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Sustainable Assistive Device Design for Buttonhole Machine Operation by Wheelchair Users: A Pugh's Method Approach

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ABSTRACT : This study aims to support inclusive and sustainable industry practices by designing an ergonomic assistive device for wheelchair users operating buttonhole machines. Using a participatory approach, a morphological chart, and the Pugh method, six design concepts were developed and evaluated. The optimal design, Concept III, incorporates iron material, a by-wire mechanism, and a pull-type lever. Evaluation using the Nordic Body Map (NBM) showed a reduction in musculoskeletal complaints among all respondents. The total estimated manufacturing cost is Rp266,278, consisting of Rp71,898 for materials, Rp150,000 for processing, and Rp44,380 for overhead. This low-cost, minimal-maintenance solution aligns with the principles of social and technical sustainability and is appropriate for small and medium-sized enterprises.

Keywords – Ergonomics, Inclusive Design, Pugh method, Sustainable Development, Wheelchair User

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1. INTRODUCTION

The garment sector remains strategically important in Indonesia's economic growth. According to the Manufacturing Industrial Directory 2024, there are approximately 30,000 medium-sized to large manufacturing firms in the country, which include garment manufacturers [1]. In Q1 2024 [2], the textile and garment sub sector posted production growth of +3.08% for ready-made garments, while employment in the TPT sector remained significant, with 3.87 million workers as of 2024, down from 3.98 million in 2023 [3]. In line with Sustainable Development Goals (SDGs) 8, 9, and 10 [4], inclusive work environments are promoted by Law No. 8 of 2016, which mandates companies to employ persons with disabilities [5].

Existing machines such as the buttonhole sewing machine pose accessibility challenges for wheelchair users due to their reliance on foot pedals. Although previous studies have evaluated ergonomic risks among conventional garment operators [6]. Accessibility issues for disabled workers remain under-addressed. Designing assistive devices based on anthropometry and ergonomics is crucial for supporting inclusivity and sustainability [7], [8].

This study applies systematic design tools including Pugh's selection matrix [9], morphological charts [10] and Ulrich & Eppinger's evaluation framework [11] to redesign an assistive facility that meets user needs, with validation through ergonomic and cost assessments. This study is also aligned with the approach proposed by Silaen *et al*. in [12], which demonstrated productivity improvements through workstation redesign using the Pugh method.

2. METHOD

This study was conducted at BBRSPDF Prof. Dr. Soeharso Surakarta, a technical implementation unit responsible for delivering social rehabilitation services to persons with physical disabilities. Initially, one wheelchair-using worker and four stakeholders (two instructors, the manufacturer, and the researcher) participated in concept selection; later, four workers joined the ergonomic evaluation. Observations and interviews identified barriers in operating buttonhole machines, followed by ergonomic assessment using the Nordic Body Map (NBM) [13], [14]. Design development applied a morphological chart [10] to produce six alternatives, evaluated with the Pugh method [9] by five experts to select the optimal concept. Anthropometric data (shoulder height, seated elbow height, reach distance) ensured ergonomic compatibility [11], while cost and sustainability analyses addressed materials, production, and maintenance for implementation by small and medium-sized enterprises (SMEs).

3. RESULTS AND DISCUSSION

1.1 Identification of Needs and Criteria

User needs were identified through a participatory approach involving five stakeholders: one wheelchair-using worker, two work instructors, one manufacturer, and one researcher. Questionnaires were used to gather specific needs for improving the assistive device for buttonhole machines. Initially, eight criteria with seventeen sub-criteria were identified, as shown in Table 1: Identified Design Criteria and Sub-Criteria. After reliability and validity testing, six criteria with ten sub-criteria were selected as the most influential for design, as presented in Table 2: Final Design Criteria and Sub-Criteria. These finalized criteria served as the foundation for generating design alternatives in the next stage.

Table 1: Identified Design Criteria and Sub-Criteria

No	Criteria	Sub-Criteria
1	Accessibility	The assistive device functions properly when operating the buttonhole machine
2		The assistive device is easy to use
3		The assistive device is detachable
4	Effectiveness	Worker's motion in operating the assistive device is not complex
5	Easy to handle	Easy to install
6		Applicable to all types of buttonhole machines
7	Ergonomic	Minimizes muscle fatigue
8		Requires low physical effort when operating the assistive device
9		Provides comfort during operation
10	Tool performance	The frame structure of the assistive device is sturdy
11	Material	Made from strong materials
12		Lightweight material
13		Durable materials
14	Design	The assistive device is space-saving
15		The design of the assistive device is simple
16	Sustainability	Comfortable for long-term use
17		Cost-efficient in production and maintenance

Table 2: Final Design Criteria and Sub-Criteria

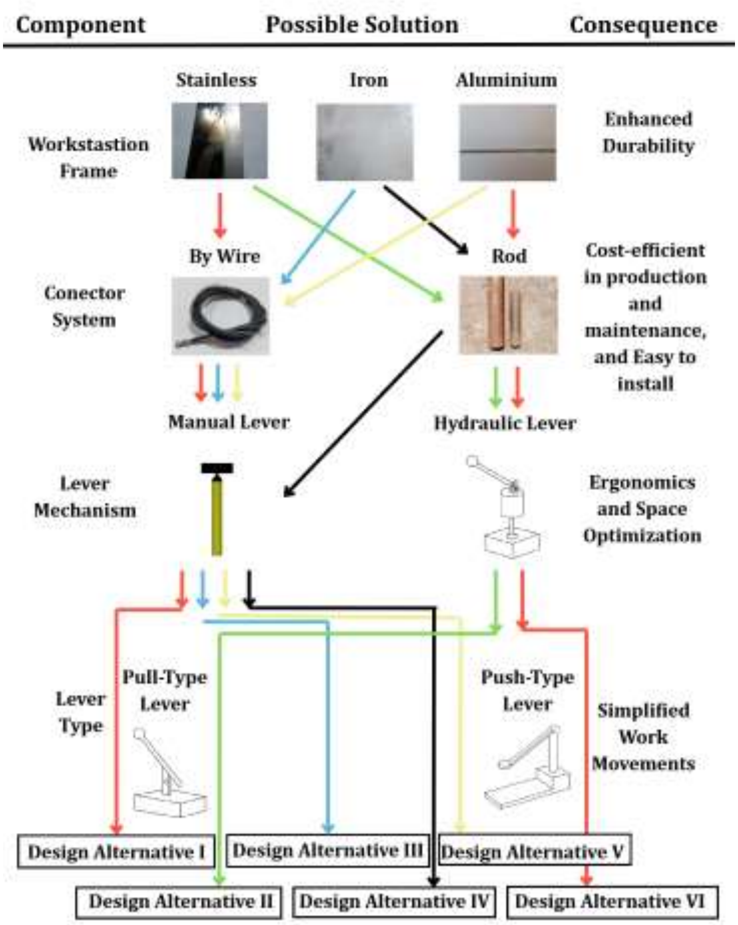
Criteria	Sub-Criteria
Effectiveness	Worker's motion in operating the assistive device is not complex
Tool performance	The frame structure of the assistive device is sturdy
Material	Made from strong materials
	Durable materials
Sustainability	Comfortable for long-term use
	Cost-efficient in production and maintenance
Easy to handle	Easy to install
	Applicable to all types of buttonhole machines
Design	The assistive device is space-saving
	The design of the assistive device is simple

1.2 Design Alternatives Using Morphological Chart

Based on the finalized design criteria, six design alternatives were developed using a morphological chart. Variations included material (stainless steel, iron, and aluminium), connector system (by-wire and rod), lever mechanism (manual lever and hydraulic lever), and lever type (push/pull).

The morphological chart illustrating these combinations is presented in Table 3: Morphological Chart of Assistive Device Design Alternatives. This chart served as the foundation for selecting the most feasible design alternative in the subsequent evaluation stage.

Table 3: Morphological Chart of Assistive Device Design Alternatives



1.3 Design Evaluation Using Pugh Method

The six design alternatives were evaluated using the Pugh method to select the optimal concept. Evaluation criteria were based on the finalized design criteria. The process included two stages: initial concept filtering as shown in Table 4 and final assessment using the assembly tools matrix as presented in Table 5. Five expert respondents rated each alternative against a baseline concept, and the design with the highest score was selected for further development.

Table 4: Results of Filtering Concepts

Criteria	Sub-Criteria	Concept Selection						
		Base Line	I	II	III	IV	V	VI
Effectiveness	Worker's motion in operating the assistive device is not complex	0	+	+	+	+	+	+
Tool performance	The frame structure of the assistive device is sturdy	0	+	-	+	+	-	-
Material	Made from strong materials	0	+	+	+	+	-	-
	Durable materials	0	+	+	0	+	+	0
Sustainability	Comfortable for long-term use	0	+	+	+	+	0	-
	Cost-efficient in production and maintenance	0	+	+	+	0	+	-
Easy to handle	Easy to install	0	-	+	+	-	+	0
	Applicable to all types of buttonhole machines	0	+	-	+	-	-	-
Design	The assistive device is space-saving	0	-	-	-	+	-	+
	The design of the assistive device is simple	0	0	+	+	-	-	+
Number of (+)			7	7	8	6	4	3
Number of (-)			2	3	1	3	5	3
Number of (0)			1	0	2	1	1	3
Final Score			5	4	7	3	-1	0
Rank			2	3	1	4	6	5
Proceed?			Yes	Yes	Yes	No	No	No

Table 5: Assembling Tools Assessment Matrix

Criteria	Sub-Criteria	Weight	Concept					
			I		II		III	
			Rating	Rate Load	Rating	Rate Load	Rating	Rate Load
Effectiveness	Worker's motion in operating the assistive device is not complex	18%	3,40	0,61	3,4	0,61	3,6	0,65
Tool Performance	The frame structure of the assistive device is sturdy	14%	4,20	0,59	5	0,70	4,4	0,62
Material	Made from strong materials	8,64%	3,60	0,31	5	0,43	4,2	0,36
	Durable materials	9,36%	2,80	0,26	4	0,37	4,2	0,39
Sustainability	Comfortable for long-term use	10,56%	4,00	0,42	3	0,32	4,2	0,44
	Cost-efficient in production and maintenance	13,44%	3,60	0,48	2,4	0,32	4,4	0,59
Easy to handle	Easy to install	9,28%	4,00	0,37	3	0,28	4	0,37
	Applicable to all types of buttonhole machines	6,72%	3,60	0,24	3,4	0,23	3,8	0,26
Design	The assistive device is space-saving	6%	2,80	0,17	2,8	0,17	2,8	0,17
	The design of the assistive device is simple	4%	3,40	0,14	2,8	0,11	3,4	0,14
Total			3,60		3,54		3,99	
Rank			2		3		1	
Conclusion			No		No		Yes	

Based on the Pugh evaluation, Concept III was selected as the optimal design due to its highest final score among the six alternatives in Table 5. Fig. 1 shows the selected design concept, consisting of a pull lever mechanism, by-wire actuation, and an iron frame.

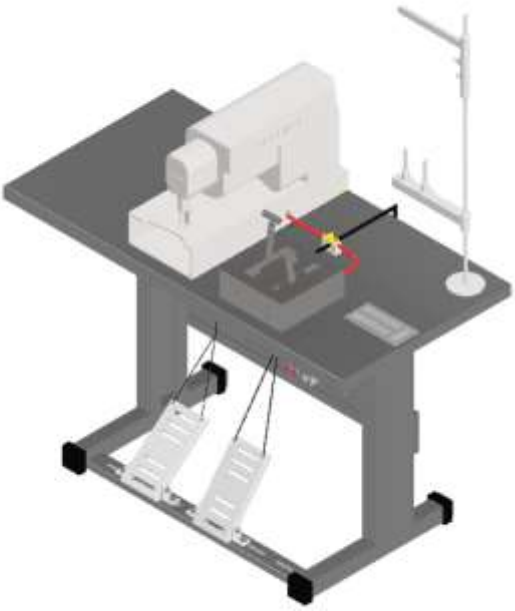


figure 1. selected design concept III

1.4 Detailed Design and Dimensions

The assistive device was designed using anthropometric data from four wheelchair-using workers, covering forward grip reach, popliteal height, and seated shoulder height, as presented in Table 6. These data were used to determine the workstation dimensions, as shown in Table 7, with the 2D design illustrated in Fig.2.

Table 6: Anthropometric Data of Wheelchair Users

No	Anthropometric Dimensions	$\bar{x}$	σ	Percentile (cm)		
				P5	P50	P95
1	Forward grip reach	64.98	4.24	58.02	64.98	71.95
2	Popliteal height	38.22	3.26	32.86	38.22	43.58
3	Sitting shoulder	50.02	4.81	42.11	50.02	57.92

Table 7: Buttonhole Machine Workstation Dimensions

No	Size	Name of product (mm)
1	The height of the left lever from the floor	1015
2	Left lever height	208
3	Distance of left lever to body	580
4	The height of the left lever from the floor	979
5	Right lever height	172
6	Distance of right lever to body	580
7	Box Length	220
8	Box Width	220
9	Box Height	84
10	Buttonhole machine table height	745

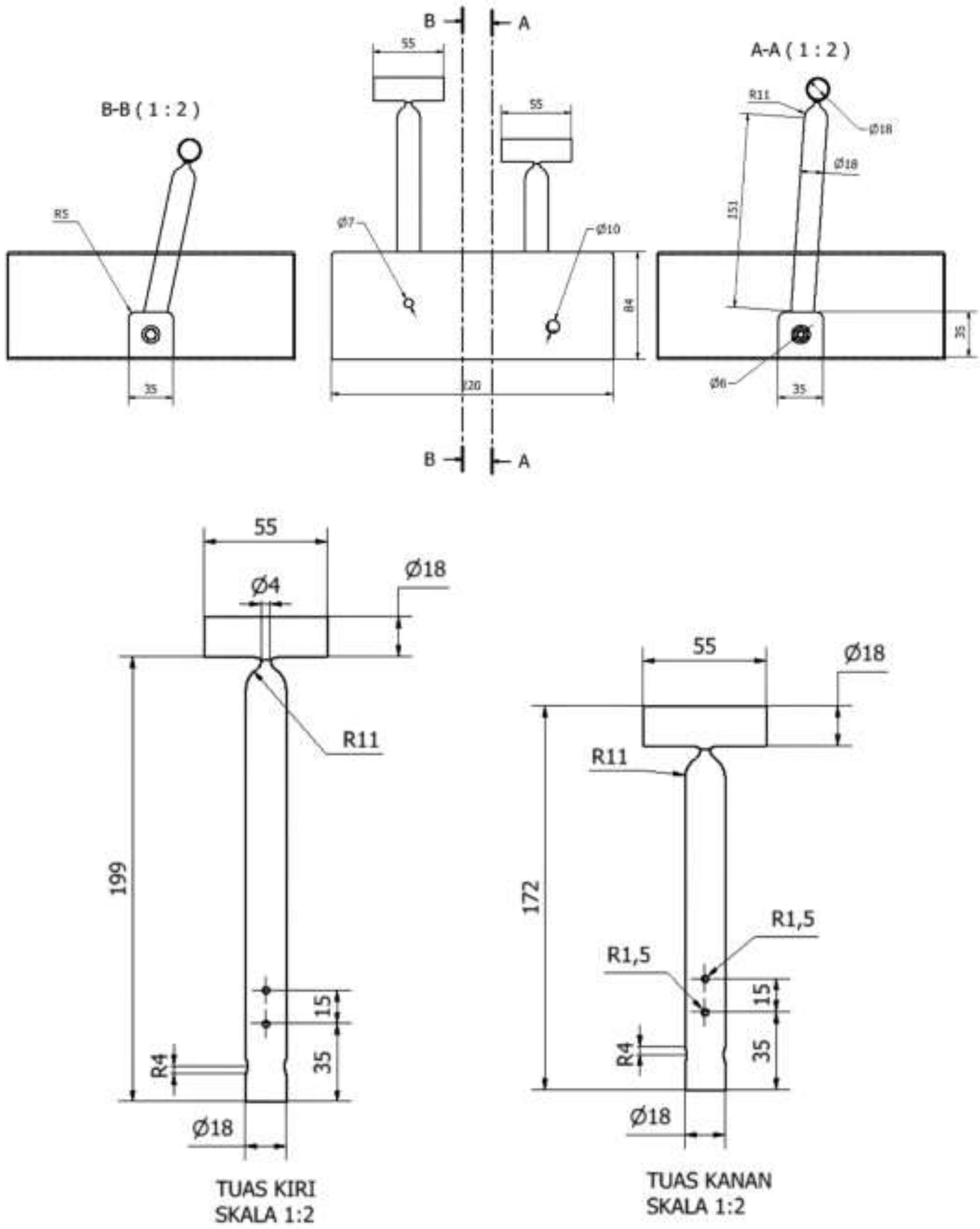


figure 2. 2d design of selected assistive device concept

1.5 Ergonomic Validation and Posture Visualization

Ergonomic validation with four wheelchair users showed decreased NBM scores from medium-high risk to low after the workstation redesign Table 8. The Wilcoxon Signed-Rank Test ($N = 4$, $W = 0$, $p < 0.05$) confirmed a significant reduction in musculoskeletal complaints. Posture visualization further illustrated improvements in one representative respondent, with similar trends observed in the other three Fig. 3.

Table 8: NBM Score Classification Pre-Design and Post-Design

Respondent	**Pre-Design**		**Post-Design**		**Score Difference**
	Score	Classification	Score	Classification	
Respondent 1	42	High	18	Low	24
Respondent 2	21	Medium	2	Low	19
Respondent 3	22	Medium	0	Low	22
Respondent 4	21	Medium	6	Low	15

(a) (b)

figure 3. posture change visualization of a representative respondent: (a) pre-design and (b) post-design

1.6 Sustainability and Cost Evaluation

The iron-based design ensures durability, local availability, and low-cost mass production, making it suitable for SMEs. The total manufacturing cost is Rp266,278, consisting of three main components: the box (steel plates, M12 bolts, and tapping screws) with Rp35,744 for materials, Rp50,000 for processing, and Rp17,149 overhead (total Rp102,893); the lever (steel pipes, lever base, and M12 bolts) with Rp16,154 for materials, Rp50,000 for processing, and Rp13,231 overhead (total Rp79,385); and the connector (bicycle brake cable and clamp) with Rp20,000 for materials, Rp50,000 for processing, and Rp14,000 overhead (total Rp84,000). Overall, this amounts to Rp71,898 for materials, Rp150,000 for processing, and Rp44,380 for overhead. Maintenance is minimal, limited to periodic replacement of the bicycle brake cable every 1–2 years at approximately Rp10,000 per unit.

4. Conclusion

The redesigned assistive device successfully addresses accessibility challenges for wheelchair users operating buttonhole machines. Concept III, featuring an iron structure, by-wire mechanism, and pull-type lever, was validated as the most effective alternative through ergonomic evaluation and Pugh scoring.

The developed design not only fulfilled ergonomic criteria but also supported sustainability by using strong, locally available, and cost-effective materials. With a participatory and anthropometry-based approach, the assistive device has the potential to be widely implemented in small to medium-scale garment industries. In addition to promoting the inclusion of persons with disabilities, this innovation contributes to achieving Sustainable Development Goals, particularly *SDG 8* (decent work), *SDG 9* (industry and innovation), and *SDG 10* (reduced inequalities).

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