Anthropometry of the Hand and Product Design

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Abstract:

Statement of the problem: Given the importance of the hand in many tasks requiring the manipulation of objects, the information gathered in this study may help in the development of a human hand anthropometric model that is simple and straightforward to use for all product designers. A set of key anthropometric characteristics that are pertinent to the creation and design of human digital models have been suggested by recent research. Nevertheless, there is a severe absence of the dimensions of available data that allow designers to operate as effectively and efficiently as possible. Designing consumer goods for commercial usage has been incredibly slow when it comes to user anthropometry research. **Objective**: The purpose of this study is to define, characterize, and illustrate hand measurements and their implications and associations for product design. In order to facilitate a better knowledge of hand dimensions and their relationships, the study has also examined the anatomy and structure of the human hand for employing real key measurements and parameters. Therefore, a prevalent study has been dedicated to anthropometric data collection methods covering from traditional to most sophisticated techniques. For convenience and preference, it also creates a link between user and product sizes. Furthermore, it draws implications for design that are particular to user groups, generalizes these implications for a range of goods, and illustrates these implications throughout the product development cycle. **Methodology**: The study employed both analytical descriptive and deductive approach in order to developing a product design criterion based on and implementing hand anthropometry. **Results**: A summary of all the variables linking hand anthropometry to product design and potential future developments in this area concludes the study. Product designers should be able to readily match product interfaces with human capabilities and competencies thanks to the data sets offered and comparisons made.

Keywords:

Hand Anthropometry, Hand Anatomy, Product Design, Photogrammetry, 3D Body Scanning

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1.Introduction

The human body has been a perennial interest to scholars and scientists in many different fields and disciplines. This interest increases even further when the elements and components of the human body are easily and directly measurable in terms of numerical size or shape, which may be related to genetics, sex, race, age, and individual variation, and as such, can be statistically understood. Research purposes differ from academic, industrial, or medico-legal urgencies to more psychological, artistic, professional, and largely, public interest issues in themes and topics such as diet, apparel or residential sizes, parking, and all sorts of working objects inside and outside the home. These concerns, whether materials or pieces, on one side, depend on their size components, their adaptation, and utilization for their functionality acceptance, as well as, on the other side, the choices made by the consumer (Rumbo-Rodríguez et al.2021).

1.1. Background and Significance

That this area of investigation is a large one is indicated by several factors. Physiologically, the hand is a complex organ with intricate bones, nerves, muscles, and skin; considered as an agent in anthropometric terms, the hand shape can vary considerably, taking into consideration that attributes such as sex, dominance, and activity can influence the hand's physical dimensions. Furthermore, unlike the functions of the brain, the functions of the hand can be directly physically measured and quantified. Moreover, manual prehension (the action of grasping or seizing) or manipulation is the single most important factor in the evolutionary development of the hand. Indeed, over 5,000 terms exist to describe the hand in its various anthropometric functions. Determining human skills, as embodied in the hand, can be carried out in many ways, some natural and some artificial. Ethnographers, anthropologists, physiologists, behavioral scientists, artists, engineers and designers have their respective views of the range of human manipulative skills. Furthermore, motion deconstruction and analysis can describe and quantify natural skills of human prehension or manipulation.

The human hand is a versatile organ and a vital part of function for all human beings. Inside a complex physical and cultural environment, it tackles a broad range of biosocial tasks. While understanding of both human abilities and the requirements on designed products can be used to make natural and artificial worlds more coherent and to make sense out of the considerable investment humans have made in shaping their living, working, and recreational environments, the characterization and incorporation of human abilities are often ignored, resulting in poorly performing and seldom used products in extreme cases.

1.2. Scope of the Study and Problem statement

The hand is crucial in various tasks involving object manipulation, and a comprehensive biomechanical model of hand anatomy is needed to understand its function in various scenarios. This model should capture the important morphological features of the human hand. While this paper does not claim to create a specific model, the collected data and knowledge may enhance efforts to establish it. Recent studies have proposed a set of principal anthropometric features that are relevant to the design and fabrication of human digital replicas. Hand measurements are defined and described, and their implications in product design are demonstrated. However, the conclusion is discouraged due to the possibility of low statistical precision when a generalized design criterion is compromised to allow for judgment.

Although the anthropometry of the hand has yet to be fully investigated for all pertinent product design variables, there is enough data that has been established and which may be useful in design. However, it is not ascertained to what degree existing anthropometric data may be applicable. If a relationship between the human hand and other bodily measures can be established, this relationship will show that such data developed for the military and the space program in the USA might be extended to product design.

Product designers and researchers are increasingly exploring the relationship between user and product sizes for usability and preference. This has led to the development of adaptive interfaces using anthropometric data to adjust products' orientation, layout, and control interface to accommodate variations across user age groups. However, research on user anthropometry has been slow in designing consumer products for commercial purposes.

1.3. Objectives:

General Objective:

The purpose of this study is to define, characterize, and illustrate hand measurements and their implications and associations for product design, to facilitate a better knowledge of hand dimensions and their relationships.

Specific Objectives:

The specific objectives of this study include:

- Examining the anatomy and structure of the human hand for employing real key measurements and parameters.
- Reviewing anthropometric data collection methods covering from traditional to most sophisticated techniques, for convenience and preference,
- Creating a link between users and product sizes drawing implications for design that are particular to user groups, generalizing these implications for a range of goods, and illustrating these implications throughout the product development cycle.
- Investigating how anthropometric data of human hands are affected by ages, occupations, ethnic background, and other factors for new consumer products.

2. Definitions and Concepts

The word “anthropometry” is derived from the Greek words “Anthropos” (man) and “Metron” (measure), and means measurement of the human body (Bridger, Robert, 2018). It is also defined as the "study of human measurement and body size", and as “the study of, and collection of data related to, human body dimensions, which allows for a comprehensive physical description of an individual". The term anthropometry is used here to describe the detailed measurement of body dimensions to quantitatively describe the variation of size and shape in any given population for the purpose of product design. Many of the methods used in anthropometry originate from industrial data collection, where very large data sets can be the norm (Thelwell et al.2020). Data acquired through anthropometry is utilized in various scientific pursuits, including but not exclusive to ergonomics (human-machine interface), biomechanics, product design, clothing design, and healthcare (anthropomorphic injury prediction), among others. For these subjects, data can be utilized to create generalized size and shape-scaled 3D computational or physical design models for human operator interfaces. These same data can provide a useful tool for the design and curation of products for populations of any size and categorization, as there are easily acquired data available across dozens of databases. Anthropometric data collection has evolved over time, with new approaches favoring large-scale designs. This allows for rapid dissemination of data for improved product design and better modeling of the human form. With the rise of 3D scanning technology and large-scale database management, anthropology and ergonomics are focusing on new data collection methods, utilizing existing population resources to create large coherent samples for substantial data examination. This adaptability has led to improved product design and better modeling of the human form.

3. Anthropometric Data Collection Methods

The collection of data, particularly in questionnaires and manual measurements, can be a time-consuming task. Conversely, automated measurement systems and computerized data collection have the potential to vastly reduce the data collection times but are still usually not as accurate as direct measurements (Wang et al., 2021). Anthropometric data collection must be both reliable and accurate. To see why, consider the impact of the conclusions drawn from the data. If, for example, data on the percentage of women smaller than some foliage thickness was determined to be 99%, this would suggest that an unacceptably large number of women would be too large to pass through this obstacle, leading perhaps to injury. The analysis would quite properly be accepted, and design changes recommended to minimize the risk of injury to the user population. To ensure that the design (i.e., products and processes) properly considers its relevant human factors, we must know the population of potential users and their anthropometric variations. This being the case, anthropometric databases describing the variation of the various body dimensions of interest throughout the relevant user population are needed in the design process (Ma & Niu, 2021). The strength of any human factors or design solution largely depends on the data at hand, and the data must be relevant to the work at hand.

Methods of collecting anthropometric data can be simply classified as traditional, using methods where linear measurements are taken, and modern, using instruments, tools, and software especially digital technologies. In general, the proximity of the stations or the size of the object should be considered with the desired accuracy of the measurements. Designers should pay the most attention to methods and techniques that are suitable for measuring hand dimensions or are related to measuring hand dimensions (Morgan & Liker, 2020).

Anthropometric studies use a variety of sources of error that can compromise the reliability and validity of the data. It is important to obtain accurate and reliable measurements throughout the anthropometric research. Most researchers would claim that a single error could be the difference between acceptance or rejection of the hypothesis of an anthropometric study with design and vice versa. A factor that creates most of the errors is poor research design. Thus, it is very important to make extremely accurate measurements to successfully realize the anthropometric measure and to match the measurement with the purpose of purchase. Nowadays, the recommended solution to this problem is through the use of instruments or tools and biometric technical software applied in the field of anthropometric measurements (Reiman et al.2021) (Taifa et al.2021).

3.1. Traditional Data Collection Methods

To historically perceive the modern developments in anthropometric data collection, it is important to notice what has been done in ancient times. After inventing the metric system in France by the French Academy of Sciences in 1791, an important event took place in health science as well. It was Frenzel who, in 1869, published his book in which he described the height and weight of 2553 individuals. Later on, many researchers collected data on the height, weight, and body build of their male students, and it seemed like people all over the world started to show their interest in studying the subject. Later on, at the international level, anthropometric data were collected. There are studies conducted by Höfer, Erdos, and others, who even published a number of books on the topic. Therefore, it can be said that anthropometric data collection is viewed as nearly a two-century-old tradition (Martin, 2023).

3.1.1 Direct Measurements

The human body's dimensions are measured either directly or indirectly to provide precise data. Setting up regular landmarks on the subject's body and developing rules (depending on body type, age, and sex) for taking measures are both difficult steps in the process of obtaining direct measurements. A range of anthropometric tools are typically used for direct body size measurements, such as spreading calipers (which are useful for measuring skinfolds, hand lengths, hand breadths, finger lengths, and breadths, among other things) and sliding calipers (which are typically used for measuring larger body linear segments like arms and legs, among other things). Any body part's circumference (girth) can be measured using tailor tapes, steel tape, or flexible steel tape. Some use stadiometers, anthropometric rods and rulers also for similar linear measurement especially body heights figure (1 to 4)

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Figure (1) Conventional spreading caliper

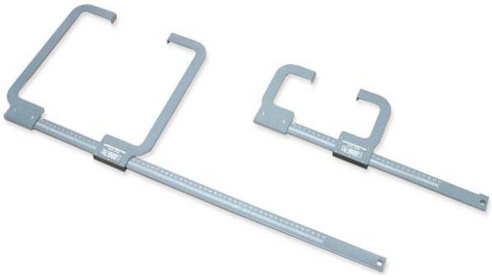


figure (2) large Lafayette anthropometer

Figure (3) Digital Vernier caliper

Figure (4) Stadiometers for measuring body heights

Figure (5) Standard and Retractable Measuring Tapes

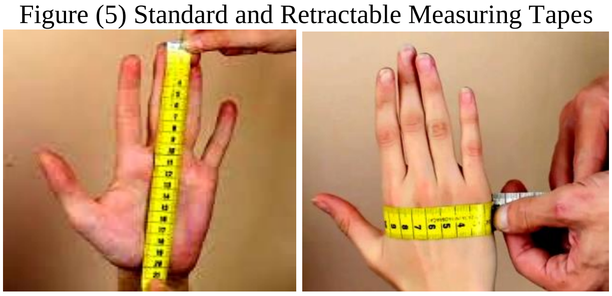


Figure (6) measuring hand length and palm circumference using tape

Procedures for taking direct measurements vary depending on the anatomical area being examined and the type of measurement being taken, though all measurements can be used in conjunction with each other to enhance accuracy (Seifert, 2020) (Uriel et al.2022).

Direct measurements of anthropometric variables have been established, and tools have been created to provide precise and reliable results. These measurements include hand lengths, depths and breadths. Additionally, for many of the anatomical parameters, there may be established guidelines for how to carry them out on specific people, in terms of age group within the particular population (child, adult, or elderly person) and gender.

The inclusion of percentile values in survey results allows for a comprehensive understanding of the population's body variations. It is worth noting that these guidelines cater to both males and females, ensuring that the obtained body measurements are representative of the selected population. To gather these body measurements accurately, direct measurements are taken on individuals sitting or standing in an upright position. By considering factors such as body type, age, and gender, guidelines can be developed to ensure optimal comfort and space design for a diverse population (Padilla et al., 2021).

3.1.2. Indirect Measurements

Indirect body size measurements use external fixtures and equipment at the person's disposal. It includes photographs measuring the length and girth of body parts using natural units (e.g., penne, small paper clips). A subset of indirect body size measurement is the digit ratio (2nd, 3rd finger length) measurement, which is a hot topic in human evolution studies currently (Cotes, 2020).

Sociocultural factors, such as modesty, make many women and some men uncomfortable with traditional direct methods of body measurement. Many Egyptian women reject that their hands are being held or even touched by a man. Because of this, many researchers use a variety of indirect measurements to estimate body measurements without having to directly assess the body. Two of the most widely known indirect methods are those that estimate fat based on body density and anthropometry, and the methods that estimate total body water based on height, weight, and simple measurements such as waist and wrist girth (Dimitrijevic et al.2021). Measuring hand span is ann example of using a ruler or paper grid or even plain paper figures (7 to 9).

Figure (7) measuring hand span using a ruler

Figure (8) measuring by tracing hand on a plain paper

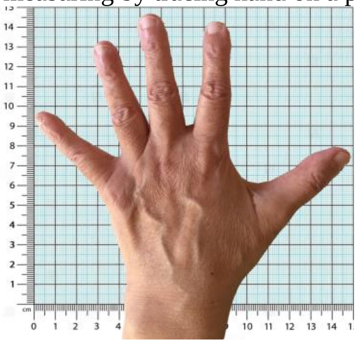


Figure (9) measurement of hand using a grid paper

3.2. Contemporary Technologies

In contemporary contexts, there are advanced technologies that are used in anthropometric data collection. First among these is 3D body scanning, which is a diverse data collection method that has the potential to capture the shape of the body or particular body parts. Most 3D scanning processes also include the capacity to measure girth and length parameters in addition to shape information. It can be a generic process, such as hydrostatic weighing, allowing it to be employed in varied applications. The measurement also occurs in a three-dimensional manner allowing shape to be recorded and analyzed. The three-dimensional nature of this method can simplify the acquisition and analysis of body shape and allow for detailed evaluation of non-skin anthropometric dimensions such as the foot (Saaludin et al.2022).

3.2.1. 3D Body Scanning

Affordable, quick and hands-free 3D scanning techniques are now widely utilized because of a surge in technological innovation in the form of consumer 3D sensors. Consequently, 3D fine data acquisition is gradually replacing manual measurements. Compared to traditional direct or indirect manual measurements, 3D scanning technologies have the capability of capturing comprehensive body measurements. They provide the full shape of the body and details of any specific body part, thus allowing the generation of an accurate 3D model. Anatomical landmarks and measurements can be easily extracted from these models for different anthropometric applications, such as scan matching, morphing, monitoring, etc., as well as the principal benefits of creating individual body scans that have numerous applications. The novel software development and increased availability of 3D scanning equipment enable tailored clothing measurements, personalized size charts, and improved size prediction; hence many commercial companies are applying 3D body scanning widely (Smith et al. 2022).

The applications of 3D body scanning technology include the medical field in terms of reconstructive surgery, ergonomic and anthropometric measurements for the design of tools or protective gear, in the fashion industry for clothing fit assessment, and virtual shopping assignments, within the sports industry to create customized equipment and improve performance, and for the virtual tryouts of clothes. However, given the many applications and demands of 3D scanning devices, and like every other assessment, 3D body scanning has some issues that may form obstacles, such as scan and measurement quality, technological concerns, low data precision and accuracy, security, and expenses that can restrict a wide range of scans (Javaid et al., 2021). A large number of studies use 3d scanning for capturing and measuring samples of human hand. The following is only 5 of those surveys.

A study by (John-John Cabibihan & Aya Gaballa, 2021) Figure (10), proved that indirect hand measurement improved remote accessibility and non-contact acquisition methods, especially for custom products like prostheses or gloves. However, acquiring these measurements can be challenging due to specific specifications and obstructions in 3D scans.

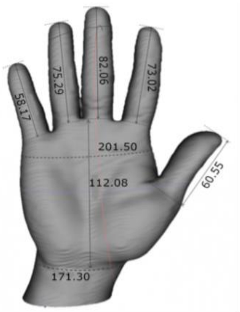
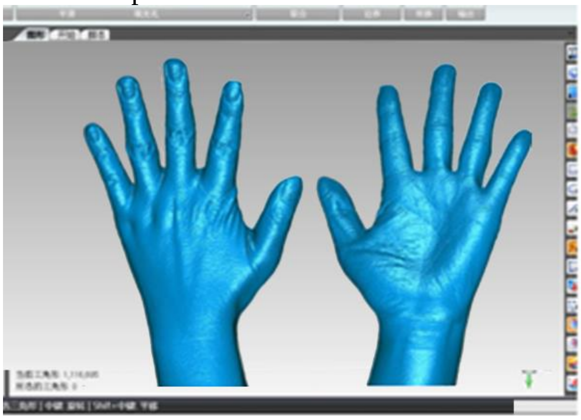


Figure (10) A 3d scan of hand by John-John C. & Aya G., 2021)

Another study by (Fang Y., et al. (2020) identified an efficient 3D imaging method comparing three methods for measuring a plaster hand model: direct measurement (DM), 3D CT scanning (CT scanning), and Gemini 3D structured light scanning (SL scanning). 24 identifiable landmarks were chosen, with a series of linear measurements based on these landmarks for comparative measurements figure (11).

In the study of (Linsey Griffin, et al. 2019), repeatable 3D scanning protocol was created for large anthropometric studies, minimizing user error, increasing speed and efficiency, and enabling collaboration across multiple sites. It involved testing landmark placements and tools, as well as stability/scanning platforms for the hand and foot. The testing led to the creation of a repeatable scanning protocol for future anthropometric studies across multiple sites.



Figur (11) An image resulting from the study of Fang Y., et al.

The study of (Szkudlarek, J. et al. 2023), created a 3D Hand Scanning Methodology for Determining Protective Glove Dimensional Allowances to measure fit of personal protective equipment (PPE) and for determining the safe and comfortable human interaction with tools and machines, The obtained results were useful for designers, and especially for designing keys on panels and LCD touch displays and monitors integrated with machines.

3.2.3. Photogrammetry

Photogrammetry is a generic, non-contact, portable technology used to measure an individual's or body part's shape during fieldwork and national surveys. It is frequently used in conjunction with 3D scanning for whole body or body component shape measurement since it captures the three-dimensional aspect of body measurement. Inertial measurement units (IMUs) and goniometers are examples of wearable technology that is increasingly being used to secure data from adults and children that are free-living (Stark et al., 2022; Pal et al., 2024).

Photogrammetry produces images, maps, drawings, models, and three-dimensional information on the properties of surfaces and solid objects. It uses photographs and medical imaging to measure distances between points on objects' surfaces, allowing for triangulation and calibration of spatial coded measurements. Commercial photogrammetric solutions for anthropometry include Sensory Markers and Photomodelers (Pepe & Domenica, 2020). In comparison to MRI, photogrammetry is less expensive and provides a great deal of precise spatial data as well as joint locations. Nevertheless, there are certain restrictions, such as the requirement for a static, neutral, relaxed referred zero posture and the possibility of movement restrictions. Even with these drawbacks, photogrammetry is still a useful technique to track dynamic changes when the subject is wearing markers on their body. (Ferrari et al.2021) . In figure (12) the process of Photogrammetry of a hand and the results, Figure (13), in both formats, scalled and textured (Tuong N. V., Natasa N., 2024)

Figure (12) Photogrametry for anthropometry

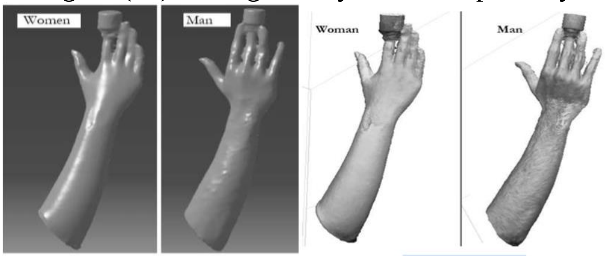


Figure (13) Scaled Model and Textured Model

3.2.4. Wearable Sensors

Wearable technology has revolutionized the collection of detailed quantitative anthropometric data, allowing studies to gather data from a more free-living environment over extended periods. This allows for a more realistic assessment of daily activity, documenting anthropometry in varying dynamics. Advances in technology have enabled the use of miniaturized and low-energy sensors, interpreting dynamic human body multi-segmented data to examine movements, joint angles, whole segment displacement, and environmental measurements. Sensors used include location-based GPS, accelerometers, gyroscopes, heart rate monitors, thermal imaging cameras, Galvanic Skin Response (GSR), and Pressure Sensing mats (Gupta, 2020) (Shan, 2023) .

Figure (14) Wearable sensors worn by volunteers.

Wearable sensor technology measures movement and acceleration using single or multi-axial accelerometers; it also collects data on temperature, pressure, image analysis, GPS, gyroscopes, and magnetometers. Numerous sectors, including anthropometrics, sports, exercise science, medicine, rehabilitation, and coaching elite sports, are served by these methods for data collection. Wearable sensor technology has a lot of promise for supportive sports injury wearable technology since it is continuous and unobtrusive. Accurately co-locating sensors with appropriate components for data gathering or with bio-markers within the human body presents obstacles, nevertheless. Future advancements in wearable sensor technology will bring about innovations in sensor location and secure attachment, as well as improvements in sensor shrinking and novel sensor creation. (Vijayan et al.2021).

4. Technological Advancements

The advent of advanced technologies and developments in scanning devices, such as 3D scanners and laser scanning devices, has paved the way to increase the quality of products. The ability to capture both complex and easy-to-miss user interactions with a large number of products became a priority, and the need for high-quality capture methods became an ever more rapidly advancing development. In bounding to 3D anthropometric data, the use of 3D software for ergonomic research has gone from non-extensive, as was the case only a decade or so ago, to a broad view in design as a way to personalize products and environments that are more optimal in terms of ergonomics and user-product interaction, thus product usability. The advancements in technology – particularly in scanning, CAD, and the capabilities of the human body – have allowed for the capture of both hands, heads, torso, feet, and ear. As they discovered that traditional methods always lead to poor repeatability and large variances, particularly when measurements are taken of different people and that commercial 3D scanner to create a 3D body part model can be very costly They proposed a low cost 3D foot scanner system by integrating available image capture technology such as the Kinect®, appropriate 3D scanning software and a foot scanner rig. They managed to get better results by merging these advanced, but low cost, equipment into a successful experience (Bruno et al.2020) (Kermavnar et al., 2021).

New technology, as well as advancements on previous software, has created new capabilities and opportunities for researchers to capture and model anthropometry; both of the human body – such as hand anthropometry – and the products/devices for which the bodies are interacting. New hardware comes with many advancements, which have been detailed above, but for example, increases both the efficiency of capturing and modelling anthropometry within software. The advancements made in digital scanning technologies and the abilities of such software have enabled the capture of extensive anthropometry for the human hand. With its relatively small volume and accessibility around other body and product components, it has been one of the first anthropometric measurements captured in extensive amount of anthropometric landmarks in unity, followed by the ear (Ashdown, 2020) (Bartol et al., 2021) .

In a study by (N. Kaashki, et al, 2022), showed that advancements in 3D scanning technologies have enabled the acquisition of hand geometry as a three-dimensional point cloud, crucial for applications in medical sciences, fashion, and AR/VR. Traditional methods for hand measurement extraction require manual intervention and are time-consuming. The paper proposed the first deep neural network for automatic hand measurement extraction from a single 3D scan (H-Net). The network follows an encoder-decoder architecture design, taking a point cloud of the hand as input and outputting the reconstructed hand mesh and corresponding measurement values. Experimental results show that the proposed method outperforms state-of-the-art methods in terms of accuracy and speed.

5. The Human Hand structure and anatomy

5.1. Structure of the Hand

There are 27 bones in the hand, which are divided into the carpus, metacarpus, and digits. It is a complicated system. The carpus is a group of eight asymmetrically formed bones that are found on the forearm. The five long, tubular bone cylinders that make up the metacarpus—which houses the palm—are joined to the wrist bones by means of connections. With the exception of the thumb, which has only two phalanges, the hand also has fourteen long, thin finger phalanges. The phalanges of each finger have three bones each; however, the thumb has just two phalanges—one of which is the metacarpal (Kivell et al., 2020).

The human hand is capable of many different actions, including gripping, holding, turning a key, typing, lifting, and moving. It is the best and most adaptable tool that development and research have not been able to create or duplicate. The hands are the main tools utilized for several tasks such as part preparation and object manipulation. The fingers are specifically utilized anytime necessary handling is required for manipulation or function. The word "handling" as it relates to mechanical function and manufacturing preparation is emphasized. The hand's abilities determine how complicated its structure is, but we're still not entirely sure why agility and structure work so well together. The functions of the hand can be grouped. These include size and shape of the human hand, rank of reach of the entire hand, grip strengths and forces, palmar width measurements and patterns, pinch strengths and forces.

5.2. Anatomy and Function

The human body has two major and four minor joints per finger, which connect the metacarpal and finger bones through middle and distal joints. The big palmar and dorsal articulations are the most significant articulation points because they produce phalangotubs that are used to tighten fingers. The size of the wrist, index, and middle and index fingers determines the hand's proportional length, whereas the location, thickness, and length of each finger component determines the thickness and volume of the surrounding finger. Finger components' anatomical alignment is determined by their shape (Dunai et al., 2020). The function of the hand reveals the physical makeup of the human hand as well as the intricate interactions between its many interior parts. At every level, the hand is beautifully formed for its role in us as tool users and makers. This section describes in some detail both the external format of the hand and an analysis of its functional components. It is clear that these factors should have particular implications within engineering design specific to hand tools and handheld products.

The upper limb's structure from the elbow down makes up the hand's structure. In the anatomical posture, the wrist is flexed forward at an obtuse angle of approximately 20° to 30°, and the five fingers—aside from the thumb—are extended to form a fan shape with the palm of the hand facing forward. The hand is perfectly formed for grasping when it is in this position, with the thumb adducted (Kashef et al., 2020). Because of the unique relationship between the carpal bones and the proximal epiphyses of the metacarpals, the palmar surface of the hand is concave from side to side, allowing the fingers to extend and flex during gripping. as the long tendons of the extrinsic muscles run over the convex anterior surfaces of the carpal bones. The concavity of the palm is largely filled by the softness of the hypothenar and the ball of the thumb. The fingers are light in structure and have no muscles in them (Capsi-Morales et al.2020). Their flexion and extension movements are produced by the action of extra digital tendons that pass through the fingers and are motorized by the muscles of the forearm, which have their motor nerves lying in the forearm. Such tendons are connected above the joints in the hand by tough fibrous sheaths. These sheaths prevent significant bowstringing of the tendon between the flexor retinaculum and the long bones of the fingers.

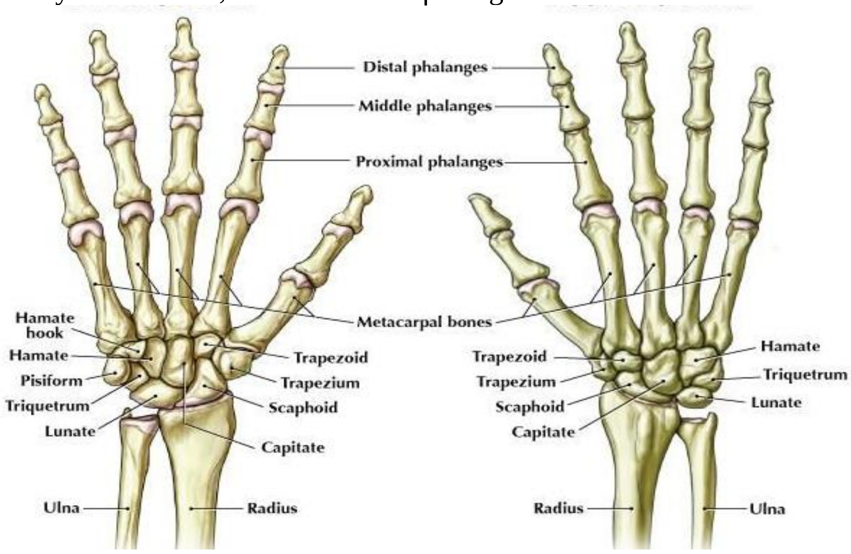


Figure (1) Bones of the human hand and wrist (Anterior and Posterior Views)

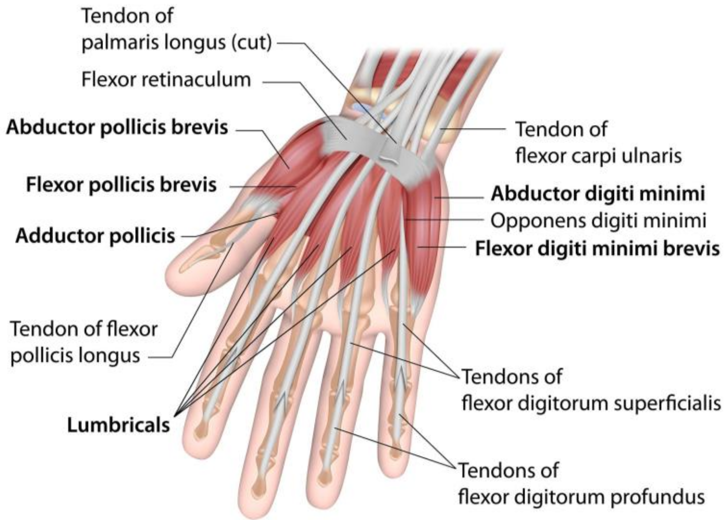


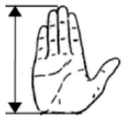
Figure (2) Muscles of the human hand and wrist (Palmar Superficial view)

5.3. Key Measurements of the Hand

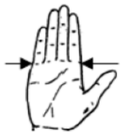
Without hands, it is impossible to hold objects or complete most daily tasks. In addition to the sole requirement that a hand must physically fit inside a product, sometimes even harder to address is how a person's hand, which integrates varied hand dimensions, will use a tool and then interact with the product that the hand generally holds. Hand anthropometry directly relates to both product design and ergonomics. The larger the variance in a hand dimension, the more accommodation in product design. Measurements should consider the term "comfort zone", or the overall range of hand dimensions within which the majority of a human population exists. Techniques using hand models moldable from feature research data must be developed and used for testing a larger range of concepts during the concept down-selects stage of each new product design (Reiman et al.2021).

5-4 Definition of measurements:

Hand length: Subject's right hand was extended, palm up, with the bar of the sliding caliper parallel to the long axis of hand. The distance from the wrist crease baseline to tip of longest finger was measured.



Hand Breadth: Subject's right hand was extended, palm down, thumb held away from the fingers. With the bar of the sliding caliper lying across the back of his hand. The hand breadth between metacarpal-phalangeal Joints II and V was measured.



Hand Girth; Metacarpal: Subject's right hand was extended, palm down, thumb held away from the fingers, the hand girth was measured with the measuring tape passing over metacarpal-phalangeal Joints II and V.

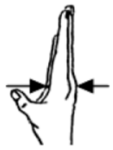
Hand Girth; Metacarpal (Min) Subject extended and narrowed his right hand as much as possible. With the tape passing over metacarpal phalangeal Joints II and V, the hand girth was measured.

Hand Girth; Fingertips Even: Subject tapped his five fingertips even on **a** flat surface. The girth of the hand around midpoints of the proximal phalanges of all five digits was measured.

Fist Girth: Subject made a tight fist with his thumb tucked against the middle phalanges of digits II and III. The fist girth was measured with the tap passing over all metacarpal phalangeal joints.

Wrist Girth: Subject's right hand was extended. With the tape perpendicular to the long axis of the forearm, the girth of the wrist at the wrist crease level was measured.

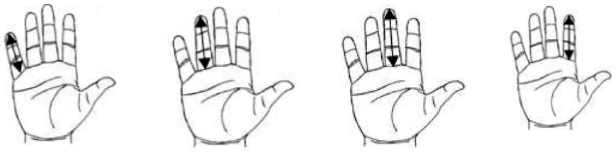
Hand Thickness (Metacarpal III): Subject's right hand was extended. The maximum thickness of the metacarpal-phalangeal joint of the digit III was measured with the sliding caliper.



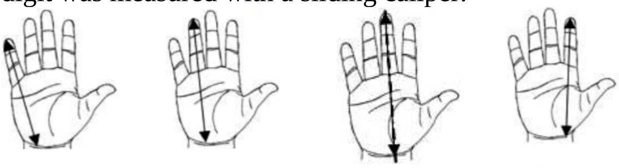
Hand Depth (Thenar Pad): Subject's right hand is extended with the thumb lying adjacent to the volar surface of the digit II. The maximum depth from the volar side of the thenar pad to the dorsal surface of the hand was measured with a sliding caliper.

Wrist Breadth: Subject's right hand and wrist lie on a flat board. The breadth of the wrist at the level of the wrist crease baseline was measured with a sliding caliper.

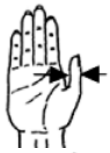
Digit 1,2,3.4 and 5 Length: Subject's hand was extended. The distance along the axis of the specified digit from the midpoint of the digit to the level of hand crotch was measured.

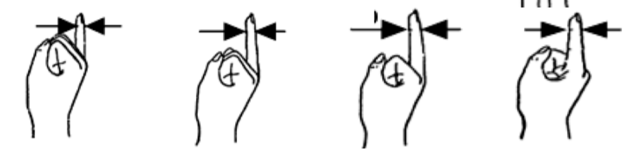


Digit 1,2,3,4 and 5 Height: Subject's hand extended with hand and wrist lying on a measuring board, the perpendicular distance from the wrist crease baseline to the midpoint of the tip of the specified digit was measured with a sliding caliper.



Digit 1,2,3,4 and 5 Depth: Subject's hand was extended. The maximum depth of the interphalangeal joint of the specified digit was measured with a sliding caliper.





Digit 1,2,3,4 and 5 Breadth: Subject's hand was extended. The maximum breadth of the interphalangeal joint of the specified digit was measured with a sliding c aliper.

A set of 30 hand dimensions was selected to reflect the parts of the hand frequently involved in the use of controls. This selection was based upon; the expected tolerance of subjects, team size, time and budget constraint, and finally the adequacy of the measurement on its own to provide a complete and consistent set of data and also to enable comparisons with similar surveys on other populations.

Tables 1 and 2 show the statistical analysis of data hand dimensions of a sample of Female and Male Egyptians (Moustafa A. 2016) with a comparison of both sub-samples (Female and Male illustrating mean, Standard Deviation and most practical percentile values in design). Table 3 compares female and male results showing the significant differences of both. Table 4 compares the results the Egyptian Female data with three other populations, American, British, and Jordanians.

Table (1) Mean, Standard Deviation and Percentiles values of the Egyptian Female Hand Dimensions

	Mean	SD	5th	10th	25th	75th	90th	95th
1. Hand length:	17.33	0.87	15.89	16.22	16.75	17.91	18.44	18.77
2. Hand Breadth:	8.15	0.38	7.52	7.66	7.90	8.40	8.64	8.78
3. Hand girth; Metacarpal:	18.15	0.94	16.60	16.95	17.52	18.78	19.35	19.70
4. Hand Girth; Metacarpal Min:	20.71	0.99	19.08	19.44	20.05	21.37	21.98	22.34
5. Hand Girth; Fingertips Even:	21.83	1.10	20.02	20.42	21.09	22.57	23.24	23.65
6. Fist Girth:	23.99	1.45	21.60	22.13	23.02	24.96	25.85	26.38
7. Wrist Girth:	14.83	1.20	12.85	13.29	14.03	15.63	16.37	16.81
8. Hand Thickness (Metacarpal III):	2.96	0.18	2.66	2.73	2.84	3.08	3.19	3.26
9. Hand Depth (Thenar Pad):	4.91	0.42	4.22	4.37	4.63	5.19	5.45	5.60
10. Wrist Breadth:	5.82	0.35	5.24	5.37	5.59	6.05	6.27	6.40
11. Digit I Length:	5.18	0.29	4.70	4.81	4.99	5.37	5.55	5.66
12. Height:	8.39	0.88	6.94	7.26	7.80	8.98	9.52	9.84
13. Depth:	1.64	0.14	1.41	1.46	1.55	1.73	1.82	1.87
14. Breadth:	1.85	0.13	1.64	1.68	1.76	1.94	2.02	2.06
15. Digit 2 Length:	6.66	0.60	5.67	5.89	6.26	7.06	7.43	7.65
16. Height:	15.86	0.94	14.31	14.66	15.23	16.49	17.06	17.41
17. Depth:	1.28	0.09	1.13	1.16	1.22	1.34	1.40	1.43
18. Breadth:	1.49	0.11	1.31	1.35	1.42	1.56	1.63	1.67
19. Digit 3 Length:	7.52	0.54	6.63	6.83	7.16	7.88	8.21	8.41
20. Height:	16.15	0.88	14.70	15.02	15.56	16.74	17.28	17.60
21. Depth:	1.57	0.10	1.41	1.44	1.50	1.64	1.70	1.74
22. Breadth:	1.68	0.15	1.43	1.49	1.58	1.78	1.87	1.93
23. Digit 4 Length:	7.07	0.61	6.06	6.29	6.66	7.48	7.85	8.08
24. Height:	15.99	0.89	14.52	14.85	15.39	16.59	17.13	17.46
25. Depth:	1.82	0.15	1.57	1.63	1.72	1.92	2.01	2.07
26. Breadth:	1.67	0.13	1.46	1.50	1.58	1.76	1.84	1.88
27. Digit 5 Length:	5.30	0.39	4.66	4.80	5.04	5.56	5.80	5.94
28. Height:	12.58	0.92	11.06	11.40	11.96	13.20	13.76	14.10
29. Depth:	1.19	0.09	1.04	1.07	1.13	1.25	1.31	1.34
30. Breadth:	1.30	0.09	1.15	1.18	1.24	1.36	1.42	1.45

Table (2) Mean, Standard Deviation and Percentiles values of the Egyptian male Hand Dimensions

	Mean	SD	5th	10th	25th	75th	90th	95th
1. Hand length:	19.17	2.22	15.51	16.33	17.68	20.66	22.01	22.83
2. Hand Breadth:	8.52	1.07	6.75	7.15	7.80	9.24	9.89	10.29
3. Hand girth; Metacarpal:	19.06	0.36	18.46	18.60	18.82	19.30	19.52	19.65
4. Hand Girth; Metacarpal Min:	21.75	0.69	20.61	20.86	21.28	22.21	22.63	22.88
5. Hand Girth; Fingertips Even:	22.92	1.63	20.23	20.84	21.83	24.01	25.01	25.61
6. Fist Girth:	25.19	0.67	24.09	24.33	24.74	25.64	26.05	26.29
7. Wrist Girth:	15.57	0.74	14.34	14.62	15.07	16.07	16.52	16.80
8. Hand Thickness (Metacarpal III):	3.28	0.55	2.37	2.58	2.91	3.65	3.98	4.19
9. Hand Depth (Thenar Pad):	5.75	0.63	4.71	4.94	5.33	6.17	6.56	6.79
10. Wrist Breadth:	6.79	0.48	6.00	6.18	6.47	7.11	7.40	7.58
11. Digit I Length:	6.53	0.58	5.57	5.79	6.14	6.92	7.27	7.49
12. Height:	8.81	0.18	8.51	8.57	8.69	8.93	9.05	9.11
13. Depth:	1.72	0.14	1.49	1.54	1.63	1.82	1.90	1.95
14. Breadth:	1.94	0.13	1.73	1.78	1.86	2.03	2.11	2.15
15. Digit 2 Length:	7.72	0.64	6.66	6.90	7.29	8.15	8.54	8.78
16. Height:	16.18	0.75	14.94	15.22	15.67	16.68	17.14	17.42
17. Depth:	1.31	0.11	1.12	1.16	1.23	1.38	1.45	1.49
18. Breadth:	1.52	0.06	1.42	1.44	1.48	1.56	1.60	1.62
19. Digit 3 Length:	8.14	0.66	7.05	7.30	7.70	8.58	8.98	9.23
20. Height:	16.47	0.29	16.00	16.10	16.28	16.67	16.84	16.95

21. Depth:	1.92	0.22	1.56	1.64	1.77	2.07	2.20	2.28
22. Breadth:	2.09	0.43	1.38	1.54	1.80	2.38	2.64	2.80
23. Digit 4 Length:	7.60	0.58	6.64	6.86	7.21	7.99	8.34	8.56
24. Height:	16.31	0.48	15.52	15.70	15.99	16.63	16.92	17.10
25. Depth:	1.86	0.01	1.84	1.85	1.85	1.86	1.87	1.87
26. Breadth:	1.70	0.17	1.42	1.49	1.59	1.82	1.92	1.98
27. Digit 5 Length:	5.41	0.43	4.70	4.86	5.12	5.69	5.96	6.12
28. Height:	12.83	0.67	11.72	11.97	12.38	13.28	13.69	13.94
29. Depth:	1.30	0.09	1.15	1.18	1.24	1.36	1.42	1.45
30. Breadth:	1.33	0.11	1.14	1.19	1.25	1.40	1.47	1.51

Table (3) A comparison between Male and Female Samples

	Egyptian Females		Egyptian Males	
	Mean	SD	Mean	SD
1. Hand length:	17.33	0.87	19.17	2.22
2. Hand Breadth:	8.15	0.38	8.52	1.07
3. Hand girth; Metacarpal:	18.15	0.94	19.06	0.36
4. Hand Girth; Metacarpal Min:	20.71	0.99	21.75	0.69
5. Hand Girth; Fingertips Even:	21.83	1.10	22.92	1.63
6. Fist Girth:	23.99	1.45	25.19	0.67
7. Wrist Girth:	14.83	1.20	15.57	0.74
8. Hand Thickness (Metacarpal III):	2.96	0.18	3.28	0.55
9. Hand Depth (Thenar Pad):	4.91	0.42	5.75	0.63
10. Wrist Breadth:	5.82	0.35	6.79	0.48
11. Digit I Length:	5.18	0.29	6.53	0.58
12. Height:	8.39	0.88	8.81	0.18
13. Depth:	1.64	0.14	1.72	0.14
14. Breadth:	1.85	0.13	1.94	0.13
15. Digit 2 Length:	6.66	0.60	7.72	0.64
16. Height:	15.86	0.94	16.18	0.75
17. Depth:	1.28	0.09	1.31	0.11
18. Breadth:	1.49	0.11	1.52	0.06
19. Digit 3 Length:	7.52	0.54	8.14	0.66
20. Height:	16.15	0.88	16.47	0.29
21. Depth:	1.57	0.10	1.92	0.22
22. Breadth:	1.68	0.15	2.09	0.43
23. Digit 4 Length:	7.07	0.61	7.60	0.58
24. Height:	15.99	0.89	16.31	0.48
25. Depth:	1.82	0.15	1.86	0.01
26. Breadth:	1.67	0.13	1.70	0.17
27. Digit 5 Length:	5.30	0.39	5.41	0.43
28. Height:	12.58	0.92	12.83	0.67
29. Depth:	1.19	0.09	1.30	0.09
30. Breadth:	1.30	0.09	1.33	0.11

Table (4) Comparison between Egyptian, American, British, and Joednian Female hand dimensions

	Egyptian Moustafa A. W. (2016)		American Thomas. Greiner (1991),		British Matthew S., et al (2008).		Jordanian (Mandahawi, et al.2008)		Bangladeshi (Sheik N., 2009)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1. Hand length:	17.33	0.87	17.93	0.86	17.8	1.5	17.12	0.74	16.76	1.15
2. Hand Breadth:	8.15	0.38	7.71	0.38	8.45	0.75	9.39	0.56	7.30	0.38
3. Hand girth; Metacarpal:	18.15	0.94	18.71	0.83						
4. Hand Girth; Metacarpal Min:	20.71	0.99	21.46	1.23						
5. Hand Girth; Fingertips Even:	21.83	1.17	22.60	1.18						
6. Fist Girth:	23.99	1.45	24.83	1.31	24.43	1.21				
7. Wrist Girth:	14.83	1.20	14.98	0.71	15.01	0.42				
8. Hand Thickness (Metacarpal III):	2.96	0.18	2.76	0.19	2.64	0.29			2.77	0.37
9. Hand Depth (Thenar Pad):	4.91	0.42	5.17	0.39	4.05	0.49			4.20	0.27
10. Wrist Breadth:	5.82	0.35	5.83	0.33	5.91	0.55				
11. Digit I Length:	5.18	0.29	5.37	0.44						
12. Height:	8.39	0.88	8.64	0.84						
13. Depth:	1.64	0.14	1.66	0.12						
14. Breadth:	1.85	0.13	1.9	0.12						
15. Digit 2 Length:	6.66	0.6	6.9	0.52	6.69	0.5				
16. Height:	15.86	0.94	16.43	0.92						
17. Depth:	1.28	0.09	1.28	0.09						

18. Breadth:	1.49	0.11	1.54	0.10	1.52	0.09				
19. Digit 3 Length:	7.52	0.54	7.79	0.51	7.78	0.53	7.51	03.60	4.57	0.41
20. Height:	16.15	0.88	17.63	0.92						
21. Depth:	1.57	0.10	1.64	0.09			1.33	02.10	1.56	0.17
22. Breadth:	1.68	0.15	1.70	0.12	1.53	0.13	2.03	02.40	1.07	0.14
23. Digit 4 Length:	7.07	0.61	7.31	0.52	7.28	0.50				
24. Height:	15.99	0.89	16.36	0.88						
25. Depth:	1.82	0.15	1.57	0.11						
26. Breadth:	1.67	0.13	1.69	0.1	1.66	0.12				
27. Digit 5 Length:	5.3	0.39	5.46	0.44	5.69	0.44	5.66	04.60	1.07	0.10
28. Height:	12.58	0.92	13	0.89						
29. Depth:	1.19	0.09	1.13	0.08	0.90	0.10	15.01	02.00	1.30	0.13
30. Breadth:	1.3	0.09	1.31	0.09	1.06	0.11	1.69	02.50	0.93	0.12

6. Case Studies:

This section corresponds to an example mentioned in the introduction about some products that have been improved thanks to the incorporation of anthropometric data, specifically hand dimensions, of the target population. In these studies, this paper outlines some case studies where the application of anthropometric principles in the design of everyday products has led to significant ergonomic improvements. Case studies or examples that apply anthropometry and visualization techniques to product design tasks are reviewed. These studies suggest that the principles offered by our work will provide conceptual starting points for more successful industrial designs that are fully responsive to the shape and range of the human hand. Most of the work presented is at the conceptual level (Moran & Carroll, 2020), (Cross, 2021).

Case Study 1:

This case was conducted as part of a final-year module in Product Design. The client, an amputee, specified a robotic concept which involved the use of a lightweight and functional thumb to enable a whole hand grip. Throughout the design process, the technology was driven by the anthropometric data of the hand, while the ergonomic aspects were driven by the anthropometric characteristics of the end user combined with performance and material requirements (Kaewdok et al.2020).

Case Study 2:

Mankind has moved into an information-driven society due to the revolution of information-driven technology such as touch interaction Digital Reading Devices (DRDs). Digital reading devices enhance reading experiences, as they are more thoughtful to humans. To influence this society to buy into new technology, product characteristics should be influenced – such characteristics include design. This case study applies anthropometry defining the measurements of the hand, its primary functions, and ethnocentrism – to enhance the capability of the touch interaction digital reading device in an ergonomic and emotionally driven manner, enhancing design, usage, and the need for society for command and control over their e-readers (Malhotra et al.2023).

Case Study 3:

Anthropometry of the hand has been utilized among many other factors affecting design in designing and evaluating the effectiveness of four adapted feeding utensils adapted feeding utensils for elderly people with essential tremor (ET) or tremor related to Parkinson's disease (Joyce Sabari, et al. 2019), However, tests carried out did not reveal statistically significant differences in ratings between the two preferred utensils. Participants had varied reactions to the different adaptive utensils and gave different reasons for preferences. There findings support the need for people with tremor related to ET or PD to have more examination to assess their real preferences.

Case Study 4:

Product design aided with anthropometry and other human factors has been typically used to help people with impaired upper extremity strength or neurological impairments, to (1) promote independent eating for as long as possible; (2) assure maximum comfort and dignity during meals; and (3) maximize food intake for people who have difficulty eating independently. The report gives details of recommended maintenance protocols for eleven different types of adaptive equipment. (Disabilities Administration, 2012) .

Other Examples

Some architectural students, a group highly trained in visualization (graphics thinking), have, begun to move to more human responsive product design that can be supported by work and issues of consumer acceptance. According to (Patrick & Hollenbeck, 2021) many occupational therapeutic products fail to target the very specific yet projected and anticipated hand-shaping requirements that are rightfully built into time-dependent and aware human hands. The existing products habitually lack consumer appeal due to their high body form configurations and generally high visual discomfort. Treatment can be enhanced through the sure likability of body forms that echo familiar natural handling experiences.

7. Results:

7.1. Human Factors in Product Design

Ergonomics (or Human Factors) is the logical investigation of individuals' connections with their surroundings. In the study of human capabilities, ergonomics is known as human factors. The main aim of ergonomics is to improve people's performance. Product design about inclusivity denotes creating items that cater to an individual's sensory requirements such as hearing, vision, smell, mood, and taste, as well as both physical and emotional conditions. Comfortable products can produce certain physiological effects, such as reducing bodily effort, while unusable products can cause discomfort, such as headaches, for example. They take into account certain answers to the following aspects of the product. First, what are the attributes of users that make them comfortable when they use a piece of equipment? Second, which product features will cause people to be more confident while they are at ease? Third, how are the behaviors that occur when someone is comfortably recognized? Finally, they can help you test a design for convenience (John D. Lee et al, 2017).

7.2. Hand Anthropometry Design Guidelines

At this point, it must be mentioned that this knowledge was obtained by various studies in the field of hand anthropometry. Some of them have been subsequently summarized by Chaffin (1991) or incorporated into ISO 7250 standards, and regularly are being utilized by designers who perform projects related to human hand and fingers manipulation. There is a number of design guiding rules we may suggest concluding fro the above studies:

- It is difficult to estimate the value of newly developed metrics because the empirical basis for their utilization undergoes a verification process, including consulting cognitive and ecological ergonomics among potential users Chaffin (1991)
- Product designers seek a more concrete basis for human hand design rather than holistic studies that deal with the entire hand-finger interactive function. (Shahriar et al. 2020)
- New hand-finger metrics can be used as a size basis for products. These guidelines are based on meaningful relationship-type hand-finger metrics validated by various studies (Rosu et al., 2024)
- The study of human body dimensions provides designers with valuable tools that can be used to produce products that avoid injury, enhance safety, and increase user comfort (Albin & Molenbroek, 2023) .
- Hands have a crucial role in the classification of products. The energy of the human body is transferred to the product through the hand and the transfer system.
- Thus, the hand is very important as the element that enables the use of various products which entails the harmonious matching of the product with the extent of the hand and its components, the ease of performing the function aimed at for a long time, and the suspension and comfort of the task undertaken.
- Many studies highlight the importance of measuring the compatibility of developed product parts with the hand and its functional regions, in addition to their functional properties (Morgan & Liker, 2020).
- Product design according to anthropometry is based on hand dimensions and strength. The more compatible the hand is in terms of hand dimensions, the more ergonomic it is to use (Yang et al., 2021) .
- Hand size, as well as other body sizes, does exhibit differences in morphological characteristics within the same population. This heterogeneity can be important when we study individuals' physical characteristics, especially to fulfill their occupational needs or to improve products for a particular market.
- Body size significantly influences overall skeletal sizes, with adult females having smaller hands and feet than males. This trend also decreases in older individuals, leading to smaller frame sizes in arms and hands. However, these generalizations can be misleading (Wen et al.2020) .
- Hand size differences are influenced by various factors such as body size, anthropometric characteristics, growth, age, muscle mass, nutrition, and other factors. Adult males tend to have longer and wider hands, while adult females tend to have longer and wider hands (Rincón-Becerra & García-Acosta, 2020) .
- Hand anthropometry a widely studied field that contributes to product design in various fields. It is crucial in designing ergonomic products, as it helps in addressing comfort, performance, and ease of use.
- Hand models yield good results when hand anthropometric information is considered. Manufacturers must produce products that meet human requirements to avoid user dissatisfaction and ensure the product meets human requirements (Hajaghazadeh et al.2022).
- Hand anthropometry is crucial for understanding human hand gestures, as they vary based on age,

gender, race, profession, and product design.
- Ergonomics and performance are directly proportional to hand dimensions, and products like handles, steering wheels, furniture, and tools incorporate anthropometry for comfort, ease of use, and quality.

7.3. Applications in Product Design

Though the application of these new parameters has been specifically here to the design of specific equipment, they may be used in other areas of product design related to manual manipulation. Measurement and application of these additional anthropometric parameters would enable all aspects of hand physiology to be considered during the design of equipment used by the hand and therefore reduce the prevalence of musculoskeletal problems related to their use. In addition to the traditional measurements used in the development of anthropometric design data, means together with tolerances for a further 70 dimensions can be found in research from the principal components analysis of a large number of hand measurements. These new dimensions indicated a wide distribution of fingertip size, although male and female means were still distinct. When these additional dimensions were used collectively to predict a given hand, there was a marked improvement in the prediction (Wang et al., 2021) .

The specific dimensions of the human hand and fingers are important in the design of user interface devices because dimensions of these devices have a major effect on physical comfort. Anthropometric parameters which should be considered in the design of frequently used hand-operated interactive electronic equipment have been developed from the combined hand data for earlier studies. The parameters developed were used to design keyboards representative of a nationally predicted hand population (Laffranchi et al.2020). The resulting design was demonstrated to have improved the averaged prediction of both reach to the far corner of the keyboard and hit rate of the central keys.

7.4. Challenges and Limitations

As discussed in this paper, the human hand has many features which appear to limit end-effector compliance, such as a high stiffness, a large range of motion, and unique grasping impedance characteristics. The hand's impedance characteristics also involve compliance and the unique relationship between force and position coordinate systems in the mechanical structure of the hand (i.e. the human hand is position dependent). Generating a soft prosthetic hand with similar properties is no trivial task, and the hand anthropometry suggests that a high number of degree of freedom DOFs is not sufficient for a prosthetic hand design to work effectively. First, the hand would require DOFs only in the flexion-extension direction, which certainly leads to a conservative design in terms of the number of actuators and other high DOF functionality, such as variable stiffness (Fulton et al.2021) .

Obtaining precise and uniform anthropometric data can be challenging for various reasons. Particularly when it comes to large data collection efforts, it is hardly possible to gather these data with the required level of reliability. Standardization of steps across datasets is not a part of traditional anthropometry, and in most cases, investigators are simply careful day by day to maintain standard procedures within their groups. This causes marked differences in how each dimensional variable is obtained (Mocini et al.2023) .

Field-specific difficulties: In some situations, it might be challenging to some extent to acquire some anthropometry measurements due to body composition or the need to take off clothes. Overweight, obesity, and adiposity may bias the measures, leading to heightened standard deviations and larger error measurements in anthropometric studies. Moreover, population preferences or ethical issues may affect the willingness of participants to provide some types of measures. A study that combined with the results of a meta-analysis highlighted some challenges, barriers, and limitations in data collection for children and adolescents. Among the challenges at the participant level were fears from the participants of not reaching puberty, gaining weight, and adhering to dietary guidelines. At the participant level, the ethical and technical knowledge of the researcher were also cited as limitations in conducting food survey research. It was also cited that the farmer was afraid to open the doors of his establishment, especially when data collection was carried out by someone from another region. Regarding the nutritional state, obesity and overweight children and adolescents were cited as a barrier due to fear, shame, and emotional issues involving body image, pointing to the lack of confidence of these subjects. Furthermore, possible prejudice such as discrimination and bullying in schools is a relevant point in research on anthropometric disorders (Nickerson et al.2020) .

7.5. Future Directions

In the near future, the development of a human-like prosthetic hand will likely involve steps based on various human activities. Analyzing anthropometric data of the human hand can help in designing robotic hands with appropriate kinematics and kinetometrics. However, existing anthropometric data has limitations such as lack of detailed measurements of forces leading to occupational hand work and a clear vision of the hand in performing complex field-based activities. There is no consensus on a common set of parameters and hand action features, as hand function is a multidisciplinary field with various modeling approaches from cognitive, dual task, biomechanical, occupational medicine, and neuroscience research. A detailed analysis of existing databases and the establishment of a unified approach toward hand action in collaboration with multiple clinical groups may provide the required data for the design of highly human-compatible hand prosthesis and exoskeletons (Kamariotou et al.2021).

As data collection demands increase, technology and methodologies will undergo significant changes. Empirical equipment for anthropometric data scanning is becoming more popular, with scanners working independently from other systems. 3D scan technology is in production, allowing devices to create models and quickly scan a person's body. However, a standard or unaltered pose is required for this modelling, similar to landmarking methods. Contour measuring equipment could provide additional size information, with potential applications in clothes sizing. This technology is not far removed from traditional methods, making it a promising advancement in data collection.

Over the next decade, new physical anthropometric methods will become crucial due to the increasing use of imaging and scanning apparatus for monitoring changes over time. Understanding measurement sensitivity and precision-reproducing quantities are necessary. However, there is a lack of empirical data to define these methods. Precision and uncertainty limits will vary significantly for objects in motion, and future research could provide a more conclusive qualification. Current safety equipment designs are poor, with volumes often used alongside theoretical density instead of mass. Future research may confirm the need for new ways to determine human factors research data. Hand anthropometry data is used to accurately measure human hands, but new methods and devices are needed to update sizing information due to technological advancements and precise pressure mapping. These devices could provide construction based on hand function in the design process. Currently, computer tools collect hand data for custom-fit products, but the next step is to develop closed-loop processes in digital twin plans. Anthropological data is used in designing clothes, orthoses, prostheses, flatware, and shoes, creating virtual manikins based on measured values. The integration of gathered data into sensors and computer models is key (Gupta, 2020).

New devices and systems face challenges in the design process, including data collection and evaluation. Current research focuses on evaluating captured data and adapting virtual hand models based on it. Further applications are investigated, with models discussed using fingerprinting criteria. No easy-to-mix approach has been developed to link user's hand profile to glove size, and more research is needed. A recent study aimed to establish the dynamic form and volume of the hand based on palm pressure distribution, using gripping a hand handle to simulate pressure points (Chow, 2022).

While it has been well acknowledged that hand anthropometry data of the target population is essential in implementing a participatory process in a product definition, many design engineers have faced constraints in obtaining this crucial set of measurements. One of the constraints is that traditional anthropometry data that can be found from existing measurement databases only comprises measurements based on direct manual construction. Therefore, these sets of tools have a limited number of measurements and lack the flexibility for use in other types of hand anthropometry data application. The other constraint faced by the design community is to generate a solution whereby new designs of measurement tools or equipment that simplify the acquisition process can be produced (Daruis et al., 2021).

A comprehensive and participatory study on hand anthropometry data is crucial for defining specifications of consumer products. This is due to the challenges in accurately measuring hand structures, operation, and finger and thumb dynamics. Research in fields like biology, anthropology, kinesiology, force-figuring, occupational therapy, hand therapy, and medicine has produced significant scientific content on hands. Hands are both perception and manipulation organs, and their information can help form intelligent patterns of behaviors for informed product and environment design decisions. Therefore, a methodical study to measure and assess hand anthropometry data is essential (Shahriar et al.2020).

The hand's importance to everyday work has been recognized by its use as the gold standard subset for general anthropometry. The human hand represents an intricate and sophisticated mechanism that comes at a relatively substantial expense. The human hand's developing anatomical functionality enables it to adapt to the needs of humans in their unending tasks and to provide the necessary range of motion and tactile information in surprise interactions during routine activity. It is not known which hand features are most suitable for descriptive and predictive applications for these distinctive actions. Moreover, the impact of hand size and hand use on health and productivity in experiments and occupational activities is evident. If a product is engineered to be compatible with the target audience's physical facets, it will result in reduced design complexities, costs, production times, and higher levels of customer satisfaction regarding product usability, quality, and professional advancement, along with enhanced workplace performance (Shan et al.2020).

8.Conclusion:

The study of human body measurements provides valuable resources for designers to create products that enhance safety, prevent harm to users, and make them more comfortable. Product designers focus on finding a tangible foundation for human hand design, as the hand plays a crucial role in enabling the usage of diverse products. This relationship includes the product's harmonious fit with the hand's extent and components, task suspension and comfort, and the ease with which the intended function can be carried out for an extended period of time. Product design with inclusion involves creating products that meet a person's physical and emotional needs, as well as their sensory needs in terms of hearing, vision, smell, taste, and mood. Unusable products can induce discomfort, while comfortable products can have specific physiological impacts, such as lowering physical effort. Designers should consider user characteristics, product attributes that make users feel more secure when they are relaxed, and actions that occur when someone is easily recognized. Hand size is influenced by factors such as body size, anthropometric traits, growth, age, muscle mass, and diet. Understanding human hand proportions and gestures, which differ depending on age, gender, race, occupation, and product design, is essential for designing ergonomic goods that address comfort, performance, and convenience of use. Using extra anthropometric characteristics, it is possible to take into account every facet of hand physiology when designing tools for the hand, reducing the frequency of musculoskeletal issues associated with their usage. The size of user interface devices significantly impacts physical comfort, so it is important to consider the precise proportions of the human hand and fingers when designing these devices.

Based on combined hand data from previous studies, anthropometric factors should be taken into account when designing products, artifacts or equipment that is handled by hand and is regularly used.

9. References:

1. Albin, T. & Molenbroek, J. (2023). ***Introduction to the Special Issue, Anthropometry in Design***. Ergonomics in Design. [Source]
2. Ashdown, S. P. (2020). Full body 3-D scanners. Anthropometry in Anthropometry, ***Apparel Sizing and Design (Second Edition)***, The Textile Institute Book Series, Pages 145-168
3. Bartol, K., Bojanić, D., Petković, T., & Pribanić, T. (2021). ***A review of body measurement using 3D scanning***. Ieee Access. [Source]
4. Bridger, Robert, (2018), ***Introduction to human factors and ergonomics***, Fourth edition, Boca Raton, Taylor & Francis, CRC Press.
5. Bruno, F., Barbieri, L., & Muzzupappa, M. (2020). ***A Mixed Reality system for the ergonomic assessment of industrial workstations***. International Journal on Interactive Design and Manufacturing (IJIDeM), 14(3), 805-812. [Source]
6. Capsi-Morales, P., Grioli, G., Piazza, C., Bicchi, A., & Catalano, M. G. (2020). ***Exploring the role of palm concavity and adaptability in soft synergistic robotic hands***. IEEE Robotics and Automation Letters, 5(3), 4703-4710. [Source]
7. Chow, L. (2022). ***Finite element model for design of pressure therapy gloves for hypertrophic scars***. [Source]
8. Cotes, J. E. (2020). ***Body Size and Anthropometric Measurements***, Wiley Research, https://doi.org/10.1002/9781118597309.ch4
9. Cross, N. (2021). ***Engineering design methods: strategies for product design***. [Source]
10. Daruis, D. D. I., Khamis, N. K., & Deros, B. M. (2021). ***The hand–the basic anthropometry.*** Human Factors and Ergonomics Journal (HFEJ), Vol. 6(2): 49 – 55
11. Dimitrijevic, M., Lalovic, D., & Milovanov, D. (2021). ***Correlation of different anthropometric methods and bioelectric impedance in assessing body fat percentage of professional male athletes.*** Experimental and Applied Biomedical Research (EABR). [Source]
12. Disabilities Administration (2012) ***Adaptive Equipment Maintenance Protocols***, Developed by Developmental Adaptive Equipment Task Force. Department of Disability Services, DC.
13. Dunai, L., Novak, M., & García Espert, C. (2020). ***Human hand anatomy-based prosthetic hand***. Sensors. [Source]
14. Fang Yu, Lei Zeng, Ding Pan, Xinlei Sui & Juyu Tang, (2020) ***evaluating the accuracy of hand models obtained from two 3D scanning techniques***, Scientific RepoRtS, 10:11875, https://doi.org/10.1038/s41598-020-68457-6
15. Ferrari, R., Lachs, L., Pygas, D. R., Humanes, A., Sommer, B., Figueira, W. F., ... & Guest, J. R. (2021). ***Photogrammetry as a tool to improve ecosystem restoration***. Trends in Ecology & Evolution, 36(12), 1093-1101. [Source]
16. Fulton, P. V., Löhlein, S., Paredes-Acuña, N., Berberich, N., & Cheng, G. (2021). ***Wrist***

exoskeleton design for pronation and supination using mirrored movement control. In 20th International Conference on Advanced Robotics (ICAR) pp. 575-580. [Source]
17. Gupta, Deepti. (2020). ***New directions in the field of anthropometry, sizing and clothing fit, in Anthropometry, Apparel Sizing and Design*** (Second Edition), The Textile Institute Book Series, Pages 3-27
18. Hajaghazadeh, M., Taghizadeh, M., Mohebbi, I., & Khalkhali, H. (2022). ***Hand anthropometric dimensions and strengths in workers: A comparison of three occupations***. Human Factors and Ergonomics in Manufacturing & Service Industries, 32(5), 373-388. [Source]
19. Joanna Szkudlarek, Bartłomiej Zagrodny, Sandra Zarychta, and Xiaoxue Zhao (2023), 3D ***Hand Scanning Methodology for Determining Protective Glove Dimensional Allowances***, Int J Environ Res Public Health. 2023 Feb; 20(3): 2645. doi: 10.3390/ijerph20032645
20. John D. Lee, Christopher D. Wickens, Yili Liu, Linda Ng Boyle (2017), ***Designing for People: An Introduction to Human Factors Engineering***, 3rd Edition, Create Space Charleston, SC, ISBN-10: 1539808009.
21. John-John Cabibihan & Aya Gaballa. (2021). ***Indirect Hand Anthropometric Measurements using 3D Scanning Devices***. IEEE Dataport. https://dx.doi.org/10.21227/7gca-j353
22. Joyce Sabari, Dimitre G. Stefanov, Judy Chan, Joyce Starr (2019), ***Adapted Feeding Utensils for People With Parkinson's-Related or Essential Tremor,*** American Journal of Occupational Therapy 73(2):7302205120p1, DOI: 10.5014/ajot.2019.030759
23. Kaewdok, T., Sirisawasd, S., Norkaew, S., & Taptagaporn, S. (2020). ***Application of anthropometric data for elderly-friendly home and facility design in Thailand***. International Journal of Industrial Ergonomics, 80, 103037. [Source]
24. Kamariotou, V., Kamariotou, M., & Kitsios, F. (2021). ***Strategic planning for virtual exhibitions and visitors' experience: A multidisciplinary approach for museums in the digital ag***e. Digital Applications in Archaeology and Cultural Heritage, 21, e00183. [Source]
25. Kashef, S. R., Amini, S., & Akbarzadeh, A. (2020). ***Robotic hand: A review on linkage-driven finger mechanisms of prosthetic hands and evaluation of the performance criteria. Mechanism and Machine*** Theory. [Source]
26. Kelkanlo, R., Kouhnavard, B., & Falaki, S. H. (2020). ***Investigating Hand Anthropometric Dimensions-A Case Study on Office Personnel and Car Mechanics***. International Journal of Occupational Hygiene, 12(3), 180-191. [Source]
27. Kivell, T. L., Ostrofsky, K. R., Richmond, B. G., & Drapeau, M. S. (2020). ***Metacarpals and manual phalanges***. Hominin Postcranial Remains from Sterkfontein, South Africa, 1936-1995, 106. [Source]
28. Laffranchi, M., Boccardo, N., Traverso, S., Lombardi, L., Canepa, M., Lince, A., ... & De Michieli, L. (2020). Th***e Hannes hand prosthesis replicates the key biological properties of the human hand***. Science robotics, 5(46), eabb0467. [Source]
29. Linsey Griffin, Susan Sokolowski, Heajoo Lee, Robin Carufel (2019), ***Methods and Tools for 3D Measurement of Hands and Feet***, In book: Advances in Interdisciplinary Practice in Industrial Design, DOI: 10.1007/978-3-319-94601-6_7
30. Ma, L. & Niu, J. (2021). Three-Dimensional (3D) ***Anthropometry and its Applications In Product Design***. Handbook of human factors and ergonomics. [Source]
31. Malhotra, S., Yadav, J., & Chopra, A. (2023, May). ***Precision Anthropometric Insights for User-Centric Mobile Phone Design***. In International Conference on Business and Technology (pp. 192-203). Cham: Springer Nature Switzerland.
32. Mandahawi, Nabeel, Sheik Imrhan, Salman Al-Shobaki, B.Sarder (2008) ***Hand anthropometry survey for the Jordanian population***, International Journal of Industrial Ergonomics, Vol 38(11), Pages 966-976, https://doi.org/10.1016/j.ergon.2008.01.010
33. Martin, P. (2023). T***he Seven Measures of the World***. [Source]
34. Matthew S. Rogers, Alan B. Barr, Boontariga Kasemsontitum & David M. Rempel (2008). ***A three-dimensional anthropometric solid model of the hand based on landmark measurements***, Ergonomics Vol. 51, No. 4, 511–526, DOI:10.1080/00140130701710994
35. Mocini, E., Cammarota, C., Frigerio, F., Muzzioli, L., Piciocchi, C., Lacalaprice, D., ... & Pinto, A. (2023). ***Digital anthropometry: A systematic review on precision, reliability and accuracy of most popular existing technologies. Nutrients,*** 15(2), 302. [Source]
36. Mohd Javaid, Abid Haleem, Ravi Pratap Singh,Rajiv Suman (2021), ***Industrial perspectives of 3D scanning: Features, roles and it's analytical application***, Sensors International, Sensors International, Volume 2, 2021,https://doi.org/10.1016/j.sintl.2021.100114
37. Morgan, J. & Liker, J. K. (2020). ***The Toyota product development system: integrating people, process, and technology***. [Source]
38. Moustafa A. W. (2016) "***Anthropometry of the Egyptian female hand with relevance to control design***", 4th International Conference of the Faculty of Applied Arts, Helwan University, Cairo (28-29 February, 2016)
39. N. N. Kaashki, X. Dai, T. Gyarmathy, P. Hu, B. Iancu and A. Munteanu, "***Automatic and Fast Extraction of 3D Hand Measurements using a Deep Neural Network***," 2022 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), Ottawa, ON, Canada, 2022, pp. 1-6, doi: 10.1109/I2MTC48687.2022.9806686.
40. Nickerson, B. S., McLester, C. N., McLester, J. R., & Kliszczewicz, B. M. (2020). ***Relative accuracy of anthropometric-based body fat***

equations in males and females with varying BMI classifications. Clinical nutrition ESPEN, 35, 136-140. [Source]

41. Padilla, C. J., Ferreyro, F. A., & Arnold, W. D. (2021). ***Anthropometry as a readily accessible health assessment of older adults***. Experimental Gerontology. [Source]
42. Pal, A., Patel, T., & Khro, K. (2024). ***A comparative study of the effectiveness of photogrammetric versus manual anthropometric measurements***. Work. [Source]
43. Parvez, M. S., Shahriar, M. M., Tasnim, N., & Hoque, A. S. M. (2022). ***An anthropometry survey of Bangladeshi university students***. Journal of Industrial and Production Engineering, 39(2), 89-108. [Source]
44. Patrick, V. M. & Hollenbeck, C. R. (2021). ***Designing for all: Consumer response to inclusive design***. Journal of consumer psychology. [Source]
45. Pepe, M. & Domenica, C. (2020). ***Techniques, tools, platforms and algorithms in close range photogrammetry in building 3D model and 2D representation of objects and complex architectures***. Computer-Aided Design and Applications. [Source]
46. Reiman, A., Kaivo-oja, J., Parviainen, E., Takala, E. P., & Lauraeus, T. (2021). ***Human factors and ergonomics in manufacturing in the industry 4.0*** context–A scoping review. Technology in Society, 65, 101572. [Source]
47. Rincón-Becerra, O. & García-Acosta, G. (2020). ***Estimation of anthropometric hand measurements using the ratio scaling method for the design of sewn gloves***. Dyna. [Source]
48. Rosu, D., Enache, I. S., Muntean, R. I., & Stefanica, V. (2024). ***Effects of Kin Ball Initiation: Pre-and Post-Pandemic Impact on Palmar Muscle Strength, Endurance, and Coordination in Non-Athlete Participants***. Sports. [Source]
49. Rumbo-Rodríguez, L., Sánchez-SanSegundo, M., Ferrer-Cascales, R., García-D'Urso, N., Hurtado-Sánchez, J. A., & Zaragoza-Martí, A. (2021). ***Comparison of body scanner and manual anthropometric measurements of body shape: a systematic review***. International journal of environmental research and public health, 18(12), 6213. [Source]
50. Saaludin, N., Saad, A., & Mason, C. (2022). ***Reliability and ethical issues in conducting anthropometric research using 3D scanner technology***. In Digital Manufacturing Technology for Sustainable Anthropometric Apparel (pp. 71-95). Woodhead Publishing. [Source]
51. Seifert, E. A. (2020). ***Comparison and Validation of Traditional and Three-Dimensional Anthropometric Methods for Measuring the Hand through Reliability, Precision, and Visual Analysis***. [Source]
52. Shahriar, M. M., Parvez, M. S., & Lutfi, M. (2020). ***A survey of hand anthropometry of Bangladeshi agricultural farm workers***. International Journal of Industrial Ergonomics, 78, 102978. [Source]
53. Shan, D., Geng, J., Shu, M., & Fouhey, D. F. (2020). ***Understanding human hands in contact at internet scale***. In Proceedings of the IEEE/CVF conference on computer vision and pattern recognition (pp. 9869-9878). [Source]
54. Shan, G. (2023). ***Exploring the intersection of equipment design and human physical ability: Leveraging biomechanics, ergonomics/ anthropometry, and wearable technology for enhancing human***, Advanced Design Research. [Source]
55. Sheik N. Imrhana; M. D. Sarderb; Nabeel Mandahawic (2009). ***Hand anthropometry in Bangladeshis living in America and comparisons with other populations***, Ergonomics Volume 52(8) pp987-998, DOI:10.1080/00140130902792478
56. Smith, B., McCarthy, C., Dechenaud, M. E., Wong, M. C., Shepherd, J., & Heymsfield, S. B. (2022). ***Anthropometric evaluation of a 3D scanning mobile application***. Obesity, 30(6), 1181-1188. [Source]
57. Stark, E., Haffner, O., & Kučera, E. (2022). ***Low-cost method for 3D body measurement based on photogrammetry using smartphone. Electronics***. [Source]
58. Taifa, I. W., Desai, D. A., & Bulsara, N. M. (2021). ***The development of an ergonomically designed product through an integrated product team approach***. International Journal of Occupational Safety and Ergonomics. [Source]
59. Thanas M. Greiner (1991) ***Hand Anthropometry of U.S. Army Personnel***, Anthropology Branch, Behavioral Sciences Division, Soldier Science Directorate, U.S. Army Natick Research, Development & Engineering Center, Natick, REPORT NUMBER MA 01760-5020
60. Thelwell, M., Chiu, C. Y., Bullas, A., Hart, J., Wheat, J., & Choppin, S. (2020). ***How shape-based anthropometry can complement traditional anthropometric techniques: a cross-sectional study***. Scientific Reports, 10(1), 12125. [Source]
61. Thomas M. Greiner (1991), ***Hand Anthropometry OF U.S. Army Personnel***, Anthropology Branch, Behavioral Sciences Division Soldier Science Directorate, U.S. Army Natick Research, Development & Engineering Center, Natick, Report Number MA 01760-5020
62. Tuong Nguyen Van, Natasa Naprstkova (2024) ***Accuracy of Photogrammetric Models for 3D printed Wrist-hand Orthoses***, Manufacturing Technology, Vol. 24 (3), Doi: 10.21062/mft.2024.048
63. Uriel, J., Ruescas, A., Iranzo, S., Ballester, A., Parrilla, E., Remón, A., & Alemany, S. (2022). ***A methodology to obtain anthropometric measurements from 4D scans***. In Proceedings of the 7th International Digital Human Modeling Symposium (Vol. 7, No. 1). University of Iowa. [Source]
64. Vijayan, V., Connolly, J. P., Condell, J., McKelvey, N., & Gardiner, P. (2021). ***Review of wearable devices and data collection***

considerations for connected health. Sensors, 21(16), 5589. [Source]

65. Wang, L., Lee, T. J., Bavendiek, J., & Eckstein, L. (2021). ***A data-driven approach towards the full anthropometric measurements prediction via Generalized Regression*** Neural Networks. Applied Soft Computing. [Source]
66. Wen, J., Wang, J., Xu, Q., Wei, Y., Zhang, L., Ou, J., & Tong, M. (2020). ***Hand anthropometry and its relation to grip/pinch strength in children aged 5 to 13 years***. Journal of International Medical Research, 48(12), 0300060520970768. [Source]
67. Yang, Y., Zhou, H., Song, Y., & Vink, P. (2021). ***Identify dominant dimensions of 3D hand shapes using statistical shape model and deep neural network***. Applied Ergonomics. [source].