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A Morphological Analysis of Ergonomic Design Reconfigurations for Crutch Versatility in the Environment of Use

By Bahram Ipaki, Zahra Saadat Ramz, Johan Molenbroek, & Seyed Ali Faregh

SIDEBAR 1:

This article gives an appropriate configuration with the assistance of morphology analysis and QFD, which contains new accessory designs for crutches alongside distinct structures, focusing on convenience criteria in environmental operation.

FEATURE AT A GLANCE: Nowadays, there are complications in the environments where the crutch is being used, which cause discomfort for users throughout the use and therapy period. There are many flaws in cities' infrastructure. Using a simple search on the internet, it can be claimed that standard crutches have an array of design faults and ergonomic problems, and users seek to fix the problems with non-industrial solutions and home treatments. For this reason, various accessories for crutches are being produced, and even designers have proposed new types of crutches as replacements. However, the majority of them still didn't pass the human-centered research procedure.

KEYWORDS: designing for disabled, medical/health products, anthropometry, biomechanics, rehabilitation

Disability is a phenomenon that generally develops owing to several factors, genetically, medically, clinically, industrially, or ecologically. Some disabilities aren't regarded as an illness, some are transitory, and some other disabilities damage people's lives forever. Therefore, persons with disabilities strive to become homogenous and integrated with regular people in society, as they don't consider themselves unhealthy (Nazli, 2012). However, this matter is depending on different factors, like the design of the environment and appliances around these users. The crutch is one of the self-care and rehabilitation facilities for disabled people, which has been developed with a variety of designs to resolve specific needs (Williamson & Guffey, 2020). Using a crutch is usually for a person who has a disabled or injured leg (Moran et al., 2015). Despite many thought-out crutch designs, disabled persons still have challenges while using crutches in public and interactional settings and they may even get wounded; hence, the necessity of design precision is posed for designers and doctors (Damm et al., 2013; Rasouli & Reed, 2020; Sherif et al., 2016).

Adjustments to the height and width of the crutch are one of the therapeutic and ergonomic solutions to facilitate using the crutch (Esposito et al., 2018; Freddolini et al., 2018). Wherein according to standard crutches designs, the capacity to change dimensions and proportions is only achievable while considering specified locations on the crutch's framework, and these points limitedly allow the reconfigurability. These constraints can also affect doctors' medical advice and suggestions. Hence, when a crutch is prescribed for the patient, numerous factors such as clinical concerns and whether it is easy to use in public areas are proposed.

As a designer, we are encountering a few challenges here. A doctor may suggest using a crutch for an extended amount of healing, rehabilitation, or other criteria. Therefore, social isolation difficulties or depression should be considered. While to cure the situation, the patient resolves to visit outside more regularly and mingle frequently. Accordingly, the environment for utilizing a crutch will become crucial for other medical issues.

Design for disabled people, even at the basic levels, is nonetheless one of the critical issues in developing countries and cities. The question is, should local standards correspond with universal standards so that based on them, with the assistance of design, gets possible to resolve disabled people's needs? Implementing the international standards around a city for impaired persons may cost a lot and need substructures and professional equipment. Also, altering substructures takes considerable time and may prevent disabled persons from basic living facilities. Thus, designing by-products and self-cares becomes the primary emphasis, and disabled individuals should satisfy their requirements with this equipment.

In the design process, general design parameters have to be considered, and then in the process of detail, the design is adapted with an optimal approach. Nevertheless, in product development or redesigning, if it gets specified that an approach can optimally solve the problems, it is crucial to utilize it to increase efficiency. Since implementing the design process from the first phase is complicated, it takes considerable time, and the results may be repetitive until the development stage. Consequently, it should be verified if the design process has to be done from the first stage or not! The design problem is semi-clear here since the crutch is a well-known product, and the goal and its use are appointed from before. However, there are some concerns about usability and function in different situations. The major challenge of the present research is to discover the ergonomic design parameters of crutch with versatility in the usage environment.

PROCEDURE

This is a qualitative design study. In this article, we examine the characteristics of using crutches in different environments and predict the parameters side by side. This approach assists us in ensuring that the final configuration of the product matches the parameters of use and will investigate the problems from multiple perspectives. Therefore, we first investigate several crutch usage environments. In the following step, we follow anthropometry data and then assign design principles. Consequently, we locate designs in the morphology chart and obtain versatile outputs. Then with the twenty individuals' support of the focus group as an expert panel, we analyze the morphological chart's output by Quality Function Deployment (QFD), and the final product design configuration will be portrayed.

On that account, there have been frequent meetings with the experts' panel for three months, which resulted in designing the checklist and also idea evaluation accordingly. The expert panel included two groups; investigating clinical perceptions (concepts) was done with the help of orthopedists and ergonomists, and investigating engineering and production perceptions was done with the help of a few industrial designers and mechanical and material engineers.

FOOTPATH (PAVEMENT)

Pavements and footpaths serve as essential pathways for pedestrians, whether they are alongside a road, a driveway, or within a park. While pavements are characterized by their firm surfaces, footpaths are the preferred routes for people with disabilities. Footpaths are often paved or feature cobblestones, polished tiles, or rough granular tiles. The condition of the footpath can substantially impact the safety and overall performance of users relying on crutches for mobility. Aghaabbasi et al., 2019 introduce the concept of fair usability in a footpath. They acknowledge that a footpath should be divided equally between people and three attributes: usability, safety, and aesthetics (Aghaabbasi et al., 2019).

The patient or user should not block the footpath when using a crutch or walker. Designing a crutch or walker is highly significant, considering anthropometry data. As there are numerous discussions regarding estimating mobility and equal usage, the walking patterns of different individuals may vary. Orthopedic doctors recommend people to walk using diverse methods as a therapeutic approach. Therefore, we establish a radial range for this purpose. Based on that, we propose two features depicted in the accompanying picture:

1. The occupied space by a typical user while walking on the footpath
2. The occupied space by a disabled person while walking on the footpath

We can reduce (limit) the range of user footstep and crutch motions by changing the design of the crutch's forms and pads. Observations of disabled adults reveal that they usually require approximately 10–15 cm of extra space. This difficulty may be rectified by proper monitoring and adjusting of the height. Standard conventional crutches have roughly 3–4 cm anthropometry error in height for each user. The distance between each height adjustment hole is roughly 4–7 cm which might fluctuate dependent on brand and crutch size. The trigonometric ratio in Figure 1 indicates that even a 1 cm change in crutch height may affect more than a 10 cm difference in footstep. Therefore, the issue needs to be addressed by millimeters.

SLOPE

Some public footpaths should have slopes of more than 6% with 45-foot lengths since a slope of 6–9% causes a crisis for disabled people. In addition, people who use a walker or crutch usually consume more energy while walking on slopes, so education on methodical walking with crutches has been emphasized (Kockelman et al., 2002; Moran et al., 2015; Rasouli & Reed, 2020) Further, in the ADA POST INSPECTION CHECKLIST, the footpath's slope is inserted at 2% or less (Kent, 2017; Leonard, 2000). However, many substructures in regions do not cover these standards. Furthermore, a disabled person should not enter there. Sometimes a disabled person is forced to walk on slopes. Designing crutches can therefore have a positive or negative impact on them. As a result, focusing on designing a crutch with adjustability to a 5–6% slope, which is common in most cities to facilitate pushing wheelchairs, is critical. With thoughtful design, we can reduce the amount of energy a disabled person uses while encountering a slope. Furthermore, slippery slopes can be extremely dangerous. For this reason, the design of the crutch's leg structures is profoundly significant. Figure 2 portrays the mobility of a disabled user.

STAIR

Attempting to climb stairs is one of the primary issues when using a crutch. The fundamental rule for moving up and down the stairs is to walk up the stairs, the healthy leg is put first, while to go down the steps, the injured leg is put first. Using 2 crutches for going up and down the stairs, depending

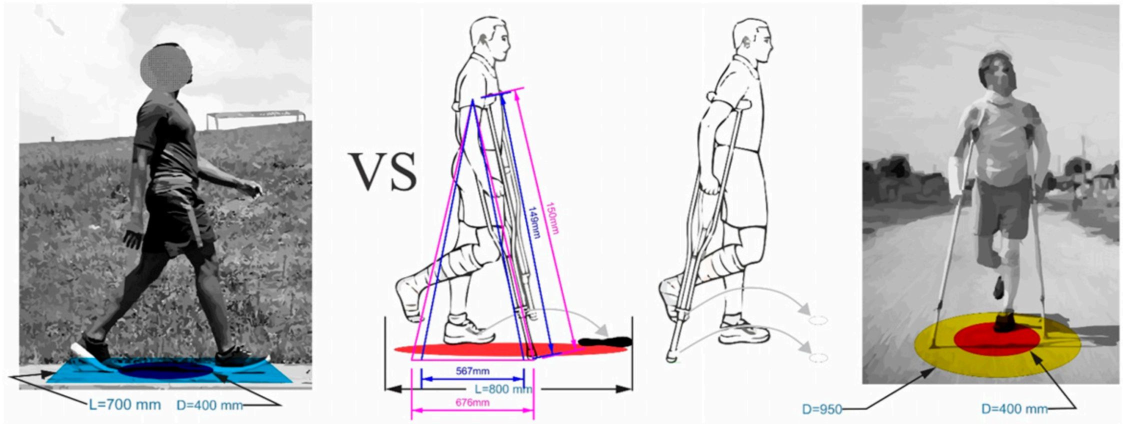


Figure 1. Trigonometric proportions of movement with the crutch.

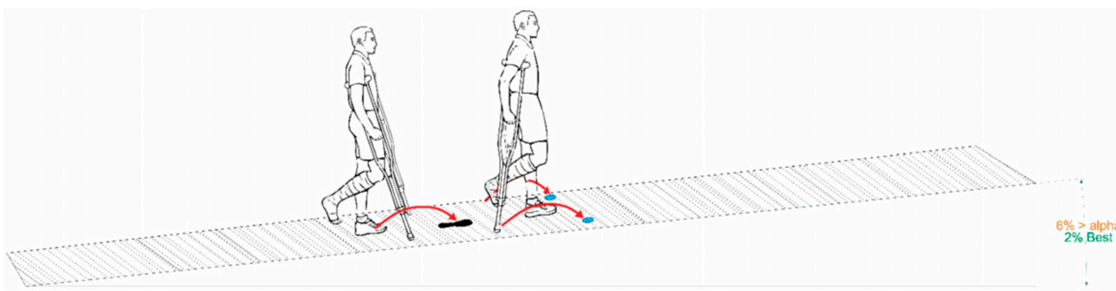


Figure 2. Walking with the crutch on the slope.

on whether the steps have banisters or not, may change. The standard height of steps is about 18–20 cm. Its breadth is roughly 30 cm. This is usually because of the slope between the tip of the crutch, which is on the lower stair, and the bottom of the user's healthy foot, which is on the upper stair, versus the vertical axis, which reaches its highest point at about 30°; the inertia of the crutch tip dramatically declines, and safety is compromised.

ELEVATORS

Previous designs for rehabilitation and disabled people primarily considered wheelchair use on escalators and elevators. People with minor disabilities or those with broken legs may use crutches. The crutch or equivalent products should not adversely affect other adjacent products or the environment, especially in public places. In some circumstances, it is seen that more crowded spaces and congestion inside the elevator make it difficult for disabled people to relocate. This is exacerbated when a crutch isn't well-designed for that situation and is cumbersome. Along with occupying space, people with disabilities may be threatened by the risk of falling. Because collisions between people with crutches could disrupt a disabled person's balance. It is also necessary for the crutches to be folded or compacted to the maximum extent possible in the elevator owing to the equitable use debate. Figure 3 illustrates the dimensions of two small-scale elevators and a user in the elevator. The angle of the crutch can make it difficult for people to get in and out.

BUS

Buses are a popular mode of transportation for disabled people owing to their accessibility and spaciousness (Ahonobadha, 2017). The reasons for using public transportation are disabled people's incapability to drive a car, or not having facilities or limited capacity for other kinds of transportation. From a universal design perspective, public situations for disabled people have been enhanced, especially on urban buses (Sze & Christensen, 2017; Velho, 2019). However, some disabilities are unable to use mid-city buses. Some developing countries have overcrowded cities where people with disabilities do not have their own stations. The crutches must be designed to make boarding a bus as simple and safe as possible. For this purpose, the crutches should be designed to allow bus boarding as effortlessly as possible for the disabled and cause no disruption inside the bus. It is technically possible to designate an exclusive stand for disabled passengers on buses. In contrast, the bulkiness and non-anthropometric dimensions of crutches can make movement

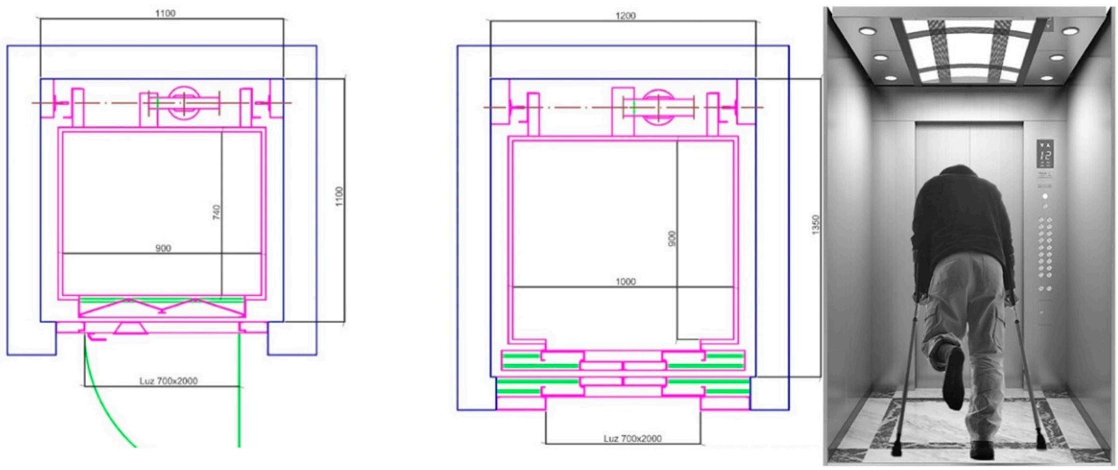


Figure 3. The dimensions and scale of three and four-person elevators.

difficult for a disabled person and others (Richards & Sang, 2018). This issue might be resolved with subassembly crutch systems since equitable use is still a problem. Figure 4 demonstrates the lack of facilities for mobility for the disabled in the city bus at the bus station in a developing country that result from the frailty of the infrastructure.

Figure 4. Flaws of a public transportation system for disabled people to get in or out of the bus in Iran, as a developing country.

TRAIN OR SUBWAY

The train is another mode of transportation that people with disabilities prefer. Overcrowding in some cities worldwide may pose difficulties in using trains for people with disabilities. Furthermore, we cannot precisely predict or calculate the behavioral and moral levels of citizens and the societal culture toward disability in each of those cities. For example, can we be certain that a citizen intends to offer their seat to a disabled person or not? As a result, when a disabled person stands still and uses a crutch, the crutch should not tire him. Furthermore, for people with disabilities, the acceleration and sudden braking of train movement are extremely distressing. The design should be adjusted as much as possible to these conditions. The question is whether the standards should be changed or whether designs must adhere to the standards. Is it necessary to change everything at once? The solution to this issue could be to focus on developing the design of the crutches' tips.

AUTOMOBILE

Some of the smaller cities do not have public transportation. Therefore, people with disabilities have only the option of taxis or personal cars. Similarly, people's medical conditions sometimes force them to use private transportation. To unravel this problem, using automatic cars without a driver, suitable for people with disabilities, has recently gained considerable attention; but this is mostly possible in developed cities (Bennett et al., 2019). This is one of the main challenges of designing a crutch. Because, according to the unadjusted anthropometric dimensions of a crutch and the size of the car's door and interior, entering and exiting crutch into a car has always posed one of the biggest challenges for all users. We have to design a crutch that is adjustable to a taxi situation. This issue may make the design process more complicated. However, it appears that this issue is both essential and beneficial. We should not consider changing the design of taxis for people with disabilities because it will be expensive and because having VIP taxis in developing countries for people with disabilities who have average salaries or economic issues is not logical or fair. Our preference is to promote public health.

Automobiles have different dimensions and proportions. As a result, their anthropometry data extraction is of significant value. From Figure 5, we extracted the typical cars' anthropometry data that they needed. While the crutches are the smallest version available, they still cause problems when getting into a taxi.

DETAILS DESIGN

Armpit Pad

The axillary support of crutches should not be used to sustain weight. Despite this, most axillary crutches contain a pad or cushion that covers the axillary support. That indicates that manufacturers know that users may continue to maintain weight on the axillary support. It has been hypothesized that incorrect use is caused by weariness or because of comfortability; this form of crutch use may boost user endurance. Weight sharing between the underarm and handgrip may be possible with more comfortable axillary support systems (Borrelli & Haslach, 2013). Putting weight on the non-ergonomic upper pillow or armpit pad causes pressure on the vessels and nerves that pass through the armpit, and this pressure can cause paralysis of the nerves in that area. In 2016, Nagasaki et al. investigated the effect of crutch position on the vertical axis on safety and stability. In their study, the armpit pad of the crutch plays an influential role in the freedom of rotation for forward movement. That is an imperative factor in ensuring safety when walking with crutches. As a result, the armpit pad must be ergonomically designed in shape and thickness in the vicinity of the armpit (Nagasaki et al., 2016). A second hypothesis researchers consider regarding the armpit pad is the possibility of creating a massage sensation beside the chest, which may reduce the user's energy while using the crutch (Miski, 2016).

Hand Grip

Yokota and Muraki (2014) examined the pad of the crutch's handle with the help of an electromyography device. The results revealed that distributing outward pressure on palms and subjective evaluation of the position of the handle between (40 mm, 45 mm, and 50 mm) forces less pressure on palms. They finally suggested a handle with a diameter of 35–40 mm, which had a length of 19–22 cm as the most optimum dimension for young adult men (Yokota & Muraki, 2014). However, the underlying material has to be made from soft, high-density foam or high-quality silicon.

However, since several materials have no holes to circulate air, they cause hands to sweat and are contaminated after using the crutches. This matter is similar to crutch armpit pads.

Making a curve on one side of the bottom of the crutch tip can facilitate the movements of people with disabilities (Capecci et al., 2015).

The crutches should not slip or relocate on the path's surface. The weather could be scorching or freezing; regrettably, the product's reaction to the environmental climate can alter safety conditions. As a result, designing the materials and structures considered in the crutch's design is critical to ensure it does not slip-on ice in winter, become distorted by summer heat, or lose its quality and endurance. Perhaps we can include extra crutch tips in the crutch pack so that the user can use them at different times.

Structure Design

Due to biomechanical concerns, crutch structure dictates every other piece's outcome and ultimate function. However, to achieve accessibility, estimating the dimensional information is essential. To build a general framework, we utilized adult Iranians as the target group, and the information has been placed in Table 1.

The attributions of any public setting for disabled people have been determined to depend on computational concerns to be included in engineering design. These extracted properties for desired versatility have been added in Table 2, and design requirements are listed by considering them.

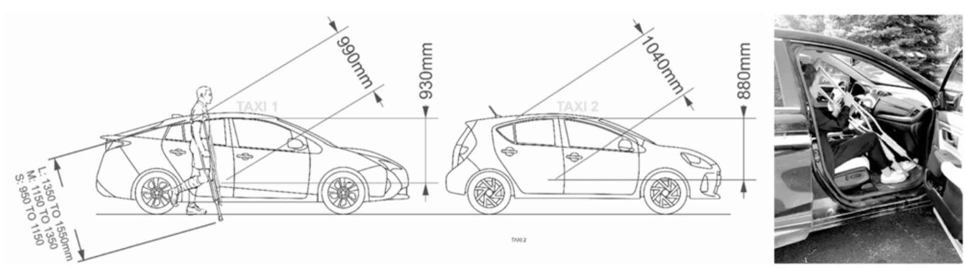


Figure 5. The approximate dimensions of taxis in cities and space occupation in a car by the crutch.

Table 1. Anthropometric Estimates Based on Iranian Adults.

	Men percentile				Women percentile			
Factors millimeter	5th	50th	95th	SD	5th	50th	95th	SD
Shoulder height	1353.9	1459.7	1565.5	64.3	1226.7	1336.2	1445.6	66.5
Armpit height	1180.9	1270.7	1360.5	54.3	1067.7	1162.2	1256.6	57.5
Wrist height	785.3	857.5	929.7	43.9	726.6	795.5	864.4	41.9

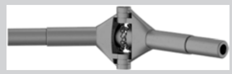
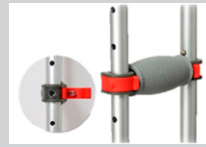
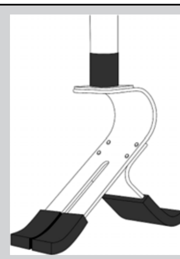
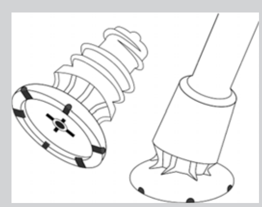
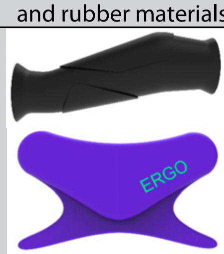
Table 2. Versatility Purpose for the Design.

Parameters	Minimum	Maximum	Results
Stair	30° h = 18 L = 30	33° h = 20 L = 30	The crutch tip and structure must be designed to keep users safe on the stair and not slip.
Pavement	$\varnothing \approx 700mm$	$\varnothing \approx 850mm$	The crutch's usage radius should be close to the minimum circumstance of 700 mm with millimetric adjustability.
Slope	$2\% = \frac{h=2}{a=100}$	$6\% = \frac{h=6}{a=100}$	The crutch tip and structure must be designed to keep users safe on a 6% slope.
Elevator	$a \times b = 0.9m^2$ 4 persons	$a \times b = 1.66m^2$ 8 persons	For inside the elevator, it is better to provide an option for folding it or making it smaller so it does not interfere with others' rights. $22.5 = \frac{0.9}{4}$
Bus (interior)	$a \times b = 0.5m^2$	$a \times b = 0.7m^2$	For inside the bus, decreasing the occupied space by the person with a disability to *squares*5*squares* is allowed.
Subway	$a \times b = 0.4m^2$	$a \times b = 0.5m^2$	For inside the train or metro, decreasing the occupied area by the person with a disability to *squares*4*sare is* is preferable.
Car/Taxi	N/A	$h = 900mm$	It is better if it is possible to lower the crutch's length fast or fold it. The length of the crutch has to be decreased to less than 900 m to be utilized in a taxi.

Table 3. Checklist for Crutch's Design and Assessment.

Factors	Description
Stability	Stability while walking on even (flat) surfaces, surfaces with rubbles, climbing up the stairs and slopes, and having balance
Preventing slips	Keeping the crutch from sliding in different directions
Mobility	Ability to move easier and faster
Easy to assembly	Possibility of easily being assembled for pre and after manufacturing
Easy to adjustably	Feasibility and height adjustment ability according to anthropometry
Quick adjustability	The height adjustment acceleration according to anthropometry
Accurate adjustability	Height adjustment accuracy (in millimeters)
Comfortable hand grip	Better gripping according to palm's anthropometry, avoid sweating and flexibility (Crutch tip flexibility may affect the amount of pressure)
Comfortable armpit pad	Armpit pad with more convenience, no sweating, flexibility (Crutch tip flexibility may affect the amount of pressure)
Low weight	Lightness on each component of the crutch structure
Block the pressures	Making a normal balance between pressure on palms and armpit or minimizing the pressure on them (handle, armpit pad, angle of crutch structure designed axis and crutch tips are influential)
Manufacturability	Ability to produce parts based on production simplicity and acceleration of components preparing process
Simplicity	The simplicity of details and elements for ease of use, simplicity in preparing process and completion of crutch
Eco-friendly materials	Possibility of material recycling and biodegradability
Versatility with the environment	Adjustability with different environmental features like space dimensions, floor, temperature, and contamination or hygiene (washability)
Occupying little space	Less space occupation with components attributes

Table 4. Morphological Chart.

Component	Option 1	Option 2	Option 3	Option 4
Mechanism M1, M2, M3, M4	 Bicycle Quick Release Seat Post Clamp	 Foldable mechanism	 Orifice for locking the handle or structure position	 Telescopic mechanism for shrinking
Adjustability Structure S1, S2, S3, S4				
Tip T1, T2, T3, T4	 Tip with Thermoplastic Polyurethane (TPU) and rubber materials	 Tip with spring steel and rubber materials	 Tip with quick movability feature	 Common standard tip
Armpit Pad Form & Hand Grip Form PG1, PG2, PG3, PG4	 Standard manufacturing	 Prosthesis molding based on the patient's body	 Universal covers	 Customized 3D print with networking properties for flexibility

VERSATILITY'S DESIGN CRITERIA

1. The crutch tip has to stay stable with a 33-degree change in the vertical axis.
2. The millimetric height adjustment can be determinative for controlling the pressure on muscles, space occupation, and user convenience.
3. The crutch tip has to provide safety against smooth, polished, slippery surfaces.
4. The crutch tip must withstand hot and cold temperatures as much as possible.
5. If possible, springs should be incorporated into the crutch structure to equalize the applied pressure to the armpit.
6. For the equitable use of spaces, it is better to place the possibility of folding the crutch or making it smaller for the train and subway circumstances as the priority as the requested dimensions are fewer than the bus dimensions. In addition, the armpit pad must be designed thinner, so the user does not have to hold it at a distance from them.
7. For boarding a cab, it is ideal if the user folds the crutch; in this form, the crutch length should be less than 900 mm.

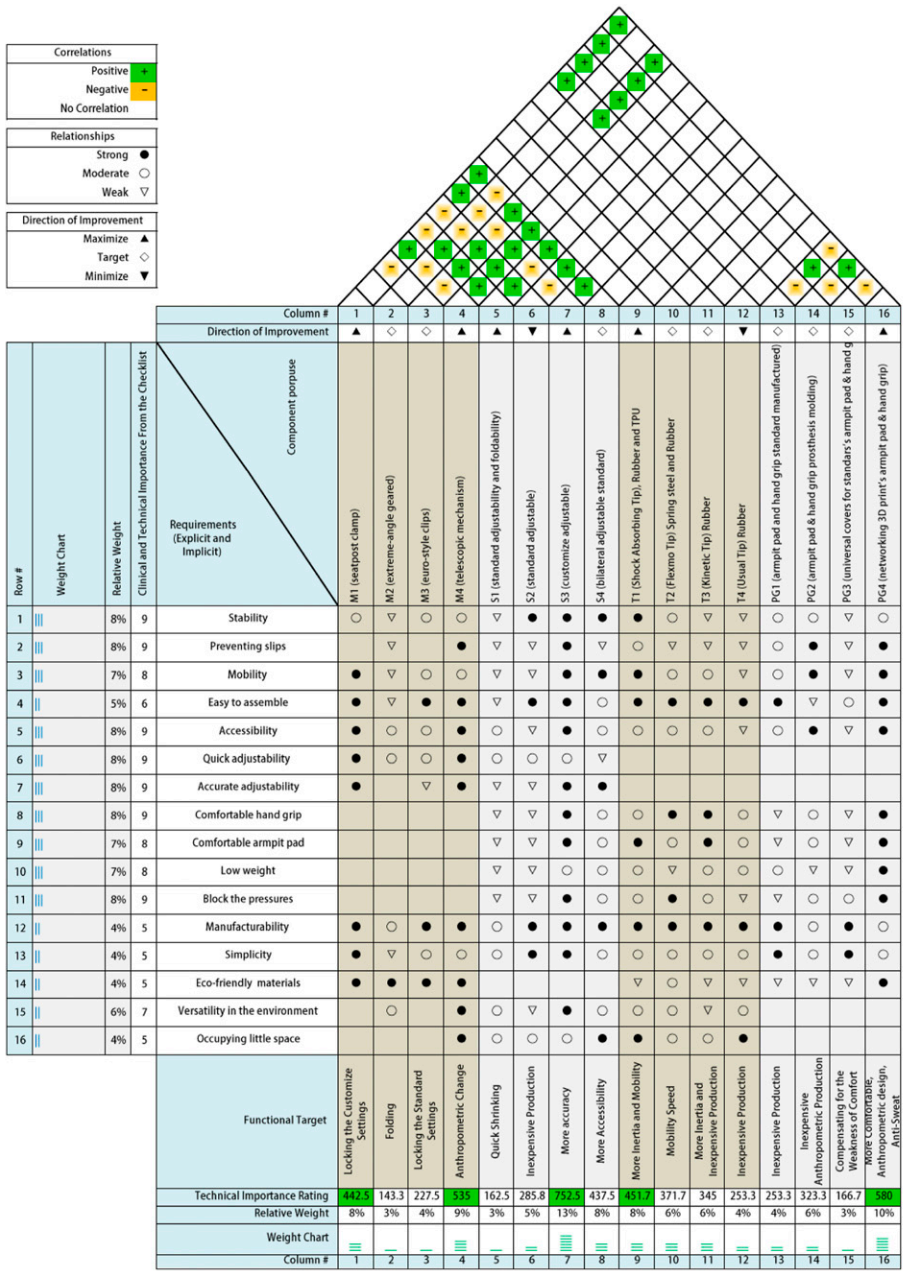


Figure 6. QFD assessment results from the expert panel (The desired table is pre-programmed and contains a specified calculating algorithm. The data collected from experts was inputted individually and ultimately summed up. The components that can be technically compatible with each other have a positive relationship. Parts that are diametrically opposed have a negative relationship. Parts that are not compatible are completely not linked to each other.).

8. The crutch handle should have a diameter of 35–40 mm with a length of roughly 14–16 cm and be made of soft-flexible materials and compatible with palm form.
9. Sweating the hand and armpit is one of the aggravating elements the discomfort while using a crutch. This may be alleviated by modifying the design and materials of the handle and armpit pad.

Since designing a crutch requires considering numerous elements, each one is useful in design and evaluation and has a particular impact coefficient. The checklist presented in Table 3 was established with the participation of the expert panel, and their clinical and technical importance weights are also presented in the House of Quality.

Since there are different items that can influence crutch applicability, to analyze various functions to reach the most reasonable design, it's needed to put ideas together which can be facilitated with the help of a morphology chart (Table 4).

After designing and inserting different ideas into the morphology chart, with the help of the outcome of the checklist that was answered by the expert panel, the idea evaluation has been done in the house of quality to determine the final configuration. This evaluation determines the strategic emphasis based on function and target. Figure 6 demonstrates the results of quality function deployment.

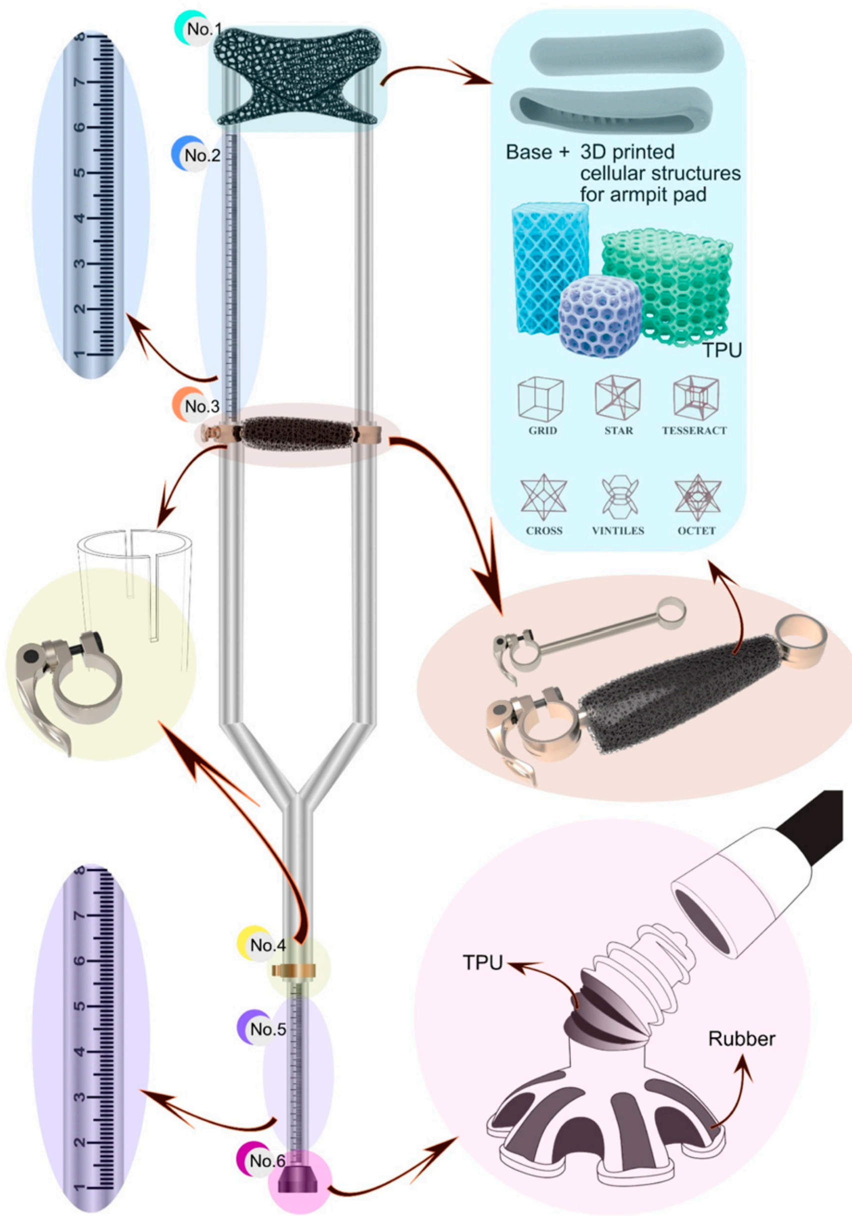


Figure 7. Final configuration.

The expert panel generated the final configuration (M1 + M4 + S3 + T1 + PG4) from the QFD assessment that is illustrated in Figure 7.

DESIGN PROPERTIES

After arranging the final configuration, a few items have been added regarding design development. The engraved symbols to indicate height adjustability are in millimeters, which is around 45 cm from the top and 20 cm from the bottom. Consequently, the dimensions of the overall structure of the suggested product are in the order of 10 + 45 + 45 + 15 + 20 + 20 + 7 = 162. The seat-post clamp facilitates precise adjustment as well as rapid height adjustments. This issue provides orthopedists with greater decision-making flexibility for more precise anthropometric modifications for medical therapies. Further, users may transfer and utilize it in various situations. By adding TPU to a piece of the crutch tip, the required flexibility for crutch stability on slopes and the crutch's inclined vertical axis when ascending up the stairs could be enabled. Besides, applying TPU for constructing 3D prints of handles and armpit pads with varying densities and also diverse cell architectures broadens therapeutic alternatives. The chosen material for armpit pads and handle grips may properly cover the anthropometric issues and effectively reduce the discomfortable perspiration. Figure 8 demonstrates the details of the design. A foldable crutch needs more space versus a compactable design since a compactable structure, due to the ability to get components or parts into each other, doesn't need additional space.

The morphology chart helps us analyze multiple elements simultaneously as parallels. It's evident that by concentrating on constructing one aspect of a crutch, claims may be more confident. However, the trouble here is that it's likely that new assumptions for other difficulties with other portions of the crutch might generate complications in future versions. All the crutches' components impact each other favorably or adversely in the end performance. Table 5 contains details of the selected material.

DESIGN LIMITATIONS AND FUTURE STUDIES

Usually, products developed for the disabled have been evaluated in restricted and distinct studies. Whereas, when we don't consider certain demands simultaneously, we may produce worse issues than the initial ones. By focusing on one answer, we disregard the other difficulties that are vital to the decision-making process. In this scenario, we should at least admit to what defections have to be solved in the future investigation. In the provided design, it's been attempted to eliminate previous crutch sub- structures, which resulted in decreasing the weight of the recommended structure. We also attempted to provide a holistic design with a generic approach. The main constraint in constructing this crutch that requires additional inquiry is children that are different in height, weight, and physical strength. It is also preferable to consider a series of EMG studies after customizing the pads and grips with parametric design and 3D printing to improve ergonomics. Due to different factors that necessitate responding to the user's needs, it will be important to customize the crutch. In this particular case, the use of morphological charts will enable the manufacturers to increase the usability of crutches. Also, for future studies, focusing on the users' needs and classifying people with disabilities at the level of physical problems is useful for reconfiguring each component of a crutch. In addition, a concentration on the material's

Figure 8. Detail design.

Table 5. Material Selection for 3D Printing the Armpit pad and Hand Grip.

Name	Extruder Flex medium Filament (TPU)			
Material Category	Thermoplastic Polyurethane (TPU) TPU is 100% recyclable and biodegradable. The TPU we use is more eco-friendly than most other plastics. It is an advanced material that is much more environmentally friendly than alternatives such as PVC since TPU is recyclable and biodegradable in 3–5 years.			
Description	The Extruder TPU Flex line, which features Extruder TPU Flex in varying degrees of hardness, has been developed mainly for use with industrial machinery.			
General	Property	Min	Max	Unit
	Density	1.15		g/cm³
Mechanical	Hardness, Shore A	98		[-]
	Tear Strength Unnicked	176		kN/m
	Tensile strength	42		MPa
Thermal	Melting point	180	200	°C
	Vicat softening temperature	110		°C
Technological properties	Handling recommendations	Store at room temperature (18–27°C/65–80°F), out of direct heat and sunlight, and in a dry place. When stored correctly, this material has a shelf life of 1 year.		
	Processing Tag	3D Printing		
Applications	Level 1	Level 2	Level 3	
	Automotive			
	Clothing Industry	Footwear		
	Manufacturing	Additive Manufacturing	Fused Filament Fabrication (Fff)	

functionality can have a direct impact on the usability of the crutches, and research on materials is highly recommended.

CONCLUSION

Since the design of a crutch is reliant on many aspects, including technological and infrastructure aspects, this article outlines how, by focusing on technical design elements with the assistance of morphological analysis, we were able to control infrastructure limitations and match the device with usage environment attributes. However, it is strongly recommended from an ethical perspective that the environment be versatile for people with disabilities. There still remain a myriad of issues, such as how well-equipped the urban utilities are, particularly in underdeveloped countries. Accurate and millimetric height adjustments and also developing a crutch tip with flexibility in multiple directions are helpful in supporting ease of use in different environments, which was one of the important results of this design study. Furthermore, the parametric design for 3D printing the armpit pad and handle were innovative concepts that might tackle issues like sweating and assist physicians in providing more effective and pleasant medical treatments. The outcomes of this design investigation are cautiously generalizable.

Supplemental Material

Supplemental material for this article is available online.

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