DEVELOPMENT OF PRODUCT DESIGN SPECIFICATIONS FOR PARAPLEGIC WHEELCHAIR

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To my late parents; Haj. Nabaran A. Mahmud, and Hajia Rabiah Mahmud who gave their all for me to succeed.

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ABSTRACT

People with disability (PwD) contribute a significant percentage of the world's population-over 15%. The attention to their special needs has long been ignored and traditional design approaches are still used to design products which PwD are not comfortable with. The front end of design process has not been well addressed in the design for products used by paraplegics, and this results in user apathy or total abandonment of these products. To address this problem, this study develops a framework for preparing Product Design Specification (PDS) through sourcing information from the equipment, the user, and the task or 'use' process. Information is sourced from the most common equipment (wheelchair) using the matrix method, segmentation technique of TRIZ (Theory of inventive Problem Solving Methodology) and the hierarchical clustering method. User's information is sourced through questionnaire, interview and observation techniques. The information collected was mined using the functional analysis techniques of TRIZ inventive principles to develop key elements which were subsequently expanded to build a comprehensive "preliminary PDS (βPDS)". The βPDS was used as basis for a computer based Auto Retrieval Tool (ART) developed to ease precision information retrieval. Moreover, the PDS ART was validated by members of the UTM robotics team. The results from the validation exercise show the PDS ART as significantly better, simple, easy to use, informative, flexible and precise in terms of amount of PDS generated and time spent. This tool will aid designers in developing comprehensive wheelchair design PDS for different clientele with respect to gender, age, weight and height.

ABSTRAK

Orang kurang upaya (OKU) meyumbang peratusan yang besar penduduk dunia - lebih dari 15%. Perhatian terhadap keperluan khas mereka telah lama diabaikan kerana pendekatan proses rekabentuk secara tradisional, dan ini mengakibatkan kebanyakkan peralatan tidak digunakan oleh OKU. Fasa awal proses rekabentuk masih belum diberi penekanan sepenuhnya semasa mereka bentuk produk kesunaah *parapelgics* merupakan penyebab produk yang dihasilkan kurang digunakan dan seterusnya ditiggalkan. Untuk mengatasi masalah ini, kajian ini bertujuan untuk membangunkan satu rangka kerja bagi menyediakan Rekabentuk Produk Spesifikasi (PDS) melalui sumber maklumat daripada peralatan, pengguna dan proses penggunaaan. Maklumat diperolehi daripada peralatan yang paling biasa (kerusi roda) dengan menggunakan kaedah matriks, teknik segmentasi Prinsip TRIZ (Theory of inventive Problem Solving Methodology) inovatif dan kaedah pengelompokan hierarki. Maklumat pengguna diperolehi melalui soal selidik, temubual dan pemerhatian. Maklumat yang dikumpul akan di analisa dengan menggunakan teknik analisis fungsi Prinsip TRIZ inovatif untuk membangunkan elemen-elemen utama yang kemudian dikembangkan untuk membina "PDS sementara (βPDS)" yang menyeluruh. βPDS telah digunakan sebagai asas untuk sistem '*Auto Retrieval Tool*' (ART) yang dibangunkan bagi mengakses spesifikasi produk dengan lebih tepat. Selain itu, ART PDS telah disahkan oleh ahli-ahli pasukan robotik UTM. Hasil daripada pelaksanaan verifikasi ini menunjukkan ART PDS adalah baik, mudah, mudah untuk digunakan, bermaklumat, fleksibel dan tepat dari segi jumlah elemen pada PDS yang dihasilkan dalam masa yang lebih singkat. Alat ini akan membantu pereka untuk membangunkan PDS yang komprehensif bagi reka bentuk kerusi roda untuk pelanggan yang berbeza jantina, umur, berat, dan tinggi.

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LIST OF ABBREVIATIONS

2-D	-	Two Dimensional
3-D	-	Three Dimensional
ADL	-	Activities of Daily Living
ART	-	Auto Retrieval Tool
CAD	-	Computer Aided Design
CRC	-	Clinical Research Centre
DfA	-	Design for All
DFA	-	Design for Assembly
DFM	-	Design for Manufacture
DFP	-	Design for piece –part Producibility
FCA	-	Functional Cost Analysis
FMEA	-	Failure Mode and Effect Analysis
FMoH	-	Federal Ministry of Health
FTA	-	Functional Tree Analysis
GDP		Gross Domestic Product
HSA	-	Hospital Sultanah Amina
HSI	-	Hospital Sultan Ismail
ID	-	Inclusive Design
MREC	-	Medical Research and Ethics Committee
NMRR	-	National Medical Research Register
PACE	-	Programme of All inclusive Care for the Elderly
PDF	-	Portable Document Format
PDS	-	Product Design Specification
PFF	-	Product form features
PwD	-	People with Disability
QFD	-	Quality Function Deployment

SCI	-	Spinal Cord Injury
SEC	-	Search Experience Credence
SPSS	-	Statistical Package for the Social Sciences
SQL	-	Structured Query Language
TRIZ	-	Theory of Inventive Principles
UD	-	Universal Design
US	-	United States
UTM	-	Universiti Teknologi Malaysia
WHO	-	World Health Organisation
βPDS	-	Preliminary Product Design Specification

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The human population can be divided into three groups when body efficiency is considered; the highest or extreme, average or normal, and the low or disabled (Nowak, 1999). Fifteen percent of the total world population, or over a billion people, live with disabilities (WHO, 2011). The World Health Organisation (WHO) defines disability as a restriction/lack of ability to perform an activity that normal or typical people do (WHO, 1980). Similarly, the World Bank estimates that 20% of the world's poorest people have some kinds of disabilities and tend to be regarded in their own communities as the most disadvantaged (Taormina-Weiss, 2011). In addition, Somavia (2007), reported that 80% of the world's people with disabilities reside in developing countries and that they are constrained by little or no access to the services they need. However, Chuan *et al.* (2010); and Green (2011) reported that disability is associated with poverty at higher levels, education and employment at lower levels, and a significant degree of social exclusion. Furthermore, Miralles *et al*. (2007) highlighted five main issues are obstacles for people with disability when looking for employment; i. Market policies, ii. Attitudes of typical people (non-disabled), iii. Accessibility, iv. Work structure, and v. Organization. The second most common reason given by employers for not hiring persons with disabilities is the fear of costly special facilities (Taormina-Weiss, 2011). Heron and Murray (2003) found that often employers are reluctant to employ people with disabilities because they regard them as unsuitable. The attention to their education is also a challenge to such individuals and their guardians or benefactors - this makes them remain poor (Croft, 2013).

There are a number of disabilities in terms of broad classifications and subcategories: mental, physical, speech, hearing, vision, and learning. Physical disability usually comprises a significant percentage of the community with disabilities. Previous studies show that the population of people with disability in Malaysia 2.8 million (Ramlee *et al.*, 2012) and that people with physical disabilities could over 33% (Lee *et al.*, 2011). Spinal cord injury (SCI), which is classified under physical disability, can result in tetraplegia (complete paralysis of all four limbs) or paraplegia (impairment of lower limb functions). In paraplegia, the upper limbs are not affected; hence, the person with paraplegia is able to use his/her upper limbs to propel a wheelchair. In Malaysia, the statistics from Hospital Kuala Lumpur, shows that 63% of 292 SCI patients included in its study conducted between January, 2006 and July, 2009, have paraplegia (Ibrahim *et al.*, 2013).

People with disability need rehabilitation to improve their body efficiency (Nowak, 1999), so that they can return as much close as possible to normal life. Rehabilitation is a method of boosting the body efficiency of people with disability (PwD) through the use of some tools including assistive devices/products (Kumar, 1992). As such, rehabilitation could include Programme of All-inclusive Care for the Elderly (PACE) that reduces the use of expensive medical services (Meret-Hanke, 2011).

The existing products do not permit the PwD to operate or manage their lives as the typical person does through using the same products/facilities; and therefore this makes them unable to achieve functional satisfaction of such products/equipment. This could be attributed to the front end design process of the machine/product that has not been well handled (Pugh, 1993), thus the quest for sustainable alternatives.

Furthermore, the abilities and contributions of the PwD to economic and societal development through the provision of sustainable alternatives will enhance their independence and benefit national governments. If they are engaged in gainful employment as their typical equivalent, they will improve in their self-help care and pay taxes which will contribute to national economy and the Gross Domestic Product (GDP). These sustainable alternatives depends on a sound product/machinery design process that, product designers can depend on in designing this category of products. This work seeks to fill the gap in

existing products for paraplegia (a spinal cord injury condition) who are part of the physically disabled, that have not been given adequate attention over the years. This is done through the development of a Product Design Specification (PDS) preparation tool.

1.2 Definition of Terms

Typical People - A term used to describe people without disability.

People with Disability (PwD) – refers to people with functional defects that makes one or more of a body organ malfunction when compared with normal people.

Paraplegia - The condition of being unable to move both legs and trunk of body below the level of associated injury to the spinal cord (Mosby, 2009). The paraplegia have wounds in the thoracic section of the spinal cord (NSCISC, 2011).

Product Design Specification (PDS) - The stage in product design process that comprehensively state measurable parameters and targets for the products.

Universal Design (UD)- UD is a general term used to describe the design for goods and services usable by both the disabled and the typical (normal) people.

Activities of Daily Living (ADL) – Activities (e.g. eating, bathing) that people tend to do every day without requiring assistance in a routine manner (Investopedia).

1.3 Problem Statement

There is lack of awareness on the challenges faced by the disabled (Robson, 2011). A great percentage of the products designed to assist the physically challenged are quickly abandoned (Hocking, 1999). The rate is reported to be as high as 75%, in the United States (US) up to 15% of these products are never used (Lauer *et al.,* 2006). One of the reasons given abandoning is the difficulty in applying mainstream design principles for design of products used by PwD. This tends to make designers follow the convention or traditional methods in designing a prototype and then modifying it to suit PwD; this makes the products unusable and inappropriate in practice (Newell *et al.,*2011). Some efforts have been made to address the problem through the principles of Universal Design (Xin *et al.,* 2009), but this does not aid design for products for the disabled. At best, they are an evaluation aid (McAdams and Kostovich, 2011). Another reason for failed product designs for PwD has been reported to be a matter of insufficient knowledge about people, their capacities, needs and desires (Redström, 2006).

The paraplegia which is a part of the physically disable group has mobility as the major problem and thus requires design tools that can support products aimed at improving their mobility and ease their sedentary situation (Van der Woude *et al.* 2006). The wheelchair which is the most common product used by people with paraplegia, because of their mobility challenge (de Groot *et al.,* 2013; Edelstein, 2007; Kawamura and Murakami, 2013; Van der Woude *et al.* 2006), still have a lot of efficiency issues that require improvement (Chenier *et al.,* 2011; Suda *et al.,* 2011). For these needs which occur every day to be met, the design approach should be one that provides direct solutions to satisfy the needs (Pullin, 2009). Information about these people or users which is at the front end of the design process has not been well handled (Pugh, 1993; Miaskiewicz and Kozar, 2011). The front end design process need to be reassessed with a view to providing sustainable tools that can support preparation of product design specification for Paraplegia.

Presently, there are no known tools that provide direct solutions that are informative and user oriented in designing products for the Paraplegia or even the disabled. Therefore, this research will address this need through the development of a framework for preparing Product Design Specification (PDS) for products used by the Paraplegia".

1.4 Objectives

The aim of this work is to develop Product Design Specification (PDS) preparation tool, for products used by the Paraplegia.

Specific objectives are:

a. To develop a framework for preparing PDS for paraplegia
b. To develop an improved product feature classification approach for products used by the paraplegia using the wheelchair as case study
c. To develop and validate a comprehensive PDS preparation tool for the wheelchair within the Malaysian environment
d. To develop a call-up Auto Retrieval Tool (ART) capable of nesting queries of generating PDS preparation reports for the wheelchair.

1.5 Scope

The front end of the design process (from the need to specification) is of general concern in this work, but specific focus is on the PDS preparation. Similarly, the general emphasis is on assistive devices/products used by the paraplegia for movement. Also, specific scope is directed at the movement need of the paraplegia through investigating their Activities of Daily Living (ADL) with emphasis on the wheelchair. This tool will entertain preparation of PDS for various categories of clientele and situations like countries, all features/specific features of the wheelchair, the environment in which the wheelchair navigates and a particular age group. Also, this tool is capable of assisting the designer in preparing a customized PDS for specific clients within an age group. This work does not consider transplant or other internal assistive inserts that the paraplegia uses.

1.6 Significance of the Study

The development of this PDS preparatory tool will avail designers an open ended opportunity to design alternative and sustainable products that the paraplegia can use and be comfortable with. This will therefore directly address:

i. The absence of a framework for design on product design for paraplegia through the development of a comprehensive and sustainable framework that can give direction to designers.

ii. The problem of lack of information on the movement needs and desires of the paraplegia through assessing their most common product (wheelchair), engaging them, and observing them. This will be done with the ADL as a guide. Also, the implication of this study on the paraplegia is that it will increase the self-help ability and reduce their dependence on others.

iii. Issues bothering on the front end of the design process which has not been well tackled, through developing improved tools like product classification tools to analyse information at the front end and capable of preparing a PDS that will reduce the rigor faced by designers in the front end of the design process especially for products used by the paraplegia. This will also solve the problem of abandonment/rejection because better products will be produced.

iv. The growing demand for computer integrated tools to aid design practice through the development of an Auto Retrieval tool (ART)

1.7 Organization of the Thesis

This thesis is divided into six chapters:

Chapter 1 discusses the background of the study, problem formulation and the problem statement. The objectives, scope and significance of the study are also discussed in this chapter.

Chapter 2 presents literature review on paraplegia, the design process: methods and tools, product classification, and products designs for paraplegia. In addition, the chapter discusses the salient issues requiring attention with respect to the front end design and the deficiencies leading to failure of products especially for the paraplegia.

Chapter 3 discusses the methods used in this study; research framework, procedure for preparation and administration of the instruments (equipment method, the questionnaire, interview and observation) used for data collection, the proposed PDS preparatory tool, the system and super system; and the ART.

Chapter 4 presents the data collection, collation and analysis. The interpretation of results was also done here.

Chapter 5 discusses the PDS Tool, derivation of preliminary PDS (βPDS) Key elements and βPDS Database; the database management with available measurements and illustrations; the ART verification exercises and the final PDS ART.

Chapter 6 presents the conclusions, limitations and areas of recommendations where further research may be done in future.

REFERENCES

Abdullah, A. and Samad, Z. (2003). *Design Optimisation of Robot Chasis Using Prototyping Process*. Johor, Malaysia: Faculty of Mechanical Engineering.

Algood, S. D., Cooper, R.A., Fitzgerald, S.G., Cooper, R., and Boninger, M.L. (2005). Effect of a Pushrim-activated power assis wheelchair on the functional capabilities of persons with Tetraplegia. *Archives of Physical Medicine and Rehabilitation, 86*(3), 380-386.

Aluminum Travel Wheelchair ATC 19. (2012) http://www.discountmobility.com. Retrieved 04/08/2012

Amalraj, P., and Syamal S. (2009). Unusual Case of Paraplegia. *Annals of Indian Academy of Neurology, 12*(3), 188-190.

Andersson. (2001). *MultiObjective Optimisation in Engineering Design, Applications to Fluid Power Systems.* (PhD), Linkongpings Universitet, Linkoping.

Anonymous (2013a). www.abilityanswers.com/ cosycushion. Retreived 28/05/2013

Anonymous (2013b). www.spinelife.com. Retrieved 29/08/2013

Anonymous (2013c). www.1800wheelchair.com. Retrieved 29/08/2013

Anonymous (2013d). www.proactiv-gmbh.com. Retrieved 29/08/2013

Anonymous (2013e). www.epc-wheelchairs.co.uk Retrieved 29/08/2013

Anonymous (2013f). www.draftwheelchairs.com. Retrieved 28/03/2013

Anonymous (2013g). www.sportaid.com. Retrieved 29/08/2013

Anonymous (2014a). www.caremedicalsource.com. Retrieved 17/02/2014

Anonymous (2014b). www.specialisedorthotics.com. Retrieved 15/08/2014

Anonymous (2014c). www.quickie-wheelchairs.com. Retrieved 15/08/2014

Anonymous (2014d). www.wheelchairparts.com. Retrieved 15/08/2014

Anonymous (2014e). www.pioneerbathrooms2-px,rtrk.co.uk . Retrieved 17/02/2014

Anonymous (2014f). www.richy group.en.alibaba.com. Retrieved 17/02/2014

Anonymous (2014g). www.upperplumbers.co.uk. Retrieved 15/08/2014

Anonymous (2014h). www.matressessizes.info.com. Retrieved 15/08/2014

Anonymous (2014i). www.archinet.co.uk. Retrieved 15/08/2014

Anonymous (2014j). www.ikea.com.my. Retrieved 17/02/2014

Anonymous (2014k). www.met.gov.my. Retrieved 17/02/2014

Appio, F. P., Achiche, S., McAloone, T., and Di Minin, A. (2011). *Understanding managers decision making process for tools selection in the core front end of innovation.* Paper presented at the International Conference on Engineering Design (ICED11).

Bailey, R. W. (1989). *Human Performance Engineering: Using Factors Ergonomics to achieve Computer Systems Usabilty*. NJ: Prentice Hall.

Bertocci, G. E., Roosemalen, L. V. (2010). Wheelchair Caster Loading During Frontal Impact. *Assistive Technology: The official Journal of RESNA, 15*(2), 105-112. doi: 10.1080/10400435.2003.10131894

Borgianni, Y., Cascini, G., Pucillo, F., and Rotini, F. (2013). Supporting product design by anticipating the success chances of new value profiles. *Computers in Industry, 64*(4), 421-435.
doi: http://dx.doi.org/10.1016/j.compind.2013.02.004

Boztepe, S. (2007). Toward a framework of product development for global markets: a user-value-based approach. *Design Studies, 28*(5), 513-533.
doi: http://dx.doi.org/10.1016/j.destud.2007.02.010

Braddock, D., Rizzolo, M.C., Thompson, M., and Bell, R. (2004). Emerging Technologies and cognitive Disability. *Journal of Special Education Technology, 9*(4), 1.

Brubaker, C. E. (1986). Wheelchair Prescription: an analysis of factors that affect mobility and performance. *Journal of Rehability Research and Development, 23*(4), 19-26.

Burzagli, L., Emiliani, P.L. and Gabbanini F. (2009). Design for All in action: An example of analysis and implementation. *Expert Systems with Application, 38*, 985-994. doi: 10.1016/j.eswa.2007.10.039

Candi, M., and Gemser, G. (2010). An agenda for research on the relationship between industrial design and performance. *International Journal of Design, 4*(3), 66-67.

Candi, M., and Saemundsson, R. J. (2011). Exploring the Relationship Between Aesthetic design as an Element of New Service Development and Performance. *Journal of Product Innovation, 28*.
doi: 10.1111/j.1540-5885.2011.00827.x

Carter, A. D. S. (1986). *Mecahnical Reliability* (Second ed.): Macmillan.

Chandrasegaran, S. K., Ramani, K., Sriram, R. D., Horváth, I., Bernard, A., Harik, R. F., and Gao, W. (2013). The evolution, challenges, and future of knowledge

representation in product design systems. *Computer-Aided Design, 45*(2), 204-228. doi: http://dx.doi.org/10.1016/j.cad.2012.08.006

Charnley, F., Lemon, M., and Evans, S. . (2011). Exploring the process of whole system design. *Design Studies, 32*(2), 156-179.

Chenier, F., Bigras, P., and Aissanaoui, R. (2011). An orientation estimator for wheelchair Casters wheels. *IEEE transactions on control systems Technology,19*(6), 1317-1326.

Chuan, T. K., Hartono, M., and Kumar, N. (2010). Anthropometry of the Singaporean and Indonesian populations. *International Journal of Industrial Ergonomics, 40*(6), 757-766.
doi: http://dx.doi.org/10.1016/j.ergon.2010.05.001

Clevenger, C. M., and Haymaker, J. (2011). Metrics to assess design guidance. *Design Studies, 32*(5), 431-456.

Costa, A. I. A., Dekker, M., Beumer, R. R., Rombouts, F. M. and Jongen, W. M. F. (2001). A consumer-oriented classification system for home meal replacements. *Food Quality and Preference, 12*(4), 229-242.
doi: http://dx.doi.org/10.1016/S0950-3293(01)00010-6

Cremer, R. (2010). Energy Consumption diminished in Paraplegia. *Deutsches Arzteblatt International, 107*(30), 541.

Creswell, J. W. (2009). *Research Design: Qualitative, Quantitative and Mixed Methods Approaches* (3rd Ed.): Sage publications.

Crilly, N., Moultrie, J. and Clarkson, P. J. (2009). Shaping things: intended consumer response and the other determinants of product form. *Design Studies, 30*(3), 224-254. doi: http://dx.doi.org/10.1016/j.destud.2008.08.001

Croft, A. (2013). Promoting access to education for disabled children in low-income countries: Do we need to know how many disabled children there are? *International Journal of Educational Development, 33*, 233-243.

Cross, N. (2008). *Engineering Design Method: Strategies for Product Design* (Fourth ed.). England: John Wiley and Sons, Ltd.

D'Anjou, P. (2011). An alternative model for ethical decision-making in design: A Sartrean approach. *Design Studies, 32*(1), 45-59.

Darius, D. D. I., Deros, B. M., Nor, and M. J. M. (2011). Malaysian Sitting Anthropometry for seat fit Parameters. *Human Factors and Ergonomics in Manufacturing and Service Industries, 21*(5), 443-455.
doi: 10.1002/hfm.20237

de Groot, S., Vegter, R. J. K., van der Woude, and Lucas H. V. (2013). Effect of wheelchair mass, tire type and tire pressure on physical strain and wheelchair propulsion technique. *Medical Engineering & Physics, 35*(10), 1476-1482. doi: http://dx.doi.org/10.1016/j.medengphy.2013.03.019

Disabledworld. (2010). Disabled World News(2010-10-09) - Facts and definition regarding Paraplegia. a paralysis of legs and sometimes lower body. Retrieved 21/03/2013, 2013, from http://www.disabled-world.com/definitions/paraplegia.php#ixzz2O9xpXy6A

ECommission. (2005). Design for All. Retrieved 23/08, 2013, from http://ec.europa.eu/information_society/activities/einclusion/policy/accessibility/dfa/index_en.htm

Edelstein, J. E. (2007). Chapter 33 - Assistive Devices for Mobility: Canes, Crutches, Walkers, and Wheelchairs. In M. H. Cameron, Monroe, Linda G. (Ed.), *Physical Rehabilitation* (pp. 877-896). Saint Louis: W.B. Saunders.

Finger, S., and Dixon, F. R. (1989). A review of Research in Mechanical Engineering Design, Part 1: Descriptive, Prescriptive and Computer-based Models of design Processes *Research in Engineering Design, 1*, 51-57.

Fuhrman, S. I., Karg, P., Bertocci, G. (2010). Characterization of pediatric wheelchair Kinematics and wheelchair tiedown and occupant restraint system loading during impact. *Medical Engineering and Physics, 32*, 280-286.

Gaal, R. P., Rebholtz, N., Hotchkiss, R. D., and Pfaeilzer, P. F. (1997). Wheelchair rider injuries : Causes and consequences for wheelchair design and selection. *Journal of Rehabilitation Research and Development, 34*(1), 58-71.

Goldschmidt, G. and Sever, A. L. (2011). Inspiring design ideas with texts. *Design Studies, 32*(2), 139-155.

Green, R. J. (2011). An Introductory Theoretical and Methodological Framework for a Universal Mobility Index (Umi) to Quantify, Compare, and Longitudinally Track Equity of Access across the Built Environment. *Journal of Disability Policy studies, 21*(4), 219-229.

Han, J., and Kamber, M. (2001). *Data Mining Concepts and Techniques*. San Francisco: Morgan Kaufmann.

Hartigan, J. A. (1972). Direct Clustering of a data matrix. *Journal of American Statistical Association, 67*, 123-129.

Heron, R. and Murray, B. (2003). Assisting disabled persons in finding employment: A practical guide (Second edition ed.). Trinidad and Tobago: International Labour Organisation.

Herrera-Saray, P., Pelaez-Ballestas, I., Ramos-Lira, L., Sanchez-Monroy, D., and Ruben Burgos-Vargas. (2013). Usage problems and Social Barriers Faced by Persons with Wheelchair and other aids. Qualitative study from Ergonomics Perspective in Persons Disabled by Rheumatoid Arthritis and other conditions. *Reumatologia Clinica, 9*(1), 24-30.

Hocking, C. (1999). Functions or feelings: factors in abadonement of assistive devices. *Technology and Disability, 11*, 3.

Hollins, W., and Pugh, S. (1990). *Successful Product Design - What to do and When*. London: Butterworths.

HSE. (2004). *Manual Handling Operations regulations 1992 (as amended): Guidance on regulations*. Surrey, UK: Crown.

Ibrahim, A., Lee, K. Y., Kanoo, L. L., Tan, C. H., Hamid, M. A., Hamedon, N. M., and Haniff, J. (2013). Epidemiology of Spinal Cord Injury in Hospital Kuala Lumpur. *SPINE, 38*(5), 419-424. doi: 10.1097/BRS.0b013e31826ef594

Ikovenko, S. (2011). *Inventing the Future with Systematic Innovation.* Paper presented at the MyTRIZ Workshop 2011, Uniten,Malaysia.

Ikovenko, S. (2012). *Using TRIZ for Competitive Patent Circumnavigation And Other Patent Strategies.* Paper presented at the MyTRIZ Workshop 2012, Batu Ferringhi, Penang, Malaysia.

Investopedia. Activities of Daily Living. Retrieved 8th September, 2014, from http://www.investopedia.com/terms/a/adl.asp

Ismail, N. R. (2012). The Right Medicine. *SIRIMLink, 2,* 28.

Karmegam, K., Sapuan, S. M., Ismail, M. Y., Ismail, N., Shamsul Bahri, M. T., Shuaib, S., Mohana, G. K., Seetha, P., TamilMoli, P., and Hanapi, M. J. (2011). Anthropometric study among adults of different ethnicity in Malaysia. *International Journal of the Physical Sciences, 6*(4), 777-788. doi: 10.5897/IJPS10.310

Kawamura, T., and Murakami, T. (2013). Multifunctional control of a two-wheel driven wheelchair considering comfort of a passenger. *IEEJ Transactions on Industry Applications, 133*(4), 404-413.

Keates, S. (2007). *Designing for Accessibility, A business guide to countering Design Exclusion*. New Jersy: Lawrence Erlbaum Associates Inc.

Khor, S. A., AbdulRahman, Z., and Sulong, N. Z. (2012). *Methods of Bladder Drainage for Traumatic Spinal Cord Injury Patients with Neurogenic Bladder*. Paper presented at the 11th ASIAN Spinal Cord Network(ASCoN) Conference, Kualar Lumpur.

Korgaonkar, P., Becerra, E., O'Leary, B., and Goldring, D. (2010). Product classifications, consumer characteristics, and patronage preference for online auction. *Journal of Retailing and Consumer Services, 17*(4), 270-277. doi: 10.1016/j.jretconser.2010.02.004

Krish, S. (2011). A Practical generative design method. *Computer-Aided Design, 43*. doi: 10.1016/j.cad.2010.09.009

Krisna, V., and Ulrich, K.T. (2001). Product Development Decisions: A review of the Literature. *Management Science 47*(1), 1-21.

Kroemer, K. H. E. (1999). Engineering Anthropometry. In W. Karwowski, Marrass, W.S (Ed.), *Occupational Ergonomics Handbook* (pp. 139-165). London: CRC Press.

Kumar, S. (1992). Rehabilitation: An Ergonomic Dimension. *Journal of Industrial Ergonomics, 9*(2), 97-108.

Lamb, G., Zimring, C., Chuzi J., and Dutcher, D. (2010). Designing Better Health Care Environments: Interprofessional Competences in Healthcare Design. *Journal of Interprofessional Care, 24*(4). doi: 10.3109/13561820903520344

Lane, J. P. (2012). The "Need to Knowledge" Model: An operational framework for knowledge translation and technology transfer *Technology and Disability, 24*, 187-192. doi: DOI 10.3233/TAD-2012-0346

Lauer, A., Rust, K.L, and Smith, R. O. (2006). ATOMS Project Technical Report - Factors in Assistive Technology Device Abandonment: Replacing "Abandonment" with "Discontinuance" Milwaukee: University of Winsconsin.

Lawton, C., Cook, S., May, A., Clemo, K., and Brown, S. (2008). Postural support strategies of disabled drivers and the effectiveness of postural support aids. *Applied Ergonomics, 39*(1), 47-55. doi: http://dx.doi.org/10.1016/j.apergo.2007.03.005

lebbon, C., and Coleman, R. (2003). A design Centred Approach In R. C. J.P. Clarkson, S. Keates and C. Lebbon (Ed.), *Inclusive Design: Design for whole population* (pp. 500-519). London: Springer-Verlag.

Lee, M. N., Abdullah, Y., and Mey, S.C. (2011). Employment of People with Disabilities In Malaysia: Drivers and Inhibitors. *International Journal of Special Education, 26*(1), 112-124.

Lee, S., W., Kim, Y, S., Park, K., and Bien, Z. (2010). Iterative Bayesian fuzzy clustering toward flexible icon-based assistive software for the disabled. *Information Sciences, 180*, 325-340.

Li, M., Ming, X., He, L., Zheng, M. and Xu, Z. (2015). A TRIZ-based Trimming method for Patent design around. *Computer-Aided Design, 62*(0), 20-30. doi: http://dx.doi.org/10.1016/j.cad.2014.10.005

Mahmud, J. O., Mohd, I. and Taib, J. M. (2012). *Trends on competitive machine/product design.* Paper presented at the Society of Petroleum Engineers - 36th Nigeria Annual Int. Conf. and Exhibition 2012, NAICE 2012 - Future of Oil and Gas: Right Balance with the Environment and Sustainable Stakeholders' Participation.

Marras, W. S. (2008). *The Working Back: A Systems View*. USA: John Wiley & Sons Inc.

McAdams, D. A., and Kostovich V. (2011). A framework and Representation for Universal Product Design. *International Journal of Design, 5*(1).

Meret-Hanke, L. A. (2011). Effects of the Program of All-Inclusive Care for the Elderly on Hospital Use. *The Gerontologist, 51*(6), 774-785.

Messler Jr, R. W. (2014). *Reverse Engineering: Mechanisms, Structures, Systems and Materials* (M. Pen Ed.): McGraw-Hill Education.

Miaskiewicz, T., and Kozar, K.A. . (2011). Personas and User-Centred design: How can personas benefit product design processes. *Design Studies, 32*(5), 417-430.

Miralles, C., Garcia-Sabater, J., Andres, C., and Cardos, M. (2007). Advantages of assembly lines in Sheltered Work Centres for Disabled. A case study. *International Journal of Production Economics, 110*, 187-197. doi: 10.1016/j.ijpe.2007.02.023

Mobi Electric Folding Wheelchair. (2012) http://www.universaldesignstyle.com. Retrieved. 04/08/2012

Mohd Ismail, M. S. (2004). *Design for Safety and cost tools for new cars.* (PhD Closed Access), Coventry University, United Kingdom.

Morris, C. (2007). *Paediatric Orthotics* (H. M. Mart Ed.). London: Mac Keith Press.

Mosby. (Ed.) (2009) Mosby Medical Dictionary (8th ed.). Elsevier Inc. 2012.

Mukhtar, M., Ismail, M, N., and Yahya, Y. (2012). A hierarchical classification of co-creation models and techniques to aid in product or service design. *Computers in Industry, 63*(4), 289-297. doi: http://dx.doi.org/10.1016/j.compind.2012.02.012

Mulgaonkar, A. P., Kornbluh, R., and Herr, H. (2008). A new frontier for orthotics and prothetics: Application of Dielectric Elastomer actuators to bionics. In F. Carpi, D. D. Rossi, R. Kornbluh, R. Pelrine and P. Sommer-Larsen (Eds.), *Dielectric Elastomers as Electromechanical Transducers* (pp. 321-329). Amsterdam: Elsevier.

Nakamura, M., Sakiyama,M., Suzurikawa, J.,Tsukada, S., Ohta, A., Kume,Y., Kawakami, H., Inoue, K., and Inoue, T. (2012). Methodology for user and user's life centered clinical evaluation of assistive technology (ULCEAT): Evaluation with prototype Robotic bed

Technology and Disability, 24, 273-282. doi: 10.3233/TAD-120358

Newell, A. F., and Gregor P. (Ed.). (1997). *Human Computer Interfaces for people with disabilities*. Amsterdam: Elsevier Science B.V.

Newell, A. F., Gregor P., Morgan, M., Pullin, G. and Macaulay, C. (2011). User-Sensitive Inclusive Design. doi: 10.1007/s10209-010-0203-y

Newsmedical (2009). news.medical.net. Retrieved 13th November, 2013

Nordy, K. (2010). Conceptual designing and technology: Short-range RFID as design material. *International Journal of Design, 4*(1), 29-44.

Nowak, E. (1999). Ergonomics and Rehabilitation. In W. Kawoski, Marrass, W.S (Ed.), *The Occupational Ergonomics Handbook* (pp. 1333-1339). USA: CRC Press, LLC.

NSCISC. (2011). Spinal Cord Injury Facts and Figures: National Spinal Cord Injury Statistical Centre, Birmingham, Alabama.

Ole, B., Andersen, V., Seim, R. (2011). Participatory ergonomics in design processes: The role of boundary objects. *Applied Ergonomics*, *42*(3), 464-472.

Ostroff, E. (2010). *Universal Design; An Evolving Paradigm* (Second ed.): MCGrawHill Companies.

Pahl, G., Beitz, W., Feldhusen, J., and Grote, K. H. (2007). *Engineering Design: A Systematic Approach* (B. Wallace K., L, Trans. Third ed.): Springer-Verlag London Limited.

Peckham, P. H., Thrope, G., Woloszko, J., Habasevich, R., Scherer, M., and Kantor, C. (1996). Technology transfer of neuroprosthetic devices. *Journal of Rehabilitation Research and Development, 33* (2), 173-183.

Pheasant, S., and Haslegrave. (2006). *Bodyspace; anthropometry, ergonomics and the design of work* (3rd ed.). Florida: CRC Press.

Pugh, S. (1993). *TOTAL DESIGN: Integrated Methods for Successful Product Engineering*: Addison-Willey Publishing Company, Inc.

Pullin, G. (2009). *Design meets Disability*. Cambridge: The MIT Press.

Quaglia, G., Franco, W., and Oderio, R. (2011). Wheechair.q, a motorized whellchair with stair climbing ability. *Machanism and Machine Theory, 46*, 1601-1609.

Ramlee, R. A., Tang, D. H. Z., and Ismail, M. M. (2012). *Smart Home System for Disabled People Via Wireless Bluetooth*. Paper presented at the 2012 International Conference on System Engineering and Technology, Bandung, Indonesia.

Rampino, L. (2011). The innovation pyramid: A categorization of the innovation phenomenon in the product-design field. *International Journal of Design, 5*(1), 3-16.

Rantanen, K., and Ellen Domb. (2008). *Simplified TRIZ: New Problems Solving Applications for Engineers and Manufacturing Professionals* (Second ed.). London: Auerbach Publications.

Redström, J. (2006). Towards user design? On the shift from object to user as the subject of design. *Design Studies, 27*(2), 123-139.

Robson, N. (2011). AC2011-1161: Developing Technologies That Enable Individuals With Disabilities: A Unique Experience.

Rousek, J. B., and Hallbeck, M.S. (2011). The use of simulated visual impairment to identify hospital design elements that contribute to way finding difficulties. *International Journal of Indusrial Ergonomics, 41*(5), 447-458. doi: 10.1016/j.ergon.2011.05.002

Rugby Defensive FS771LQ-32. (2012) http://www.healthcare deep.com. Retrieved. 04/08/2012

Sakakibara, B. M., Miller, W. C., Souza, M., Nikolova, V., and Best, K. L. (2013). Wheelchair skills training to improve confidence with using a manual wheelchair among older adults: A pilot study. *Archives of Physical Medicine and Rehabilitation, 94*(6), 1031-1037.

Sangelkar, S., Cowen, N., and McAdams, D. (2011). User activity – product function association based design rules for universal products. *Design Studies*, p1. doi: 10.1016/j.destud.2011.06.002

Sarkar, P., and Chakrabarti A. (2011). Assessing Design Creativity. *Design Studies, 32*, 348-383. doi: 10.1016/j.destud.2011.01.002

Sauret, C., Vaslin, P., Lavaste, F., de Saint Remy, N., and Cid, M. (2012). Effects of user's actions on rolling resistance and wheelchair stabilitry during handrim wheelchair Propulsion in the field. *Medical Engineering and Physics, 35*, 289-297. doi: http://dx.doi.org/10.1016/j.medengphy.2012.05.001

Savransky, D. S. (2000). *Engineering of creativity: Introduction to TRIZ Methodology of Inventive Problem Solving*. USA: CRC Press LLC.

Sawatzky, B., Kim W., Denison I. (2004). The Ergonomics of different Tyres and Tire pressures during wheelchair Propulsion. *Ergonomics, 47*, 1475-1483.

Scheaffer, R. L., Mulekar, M. S., and McClave, J.T. (2011). *Probability and Statistics for Engineers* (Fifth Edition ed.): Richard Starton.

Seymour, R. (2002). *Prothetics and Orthotics: Lower Limb and Spinal*. USA: Lippincott Williams & Williams.

Sheu, D. D. and Hou, C. T. (2013). TRIZ-based trimming for process-machine improvements: Slit-valve innovative redesign. *Computers & Industrial Engineering, 66*(3), 555-566. doi: http://dx.doi.org/10.1016/j.cie.2013.02.006

Snoek, G. J., Ijzerman, M.J., Hermens, H.J., and Maxwell, D. . (2004). Survey of the needs of patients with spinal cord injury: Impact and priority of improvement in hand functionin tetraplegics. *Spinal Cord, 42*(9), 526-532.

Soltani, S. H. K., Abas, M. Y., and Mohamad, B. A. (2011). Disabled children in Public Playgrounds: A Pilot Study. *Procedia - Social and Behavioral Sciences, 36*, 670-676.

Somavia, J. (2007). Facts on Disability in the World of Work. Retrieved 28, September, 2012, from www.ilo.org/employment/disability

Sousa, I. and Wallace, D. (2006). Product classification to support approximate life-cycle assessment of design concepts. *Technological Forecasting and Social Change, 73*(3), 228-249.
doi: http://dx.doi.org/10.1016/j.techfore.2004.03.007

Spool, J. M. (2011). Understanding the Kano Model- ATool for sophisticated Designers. Retrieved 16/08, 2013

Stevens, G., and Burley, J., . (1997). 3000 raw ideas = 1 commercial success! *Research Technology Management, 40*(3), 16-27.

Suda, A., Moriya, K., and Ioi, K. (2011). Study on a wheeled caster design for low carbon crash-wagons. *Japanese Society of Mechanical Engineers, 77*(777), 1998-2007.

Sui, K. W. M. (2010). Design Research Studies for the new needs: balance in theoretical study and design practice. *Procedia - Social and Behavioral Sciences, 2*, 1016-1023. doi: 10.1016/j.sbspro.2010.03.143

Sullivan, H. T., and Hakkinen, M.T. (2011). Preparedness and Warning Systems for Populations with Special Needs: Ensuring Everyone gets the Message(and Knows What To Do). *Geotech Geol Eng, 29*, 225-236. doi: 10.1007/s10706-010-9363-z

Sulmon, N., Slegers, K., Isacker, V., Gemou, M., Bekiaris, E. (2010). *Using Personas to capture Assistive Technology Needs of People with Disabilities.* Paper presented at the Persons with Disabilities Conference(CSUN), San Diego.

Swift, K. G., and Booker, J. D. (2003). *Process Selection from Design to Manufacture* (Second ed.): Butterworth-Heinemann.

Taormina-Weiss, W. (2011). World Facts and statistics on Disabilities and Disability Issues. Retrieved 1/10/2011,
from www.disabledworld.com/disability/statistics/who-disability

Thevenot, H. J., and Simpson, T. W. (2007). Guidelines to minimize variation when estimating product line commonality through product family dissection. *Design Studies, 28*(2), 175-194.
doi: http://dx.doi.org/10.1016/j.destud.2006.07.004

Tomiyama, T., Gu, P., Jin, Y., Lutters, Lutters, D., Kind, C. and Kimura, F. (2009). Design Methodologies: Industrial and Educational Applications. *CIRP Annala-Manufacturing Technology, 58*. doi: 10.1016/j.cirp.2009.09.003

Ullman, D. G. (1997). *The Mechanical Design Process* (International ed.). Singapore: McGraw-Hill.

Ullman, D. G. (2010). *The Mechanical Design Process* (Fourth ed.). New York: McgrawHill.

Usman, D., and Kane, I. L. (2012). Prevalence of Infectious Diseases in Katsina State: An insight using Clustering approach. *Engineering Science and Tecknology: An International Journal, 2*(6), 1009-1016.

Van der Woude, L. H. V., de Groot, S., and Janssen, T. W. J. (2006). Manual wheelchairs: research and innovation in sports and daily life. *Science & Sports, 21*(4), 226-235. doi: http://dx.doi.org/10.1016/j.scispo.2006.06.006

Vanoncini, M., Holderbaum, W., and Andrews, B.J. (2012). Electrical Simulation for trunk control in Paraplegia: a feasibility study. *Control Engineering Practice, 20*, 1247-1258.

Wang, L., ShenW., Neelakmkavil, J., and Pardasani, A. (2002). Collaborative Conceptual design-state of the art and future trends. *Computer Aided Design, 34*.

Warner, J. T., Cowan, F.J., Dustan, F.D., and Gregory, J.W. (1997). The validity of body mass index for the assessment of adiposity in children with disease states. *Ann Hum Biol, 24*, 209-215.

Wei, W., and Chang, W. (2008). Analytic network process-based model for selecting an optimal product design solution with zero-one goal programming. *Journal of Engineering Design, 19*(1), 15-44.

WHO. (1980). World Health Organisation Report.

WHO. (2011). World Report on Disability. In A. Officer, Posarac, A. (Ed.), *WHO 2011* (2011 ed., Vol. l). Malta: World Health Organisation.

Wilson, C. (2014). Unstructured Interviews: *Interview Techniques for UX Practitioners: A User - Centered Design Method* (pp. 43 -62). USA: Elsevier.

Winter, R., and Hotchkiss, R. (2006). *Mechanical Principles of Wheelchair Design.* (Masters), MIT, Massachusetts.

Wu, T., Tian, Renran., and Duffy, V.G. (2011). Performing Ergonomics Analyses through Virtual Interactive Design: Validity and Reliability Assessment. *Human Factors and Ergonomics in Manufacturing and Service Industries, 00*, 1-13. doi: 10.1002/hfm.20267

Xin, Z., Mei, Y., Chenglong, W., and Lirong W. . (2009). *Study of Sustainable Factors in Universal Design*. Paper presented at the IEEE 10th International Conference. Conference Publications retrieved from http://ieeexplore.ieee.org/stamp

Xu, Q., Jiao, R. J., Yang, X., Helander, M., Khalid, H. M. and Opperud, A. (2009). An analytical Kano model for customer need analysis. *Design Studies, 30*(1), 87-110. doi: http://dx.doi.org/10.1016/j.destud.2008.07.001

Yang, C.-C. (2011). A classification-based Kansei engineering system for modeling consumers' affective responses and analyzing product form features. *Expert Systems with Applications, 38*(9), 11382-11393. doi: http://dx.doi.org/10.1016/j.eswa.2011.03.008

Yazbeck, M., McVilly, K., and Parmenter, T. R. (2004). Attitudes Towards People with Intellectual Disabilities: An Australian Perspective. *Journal of Disability Policy Studies, 15*(95), 97-111. doi: 10.1177/10442073040150020401

Yilmaz, S., and Seifert, C. M. (2011). Creativity through design heuristics: A case study of expert product design. *Design Studies, 32*(4), 384-415.