use would cause discomfort. The armrest design that is wider according to the width of the hand can provide more comfort for the user because it can support the hand well. Besides, the armrest is considered too high so that when using, the user's shoulder rises slightly and causes discomfort.

The lever helps when climbing to higher places



With the push lever, it feels helpful when you want to move to a higher place. Levers are used to raising the front of the wheelchair when moving. The use of a lever will reduce the force used when lifting the front of the wheelchair.

2. Dimensions

The armrest is less long



Users feel that the armrest is not long enough because only half of the hand's length is accommodated. For that, it needs to be readjusted against the dimensions of the user's hand length.

The seat is not long enough

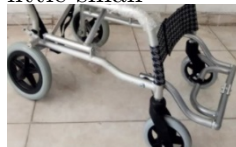


The user feels that the seat on the wheelchair is not long enough so that not all parts of the user's thigh are well supported. This is related to the dimension of the seat's length so that it needs to be adjusted again.

The backrest adjusts the user's height and is made wider

The current backrest is not high enough because it doesn't provide good postural support for the user when he wants to lean back. The backrest's width is also slightly narrower and cannot accommodate users with larger bodies.

The wheels are a little small



Users find it difficult to climb to a higher place because it requires more power to raise the wheelchair. This is related to the dimensions of the wheels that are too small (almost the same as the sidewalk height), causing the wheels to get stuck.

3. Confort

The push handle is made to adjust the height of the pusher



Pusher feels that the push handle on the wheelchair is less comfortable because the wrist position when pushing is not ergonomic. Based on the observation of one of the pushers, his wrist's posture was more than 15° away from the center, which is not a good posture according to the RULA analysis.

Add more foam to the seat pad



Users feel that the existing seat is slightly thinner and less comfortable for long-term use. Users suggest adding foam so that it can increase user comfort.

4. Convenience

Ease of moving

Users have no problems moving from and to a wheelchair because there is already a strong push handle to support the user's body when moving. A push handle in this displacement activity has also been described in the manual wheelchair guidelines by WHO [17].

It's a little difficult to open and close the footrest

The pusher has a little difficulty opening and closing the wheelchair, especially when opening the footrest. Also, the many steps involved in opening and closing a wheelchair make this activity a little complicated to do. Pusher suggested that the process could be done in just 1 or 2 steps.

3.2. Proposed design solution

The creation of a wheelchair is based on the results of the tests carried out and from the effects of thinking aloud. Besides, in the development process, design parameters/categories are based on wheelchair manual guidelines by WHO and ISO 7176-5 standards (Determination of dimensions, mass, and management space) [17][18].

The concept of developing a traveling wheelchair is according to consumer demand, which has previously been translated into several categories of needs. Then the design is also guided by the development criteria and anthropometric data. The interpretation results of the traveling wheelchair design made are shown in Figure 5.

In terms of design, development is doing to footrests by making footrests without gaps, the aim is to prevent the risk of pinched feet. Furthermore, changes to the armrests are made more comprehensive and slightly concave to hold the hand well. Design changes were also made with the addition of a push lever to use their wheelchair [19]. This is based on interviews with users who are in disability homes in Semarang, Indonesia that the majority of persons with disabilities prefer to be independent rather than assisted by other people when using a wheelchair or other mobility activities.

Based on the thinking aloud analysis data, there are several complaints regarding product dimensions. Such as the dimensions of the armrest, cushions, backrest, and wheels. The use of criteria for wheelchair dimensions items is based on the ISO 7176-5 standard (Determination of dimensions, mass, and maneuvering space) [18]. Then adjustments were made to Indonesian anthropometric data, as shown in table 8. Another difference from the design is related to the comfort category, namely by changing the push handle's shape. The curved shape of the push



**Figure 5.** Interpretation of the design of a traveling wheelchair

handle is expected to follow the pushing hand position well when pushing. Then the pusher can match the place that is most comfortable for him/herself.

**Table 8.** Wheelchair dimension data of design based on anthropometry

Wheelchair	Anthropometric dimensions	Percentile	Allowance	Dimensions
Seat length	Popliteal length (D14)	95%	5 cm	36 cm
The width of the seat and backrest	Hip width (D19)	95%	5 cm	35 cm
Seat height from footrest	Popliteal height (D16)	50%	-	30 cm
Backrest height	Shoulder height on sitting position (D10)	50%	-	38 cm
Armrest length	Forearm length (D23) - Hand length (D28)	95%	1 cm	21 cm
The height of the armrests from the seat	Elbow height sitting position (D11)	5%	-	20 cm
Wheel diameter	-	-	-	20 cm

The materials used in the improvement of the wheelchair design are almost the same as the travel wheelchair products studied. The wheelchair frame is the dominant component of a wheelchair where the material used is still aluminum because it has lightweight. Besides, the rims and footrests also use aluminum. For the backrest and seat cover using a net cloth material, the purpose is to absorb water quickly. The seat is also added to the seat cushion made of foam to increase user comfort. The armrest is made of soft foam wrapped in synthetic leather. Wheels, push handles, and push levers are made of rubber so that the pusher and the user do not slip easy when using them.

**4. Conclusion**

The results of measuring the usability level on travel wheelchairs that were tested showed that the usability level of the product was right (ranging from 89.12% - 94.56% or excellent). This indicates that the tested travel wheelchair responded well to the user and could be useful in the context of its use.

However, several problems were found related to satisfaction and thinking aloud results. Which then the problem data is used as a guide in making designs. The criteria for design problems are grouped into several categories, namely design, dimensions, comfort, and convenience. The development is then carried out based on several wheelchair development parameters such as stability, wheelchair dimensions, seat and postural support, and adjustable and ergonomic factors.

Developments are made to the footrests by making them without gaps to prevent the risk of pinching the foot. Furthermore, changes to the armrests are made more comprehensive and slightly concave to hold the hand well. Design changes were also made with the addition of a push lever to use their wheelchair. Meanwhile, dimensional changes are carried out based on the user's anthropometric dimensions, namely armrests, seats, backrests, and wheels.

Several shortcomings can be used as suggestions from the author in this study, namely, in addition to discussions with users, there is also a need for expert opinion in related fields to prepare product testing and evaluation activities. It is even better to retest the design so that it can be seen as an increase in the usability of the product design.

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