STUDY OF A CONCURRENT DEVELOPMENT-DISSEMINATION MODEL FOR APPROPRIATE TECHNOLOGY: CASE OF IMPROVISED *CHAAK* FOR POTTERY INDUSTRY

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DOCTOR OF PHILOSOPHY

By

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CERTIFICATE

This is to certify that the thesis entitled "**STUDY OF A CONCURRENT DEVELOPMENT-DISSEMINATION MODEL FOR APPROPRIATE TECHNOLOGY: CASE OF IMPROVISED *CHAAK* FOR POTTERY INDUSTRY**", submitted by **Bibhuti Ranjan Bhattacharjya** (146154001), a research scholar in the Centre for Rural Technology, Indian Institute of Technology Guwahati, for the award of the degree of Doctor of Philosophy, is a record of an original research work carried out by him under my supervision and guidance. The thesis fulfilled all requirements as per the regulations of the institute and in my opinion has reached the standard needed for submission. The results embodied in this thesis have not been submitted to any other University or Institute for the award.

Dated: 29.11.2020
Place: Guwahati

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DECLARATION

I hereby declare that the work contained in this thesis entitled "**STUDY OF A CONCURRENT DEVELOPMENT- DISSEMINATION MODEL FOR APPROPRIATE TECHNOLOGY: CASE OF IMPROVISED *CHAAK* FOR POTTERY INDUSTRY**", is my own work done under the supervision of Prof. Sashindra K. Kakoty, at the Centre for Rural Technology, Indian Institute of Technology Guwahati (IITG). I hereby declare that to the best of my knowledge, it contains no materials previously published or written by another person, or substantial proportion of material which have been accepted for the award of any other degree or diploma at IITG or any other educational institute, except where due acknowledgement is made in this thesis. Any contribution made to the research made by others, with whom I have worked at IITG or elsewhere, is explicitly acknowledged in the thesis. I also hereby declare that the intellectual content of the thesis is the product of my work, and as per general norms of the reporting research findings, due acknowledgment have been made wherever the research findings of other researchers have been cited in the thesis.

Dated: 29.11.2020
Place: Guwahati

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To

My parents

Dwijendra Nath Bhattacharjya and Rekha Devi

For their love, motivation and sacrifice

&

My brother

Medini Kumar Bhattacharjya

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Bibhuti Ranjan Bhattacharjya

Abstract

Pottery industry plays an important role in the rural economy of Assam, India. The main worry state for the sector is that the artisans are still using the age-old, traditional pottery wheel (TPW) in pottery making. Overall, the process is very time-consuming and tedious because it is a repetitive task that requires frequent bending movements. The sitting arrangement (squatting postures, *viz*., bent neck and back and folded knees) is not ergonomically correct. One of the major reasons for health issues such as musculoskeletal pain and back pain among the pottery artisans is supposed to be because of such wrong working postures. Electric-powered wheels availabe in the market are also not able to cater to their unmet needs due to the inadequate supply of elctricity in remote villages.

In the present research endeavour, an attempt is made to redesign TPW with consideration of ergonomic principle and the local people's anthropometric data. To ensure proper directon of the study, two design statements are enunciated as follows:

- *Local people's anthropometric data are essential for successful design of technology, considering the variation in anthropometric data based on gender and ethnic diversity.*
- *Design and development of context-specific improvised pedal-operated chaak (IPC) coupled with a holistic knowledge and technology management mechanism is the basic need to rejuvenate the pottery industry of Assam.*

Target users' anthropometric data are the prime requirement for successful design intervention. However, paucity of anthropometric data of target users from Assam, India, is the major concern. To bridge the void, an attempt is made here to gather and analyse the anthropometric data of five ethnic groups (Boro, Garo, Hira, Karbi, and Rabha) from Assam, India. Seventy-two anthropometric body dimensions, including the age and body weight of 453 people from different districts of Assam, India, are summarized. The sample included 265 male and 188 female participants in the age group of 18 to 60 years. The variation in anthropometric data considering gender and ethnic diversity is also examined, and significant differences are observed in relation to gender and ethnicity. T-tests are carried out to verify the statistical significance of the variations in anthropometric dimensions across ethnic diversity within the same gender. Within-gender variations in stature values when comparing the Hira community

members with the Boro, Garo, Karbi, and Rabha populations is found to be statistically significant (P< 0.01). Similarly, significant outcomes are observed between sitting height values of different communities across the same gender. Also, statistical t-test results comparing the statistical significance of variance of anthropometric data (stature and sitting height) across genders for mean values of the total sample population of male and female anthropometric dimensions depict that all the anthropometric data except spank akimbo, sitting elbow rest height, grip diameter (inside), and BMI values were found to be significantly different (Pr < 0.01) for male and female. These findings validate that anthropometric dimensions vary across occupations, genders, geographical locations, and ethnicities.

Following the morphology of design process as suggested by Asimow, 1962; Chitale and Gupta, 1999, the TPW is redesigned. *Treadle mechanism* is skilfully adapted in the machine. A four-bar crank rocker mechanism is constructed to obtain the necessary motion. In deciding the different parameters of the four-bar planner crank rocker mechanism, anthropometric data of the target users are considered. A full-scale model of the machine is fabricated and field tested. The field-testing results clearly demonstrate that the design intervention is successful in reducing the health discomfort and energy expenditure besides reduction of increased heart rate. Male artisans' average productivity is found to be almost 1.7 times higher in the case of IPC than that of the TPW. Similarly, female artisans' average productivity is found to be almost 1.8 times higher in the case of IPC than that of the TPW.

The product along with its manufacturing process is successfully transferred to three rural micro-enterprises. Manufacturing process details and maintenance-related issues are demonstrated to them. In the absence of a structured approach and institutionalized intervention, such technology design and innovation efforts do not cater to the needs of the marginalized people living at the bottom of the pyramid (BoP). Hence, in this study, based on the experiences gathered from technology transfer of IPC, an effort is made to study technology transfer framework involving rural micro-enterprises.

Keywords: *Anthropometric measurements; Ergonomic design of machine; Sustainability-orienting design (SoD), Appropriate technology; Technology transfer; Bottom of the Pyramid (BoP)*

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Nomenclature

E	*Young's modulus*
i	*Gear ratio*
C_{bm}	*Bending factor*
C_{tm}	*Torsion factor*
n_1	*Minimum number of teeth*
n	*Factor of safety*
m	*Module (mm)*
M	*Bending moment*
N	*No of cycles*
$\varnothing$	*Pressure angle*
$\propto$	*Inclination angle*
θ	*Wrapping angle*
M_t	*Nominal twisting moment*
K_d	*Dynamic load factor*
K_{bl}	*Life factor for bending*
K_σ	*Fillet stress concentration factor*
K_σ	*Stress concentration factor for the fillet*
K	*Nominal power transmitted*
P	Power Transmitted
R	Cone distance
T	Twisting moment
σ_b	*Bending stress*
σ_u	*Ultimate tensile strength,*
σ_0	*Endurance limit stress in bending for repeated stress*
σ_{-1}	*Minimum endurance limit stress for complete reversal of stress*
σ_c	*Surface stress*
σ_y	*Yield stress*
k	Constant depending upon type of tooth

Chapter 1

Innovation, design and transfer of technology: bottom of the pyramid context

1.1 Introduction

The *2020 Global Multidimensional Poverty Index* published by the *Oxford Poverty and Human Development Initiatives* on 26th July 2020 has expressed that 1.3 billion people across 107 developing countries are under acute poverty (Alkire, et al., 2020). It depicts that 22% of the world's population lives with an income less than US$1.90 a day, who face significant life challenges in day-to-day life (e.g. lack of essential services *viz.*, clean water, adequate supply of electricity, public health, etc.). Prof. C. K. Prahlad inculcated the term "*bottom of the bottom of the pyramid (BoP)*" in his book "*Fortune at the bottom of the pyramid: Eradicating poverty through profits*" to represent those people who are under extreme poverty (Prahlad, 2005). Integrated solutions are necessary that have been designed, developed and delivered squarely in the context of BoP to satisfy the unresolved needs of those marginalized people living at the BoP (Knorringa et al., 206; Hernandez et al., 2019).

Scarcity of resources/infrastructure is considered to be the primary challenge regarding the development and delivery of appropriate products/technology in BoP. A weak economy, complex social fabric, severe climatic conditions, political instability, poor governance, fragmented delivery system etc. are some of the significant challenges in such settings (Patnaik and Bhowmick, 2020). That is the reason why design, development, and delivery of a novel product/technology to fulfil the needs and aspirations of those people is a challenging endeavour. Design and delivery of a novel product are challenging, as the dynamic integration of socio-cognitive aspects of the resource-constrained society with technological factors is a complicated task. Recently, researchers have been debating on practicing sustainability-orienting (SoD) design approach to counter those challenges in BoP (Banerjee and Punekar, 2020).

1.2 State of the art

The call for the adoption of the inclusive innovation in the United Nations' Sustainable Development Goals in the year 2015, brings a tectonic move in the paradigm of design and innovation (Ceschi and Gaziulusoy, 2016; Withanage et al., 2016; Patnaik and Bhowmick, 2020). It is a universal call that has garnered significant awareness among researchers to envisage perspectives of sustainability in addressing societal issues (e.g. poverty, inequality, injustice) at the BoP. Responding to the call a fluent number of studies have discussed theoretical framework and practical experiences in "*design for sustainable community development efforts*" (e.g. Judge, et al., 2015; Wood and Mattson, 2016; Mattson et al., 2017; Thacker et al., 2017; Diaz Lankenau and Winter, 2020a; Diaz Lankenau and Winter, 2020b; Pack et al., 2020; Stevenson et al., 2020 etc.). To advance the understanding, research findings on "*design development and delivery of the sustainable product at the BoP*" have been synthesized and based on the results a framework is developed (shown in Fig. 1.1) to elucidate the innovation dynamics at the BoP.

1.3 Literature review

1.3.1 Sustainability orienting design (SoD) process

The conventional innovation process in poverty alleviation projects follows a top-down model. Such linear model (Malik 2002) of innovation follows the neo-classical theories of economic growth (Katz, 1994) which remains largely cost-intensive and exogenous to the marginalized people living in resource-constrained society (Kaplinksy, 2011). It offers a limited response to the socio-economic hurdles (e.g. weak economy, complex social-cultural norms and values, low level of skill, institutional voids etc.) leading to increasing inequality at the BoP (Pattnaik and Dhal, 2015). Achieving social and ethical fulfilment (Pandza and Ellwood, 2013) with such a linear model (Patnaik and Bhowmick, 2019) is relatively challenging (Aubert, 2004; Baskaran and Mehta, 2016). It destroys the existing ecosystem of those communities (e.g. waters scarcity, damage to soil structure, environmental issue etc.) due to application of wrong/inappropriate technology (Pattnaik and Dhal, 2015; Banerjee and Punekar, 2020). In conventional technology transfer projects, a technology/product, which is successful in the developed world, is supposed to work positively on developing nations. It works on the assumption that a lack of financial resources is the sole reason for low diffusion of novel products/technologies in resource-crunched societies. In reality, the lack of finance is not the only reason for the weak diffusion of novel product/technology in BoP. This is the reason why technologies/products are underutilized (Banerjee and Punekar, 2020) in developing world, yielding waste of money in the majority of poverty alleviation projects.

To rectify the shortcomings in the conventional innovation process, innovation scholars have been debating on inculcating a more sustainable product/technology design method, which becomes appropriate for those marginalized people. One such approach is SoD practice (Banerjee and Punekar, 2020; Keskin, et al., 2020). SoD involves (re)designing product, services or system with an emphasis to address the Triple Bottom Line of Sustainability (Elkington, 1997). In the context of design for BoP, the prime objective of SoD is to develop solution which is affordable for resource-poor consumer and at the same time it reduces negative impact on the surrounding (society and environment). It challenges all the steps in the conventional innovation process, from ideation to product delivery and maintenance at user's place. Instead of borrowing products/technologies from global north to south, it appreciates in (re)designing novel products/technologies locally inside the territory of the community. Thus, it opposes the traditional technology transfer model where leapfrogged products, which are not sold in developed nations, are delivered at a low cost in developing world (Knorringa, et al., 2016).

High-tech, sophisticated products/technologies don't suit in BoP (Patnaik and Bhowmick, 2019). That does not mean that people living in poverty deserve leapfrogged product (Knorringa, et al., 2016). They need products/technologies which is simple in engineering so that it can be managed in a resource-poor environment. It must be cost-effective and at the same time, quality should not be compromised. For example, the case of portable ECG machine designed by General Electrical (GE) for rural India can be mentioned here. In redesigning the ECG machine, GE stressed on the cost factor (drastic reduction from $10,000 to $1,000), environmental requirement (dust pollution), inadequate supply of electricity, transpiration to remote areas etc. At the same time, it complied necessary technical requirements (Pansera, 2013).

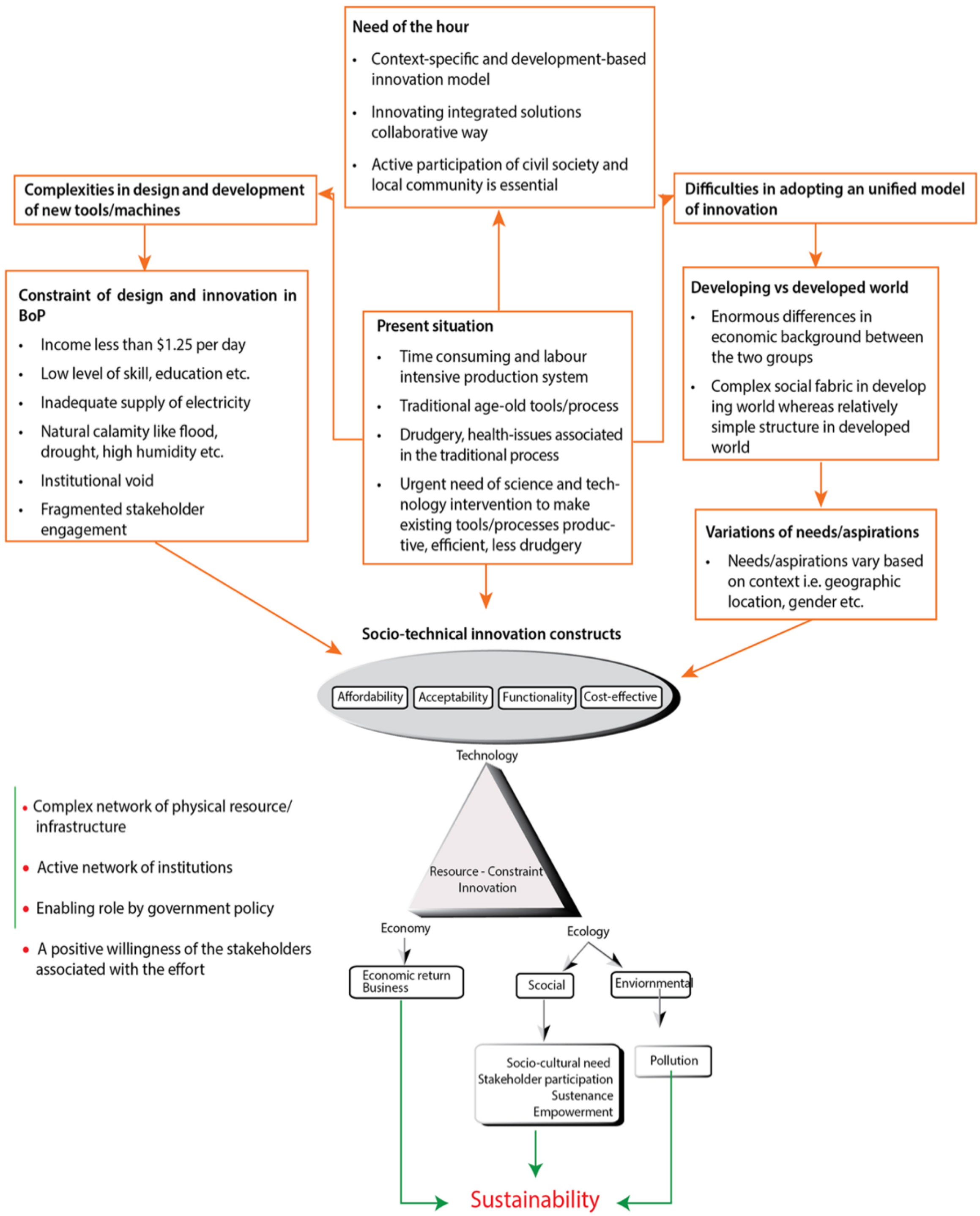


Fig. 1.1 The holistic design framework for marginalized people in BoP

A synthesis of existing literature relevant to the subject depicts that only cost reduction and simplicity in functionality could not help in improving the acceptability among the resource-poor community. Inherited socio-cultural norms/values of the target-community also need to be considered while designing an integrated solution for BoP (Viswanathan and Sridharan, 2012). Hence, another stream of literature argued that non-business organizations (academia with local actor viz., civil society, NGO, etc.) should come forward so that integrated solutions can be innovated locally as per the needs and aspirations of target-community and deliver to the marginalized people.

SoD appreciates co-designing with local people instead of design the product first and then approach them (Sanders and Stappers, 2008). The basic idea behind the co-design approach is to stimulate an effective dialogue between the technical team and the people for whom it is to be designed. Such a design philosophy is expected to accumulate broader perspectives of technology, society, economy, and environment (Cockbill, et al., 2019). Design and innovation through cooperation and mutual learning (broader aspects of society) are cherished in such innovation discourses (Hostettler and Boley, 2014). Such practices can only ensure the product to reach the people living at the BoP. It is also necessary for the design team to formulate measures that ensures long term sustenance of a new product at the users' place.

In the market-centric model of product design, the end-users are considered as customer. The design process is governed by the objective of profit maximization of the product developers. The target-users voices received very little space in the design process. As a result, many a time, it fails to address the issues, like inequality, complex socio-cultural needs, environmental concerns, etc. in the target-society. However, SoD approach considers the target-users as the co-designer. They are included in the process starting from ideation of the project. Thus, SoD induces more reflections towards adoption of an inclusive innovation strategy (Shin, et al., 2019) for achieving the target goals of SDGs (Corsi, et al., 2019; Molina-Maturano, et al., 2019; Priyadarshini and Abhilash, 2019). SoD approach appreciates bridging the gap and developing an organic linkage between society, economy and environment A pictorial representation of the basic architect of SoD process is presented in Fig.1.2.

1.3.2 Factors influencing the design, development and delivery process in BoP

In response to above discussed issues, a review of the existing literature is performed to map the characteristics of product/technology design efforts in the context of resource-constrained society. On the basis of the results, a brief summary of evolution of idea/models for design and delivery of integrated solutions for alleviating issues plaguing under poverty is presented in Table 1.1. Besides, a set of qualitative criteria explaining desirable characteristics that need to be addressed during design and delivery of appropriate product/technology in resource-crunched society is discussed in Table 1.2. Based on the review of existing literature, following characteristics are identified for successful product/technology in BoP context:

- Simple technology which requires a low investment of capital/resource and can attain intended objectives in the target-society
- Highly adaptable and flexible in target-society and easily affordable by the end-users
- Relatively labour intensive but more productive/efficient than traditional technologies
- Technology which can be understood, controlled and maintained by unskilled/semiskilled workforce
- Technology/product which can be manufactured in villages or small workshops, and hence maintenance related issues can be solved locally
- Local people's participation in the innovation process
- Technology which are flexible, can be adapted to different places and changing circumstances
- Technology which can be used in productive ways without harming the social norms/values and environment.

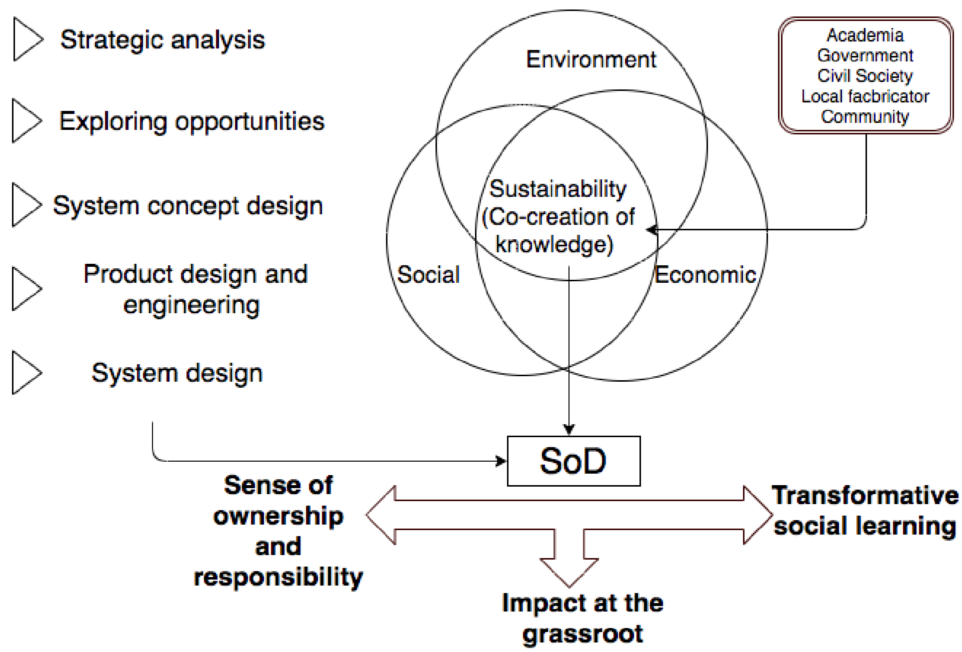


Fig. 1.2 Architect of SoD practice in new product design

1.4 Research gap

Reported literature prevails that people do not show interest for those imported products/technologies which fail to meet the socio-economic-cultural needs/aspirations of people living under poverty. For example, although many variants of improved cook stove are available in the market, people still use traditional open-fired cook stove. Most of those improved cook stove fail to fulfil the socio-cultural context of the resource-crunched setting, although technical dimensions are better than conventional cook stove.

The existing research offers little insights into the experimentation process of engineering product design and delivery for sustainable community development at the BoP (Keskin, et al., 2020). Available research articles are mostly focused on the management perspectives of technology at the BoP (Santiago, et al., 2019), which ignores how factors related to sustainable design and innovation viz., acceptability and adaptability of a new product at the grass root (Patnaik and Bhowmick, 2020) can be accommodated in the design process . The research on micro-level product/technology design and delivery in BoP is inadequate to elucidate how multiple actors/stakeholders should collaborate in the design process for successful design and delivery of novel products/technology for resource-poor people (Wood and Mattson, 2016; Mattson, et al., 2017; Jagtap and Larsson, 2019; Stevenson, et al., 2020). Existing studies are mostly concentrated on developing a better business model for BoP while ignore how context- specific socio-cultural issues to be tackled while deciding the technical features in an engineering product/technology for BoP. Existing studies fail to apprehend how broader aspects of society can be integrated into technical features for incorporation of holistic and balanced approach of sustainability during the design and development of a mechanical engineering product. Thus there is scope for further research on SoD practice in product design in a BoP context (Banerjee and Punekar, 2020).

1.5 Summary

This chapter discusses the importance of SoD practices in novel product design for addressing the unmet needs at the BoP. Knowledge gathered on the subject during the relevant literature analysis is discussed in the chapter, which is indicating that there are scopes for further research on SoD practices in design and delivery of new product at the BoP. The scope of the present work and methodology are presented in the next chapter.

Table 1.1
Summary of technology design and delivery models for BoP

- In India, M. K. Gandhi was the pioneer in initiating a movement for localized and context-specific technology intervention to reduce the drudgery of rural artisans and for the betterment of the village economy in early 1930s. He opposed import of capital intensive, large scale western technology to India fearing that it would create issues like, unemployment in villages. He opined that the infrastructure of the country is not favorable to large-scale technology. The application of such technology will underpin the massive process of exclusion as majority of the artisans are unskilled, low level of skill etc. (Pattnaik and Dhal, 2015; Patnaik and Bhowmick, 2019).

- Later, Schumacher extended Gandhi's vision of 'rural technology' and coined the term "Appropriate Technology" in 1970s. He poised an endogenous and self-reliant product design strategy that envies on (re)design traditionally used tools in day-to-day practices to make it useful and efficient rather than exporting high-tech machinery from western countries. The four criteria of 'appropriate technology' are: simplicity, small scale and decentralized, local people's control, ecological sustainability (Schumacher, 1973; Chataway, et al., 2014; Bauer and Brown, 2014; Pattnaik and Dhal, 2015; Rosca, et al., 2018).

- In 2002, Prof. C. K Prahlad introduced a market-centric approach for connecting the poor with products/technologies as per the need of marginalized people in the developing world which is known as the BoP innovation model. It stressed on co-creation of innovation for 'good enough' and 'affordable product/technology' as well as building a business ecosystem to make the innovation reach the bottom of the pyramid (Prahlad and Hart, 2002; Prahlad, 2004; Pansera and Owen, 2015; Hart, et al., 2016). Following, Prahlad's BoP innovation strategy, a host of new terminologies appear in the literature of innovation management. Overall, this new paradigm of innovation literature can be broadly classified based on three major features: cost-effectiveness, ease of use, user-friendly for marginalized people. Another stream of literature criticized enterprise-based model poised by Prof. Prahalad stating that such policy ignores the socio-economic cause of poverty and inclusion (Bhaduri, 2006; Dolan, 2013; Dolan and Rajak, 2016; Arora and Romijn, 2011; Levidow and Papaioannou, 2017; Karnani, 2017).

- Recently, SoD approach received significant attraction. Participation of non-business actors/stakeholders, especially academia and civil society received significant attention in this field. It presuppose creating more responsible products that have a positive connotation to the social and ethical aspects of the society.

Table 1.2
Landscape factors influencing design and delivery of product/technology at the BoP

Sl. No	Author	Title	Focus of research	Findings
1.	Teitel, 1978	On the Concept of Appropriate Technology For Less Industrialized Countries	Complications arises on AT design and transfer in least industrialized countries are discussed. The context considered is manufacturing industries	Criteria that made a technology inappropriate is discussed.
2.	Bowon, 1979	Appropriate Technology for Developing Countries: Some Issues	AT forecasting and identification process is discussed and parameters for evaluation of AT is suggested.	Understanding the socio-cultural, economic and political system of the target society is essential before selection of AT.
3.	Pellegrini, 1979	The Problem of Appropriate Technology. In A. de Giorgio and C. Roveda (Eds.), Criteria for Selecting Appropriate Technologies Under Different Cultural, Technical and Social Conditions	This study presented working definition of AT; criteria for success in implementation of At is analysed.	Complexities associated in the system need to be studied extensively.
4.	Clegg, 1988	Appropriate Technology for manufacturing: Some management issues	AT's role in advance manufacturing technology is discussed	Qualitative discussion is presented on types of technology, role of human and organizations to support technology.
5.	Wicklein 1999	Designing for Appropriate Technology in Developing Countries	Important factors for evaluating success or failure of AT by which efficiency of AT will be enhanced is discussed.	Appropriateness of technology in the context of AT is discussed.
6.	Akubue, 2000.	Appropriate Technology for Socioeconomic Development in Third World countries.	Role of AT in socio-economic development of Third World Countries is discussed.	AT is mentioned as progressive one, not fixed technology; attention is necessary in designing AT to foster innovation.
7.	Vanek, 2003	Design philosophies for Appropriate Technology. In *Field Guide to Appropriate Technology*	Common theories associated with AT research that aim at bringing socio-economic progress at the BoP.	Proper planning at the ideation is essential to reduce vulnerabilities in society and assure long term sustenance.
8.	Grieve, 2004	Appropriate Technology in a Globalizing World	Theories entail to AT research are discussed.	AT ensure competitive advantage in less developed countries.
9.	Choi, 2009	Technology Transfer Issues and a New Technology Transfer Model	A technology transfer model is presented.	The role of appropriateness of technology in technology transfer effort is discussed.

Table 1.2 (continued)

10.	Murphy, et al., 2009	Appropriate technology – A comprehensive approach for water and sanitation in the developing world	Comprehensive view on AT is elaborated, the concept of AT is practiced in field of water and sanitation.	AT approach is helpful in designing engineering products to address societal issues.
11.	Pradhan, et al., 2010	Design, development and testing of hand-operated decorticator for Jatropha fruit	A manual-powered is designed and developed for decortications of Jatropha fruit.	Manually-powered machine better suits in the rural Indian context due to inadequate supply of electricity
12.	Pearce, et al., 2010	Open Design Based Strategies to enhance Appropriate Technology Development	Bringing transparency in AT design and development to increase efficiency.	Open Source channel of AT is appreciated sustainability.
13.	Zelenika and Pearce, 2011	Barriers to Appropriate Technology Growth in Sustainable Development	Barriers in designing AT is discussed.	Stakeholders' views including industrial sectors and feedback from target-community is essential in AT design and development effort.
14.	Tahmoores, et al., 2011	Selecting the Appropriate Technology Transfer Method to Reach the Technology Localization	Factors that need to be considered for technology localization is discussed	Organization framework is essential component for technology localization
15.	Bolay, 2012	Appropriate Technologies for Sustainable Development	Importance of technological features in predicting social future of target community is discussed	Proper need identification is essential for sustainability.
16.	Sianipar, 2013	Community Empowerment through Appropriate Technology: Sustaining the Sustainable Development.	Necessity of establishing a systematic connection between the target-community and technology developers/implementers is discussed	Bridging the void between implementers and community is essential to achieve sustainability.
17.	Sianipar, et al., 2013a.	Design Methodology for Appropriate Technology: Engineering as if People Mattered.	Explored AT design methodology	Local people's participation is the key in design and development effort of AT
18.	Mattson, C. A. and Wood, A. E., 2014	Nine principles for design for the developing world as derived from the engineering literature	This study reviewed findings of reported studies on "engineering design for sustainable development"	This study developed nine principles for successful design and delivery of engineering products with a focus on alleviating poverty.

Table 1.2 (continued)

19.	Sianipar, et al., 2014.	Design and Technological Appropriateness: The Quest for community survivability	This study explore on how appropriateness of technology to be decided	Appropriateness is to access based on specific context of target community for which engineers need to choose proper technology and method.
20.	Sianipar, 2014a	Environmental Forensics on Appropriate-Technology enhanced Supply Chain of Rural Commodities	Link between supply chain and AT is explored	Cost based method is suggested to evaluate AT in supply chain
21.	Sianipar, 2014b	Interdependency of Cleaner Production and Cleaner Application: Towards an Integrated Assessment on Appropriate Technology	Studying the importance of proper material usage in developing to avoid environmental damage	Suggested for application of cleaner material and production system in AT design and development.
22.	Sianipar, 2014c	Materials Research in Engineering Materials, Appropriate Technology: In the Midst of Science, Engineering, and Technology.	Importance of martial research in AT field is discussed	Material researchers need to be well informed about the social, economic and environment facets of AT system.
23.	Wibisono, et al., 2014	Interface between appropriate technology and sustainable energy policy in vulnerable societies	Explored the gap between the AT developers and local community in the energy sector	Local people involvement in the process of design and development of energy technologies is suggested.
24.	Judge, et al., 2015	Developing world users as lead users: A case study in engineering reverse innovation	This paper examined the “reverse innovation” process during design and delivery of a low cost wheel chair for marginalized people	This study depicts the importance of involvement of users in the design process to identify latent needs of the target-users.
25.	Lissenden, et al., 2015	An era of Appropriate Technology: Evolutions, oversights and opportunities	Highlighted the progress of AT research in the global level	Knowledge gap identified in AT research, especially in the implementation stage
26.	Kiani, 2015	Evaluation of effective factors on the transfer of appropriate technologies in Sugarcane Industries	Technology transfer models for sugar cane industry studied	Failure of technology transfer is mostly contributed by the inappropriateness of technology.

Table 1.2 (continued)

27.	Park and Ohm, 2015	Appropriate Technology for Sustainable Ecosystems: Case Studies of Energy Self- Reliant Villages and the Future of the Energy Industry	Successful energy technology initiatives from various countries are studied	This study reveals the importance of reverse engineering (redesigning technology as per community need).
28.	Sorlini et al. 2015	Appropriate Technologies for drinking water treatment in Mediterranean Countries	Comprehensive analysis of various technologies related to drinking water	Developing common framework to analyze the appropriateness of technology is difficult.
29.	Annand and Rao, 2016	Models for deployment of solar PV lighting applications in rural India	Case-based study to understand the determinants of success and failure of solar PV lighting technologies in rural India.	Appropriate financing mechanism plays an crucial role in the success of technology transfer. Awareness and capacity building programs are essential
30.	Bauer and Brown, 2016	Remotely designed appropriate technology for emergency disaster response in Nepal	Bio-sand filter is designed for disaster affected people in Nepal.	Study on the effectiveness of the filter prevails that further modification is necessary.
31.	Carnie, et al., 2016	The development and evaluation of a speciality hand knitting yarn using appropriate technology for the empowerment of women in rural India	Process improvisation of Yarn production is explored.	AT can be used in craft sector to make standardize the traditional production process.
32.	Hazarika, et al., 2016	Adoption of modern weaving technology in the handloom micro-enterprises in Assam: A Double Hurdle approach	To understand factors influencing adoption of technology in rural handloom sector of Assam, India.	End-users' age and gender, availability of resource, access to credit/capital, marketing linkages, training/workshops etc. play an important role in technology adoption
33.	Joshi and Seay, 2016	An Appropriate Technology Based Solution to Convert Waste Plastic into Fuel Oil in Underdeveloped Regions	Simple and cost-effective solution to produce fuel prom waste-plastic.	AT contributing environmental sustainability by eliminating use of Charcoal.

Table 1.2 (continued)

34.	Sugathan, et al., 2016	The development and evaluation of a specially hand knitting yarn using appropriate technology for the empowerment of women in rural India	Developing a better tool/technology to standardize the traditional hand-knitting process of rural women in a South Indian village	Successful technology intervention necessitates adequate understanding off the cultural context of the target-group so that inherited socio-cultural aspects are reflected in the new intervention.
35.	Jianghua et al., 2017	Providing Appropriate Technology for Emerging Markets: Case Study on China's Solar Thermal Industry	New product development process within the context of At is studied.	AT is a context-specific concept, hence more in-depth study is necessary in the subject.
36.	Lee, 2018	Acceptance Factors of Appropriate Technology: Case of Water Purification Systems in Binh Dinh, Vietnam	Factors associated with successful design, development and development is accessed	Generalized model in AT is difficult to achieve.
37.	Mattson, et al., 2017	Village Drill: A case study in engineering for global development with five years of data post market-introduction	This study presented a realistic view of design and delivery of engineering product in poverty alleviation project	Six components related to product design and delivery in the context of emerging economies are discussed based on experiences gathered during design and delivery of the Village Drill.
38.	Youngwhan and Hwang, 2018	Crowd-funding as an Alternative Means for Funding Sustainable Appropriate Technology: Acceptance Determinants of Backers	Factors associated with crowd-funding in the context of AT is examined.	Important factors are: social influence, trust, effort expectancy.
39.	Joshi, et al., 2019	Adoption of solar photovoltaic lighting in rural India: Role of localization strategy	A discussion is reported based on experiences during the implementation of off-grid solar photovoltaic technology in the rural India.	Localized and context-specific technology design and delivery strategy better suits in rural Indian context.

Table 1.2 (continued)

40.	Parwez and Shekar, 2019	Understanding of grassroots innovations in India: evidence from the countryside	Aims to conceptualize innovations as solutions to the problems at grassroots	Findings reveal the importance of non-business institutions in the design and delivery of appropriate solutions for solving problems at the grassroots.
41.	Singh et al., 2019	Assessing the appropriate grassroots technological innovation for sustainable development	To understand insights into the subject of technology adoption and diffusion at the grassroots level. This study considers 32 Grassroots technological innovation in three different rural non-farm sectors.	One significant recommendation is that to standardize traditional processes existing tool/technology in practice need to be improvised instead of replacing it by an imported technology from outside.
42.	Wood and Mattson, 2019	Quantifying the effects of various factors on the utility of design ethnography in the developing world	This study examined the utility of the tool 'ethnography' in product design activities where design is primarily aimed at poverty alleviation in developing countries.	Results depict that the tool impact positively in the design process. It helps in understanding the socio-cultural needs/aspirations of the target-community effectively
43.	Pack, et al., 2020	Social impact in product design, an exploration of current industry practices	To understand the current practices of product design where product design effort is aimed at solving societal issue in emerging market	Social impact assessment and social life cycle assessment are two emerging practices in novel product design activities.
44.	Prem and Tewari, 2020	Development of human-powered fish feeding machine for freshwater aquaculture farms of developing countries	To design and development of a human-powered fish feeding machine for developing nations	Manually-powered machine better suits in developing nations rather than opting a mechanized device for marginalized people in developing countries due to weak economy.

Chapter 2

Scope of the present work and methodology

2.1 Introduction

An analysis on the available literature resulted in establishing the research gaps as presented in the previous chapter. Based on the research gaps, the problem identification through community dialogue and then drawing a methodology to pursue the goals are presented in this chapter.

In India, the cottage industry plays an important role in the rural economy. However, the worrying state is that technology adoption in the sector is almost nil. Although the industry has tremendous scope for rejuvenation, the country's research institutions and laboratories have not shown keen interest to consider it as research problem. Many a time, technology is developed but fail in successful delivery to the target-community. Such deficiency is due to that premier technical institutions and laboratories typically lack action groups that hinder necessary information sharing between academia and community. Thus there is a big vacuum between the two, which needs to be bridged. This need motivated to take it as a research challenge so that the perspectives of socio-technical system design can be experimented.

2.2 Contextual study

At the start of this work, a community-dialogue was organized at Guwahati, the capital of Assam, a state in the northeaster part of India. People from academia, civil society representatives and government officials, participated in the community-dialogue. The list of participants in the community-dialogue is shown in Table 2.1. During the meeting, many technological needs related to rural non-farm sector were discussed.

Swabhiman, a non-government organization (NGO) from Assam, India, enlightened about the necessity of technology intervention in the Pottery sector of the state. Out of a number of technological needs deliberated during the community-dialogue, one specific issue of redesigning the traditional Pottery wheel (TPW) also came up.

2.2.1 Different steps of Pottery making

Clay mixing – The first step for any potter is mixing of clay and water. It is one of the vital steps in pottery making process. The clay is the main raw material of this art. However, it is a very special kind of clay and not abundantly available in nature. The clay mixing is done manually in which only women and girls are engaged in general. It is a laborious and time-consuming process and it needs to be corrected.

Table 2.1
Details of participants from different organizations

Sl No.	*Type of organizations*	*Organizations*	*No of participants*	*Topic of discussion*
1.	Government organizations	North Eastern Handicrafts and Handloom Development Corporation (NEHHDC)	03	Technological needs, associated problems in existing technologies, policy related issues, sources of government funding for technology transfer, availability of fund for skilling artisans etc.
		North Eastern Development Finance Corporation Lt.d (NEDFi),	04	
		North Eastern Regional Agricultural Marketing Corporation, Ltd. (NERMAC)	04	
		Indian Institute of Entrepreneurship (IIE)	05	
		Rural Technology cation Group (RuTAG)	05	
2	Academic institutions	Indian Institute of Technology Guwahati	04	
		Indian Institute of Technology Kharagpur	03	
3.	Micro-enterprise:	M/S. A. P. Enterprise	02	
		M/S. Jalan Agro Pvt. Ltd.	02	
		M/S. Labanya Udyog Private Ltd.	02	
4.	Civil Society	Swabhiman	06	
		North East Centre for Sustainable Development	04	
		North-east Pottery Research and Training Centre	08	

Tilling of clay - The next process after clay mixing is the tilling of clay. The clay, which is mixed with proper amount of water in the first step, is sent to the next step of a pottery making crafts. The tilling process is carried out by using a small tool made of bamboo and the tool is used for tilling the sticky clay. The main purpose of this tilling process is to soften the clay and remove the other unwanted particles present in the clay like plant leaves, bamboo strips etc. The tilling process requires a very large amount of manual effort and it is a time consuming process which delays the production. This process improves the fineness of the clay and at the same time, it enables the potter for making fine finish products.

Moulding in *Chaak* - Moulding in a *Chaak* is the process in which the shape of the craft is provided through a proper combination of hand and mind of the potter. Here the clay is placed in a hand driven wooden potter wheel, which is rotated manually at a speed of around 200 rpm.

Rolling/Forming of clay Parts - This is a very crucial process in manufacturing bottom and neck parts of various size earthen pots. A small hammering force is applied by a number of women Potters with a small wooden hammer in order to maintain the thickness of the bottom surface of the pot.

Drying - After the required shape and design is provided, items need to be dried to get the final products. The drying is done in a clay furnace using wood/dry leaves and sometime open firing is also done to generate heat. The person engaged for drying purpose has to remain near to this hot chamber for 8-9 hours a day which is very harmful for health.

Steps involved in Pottery making have been shown in Fig. 2.1.

Fig. 2.1 Steps involved in traditional pottery industry of Assam

2.2.2 Associated concerns in the TPW

In Assam, pottery plays a vital role in providing employment opportunities to a large number of rural artisans who sell their pottery items in local markets. Besides employing artisans, the sector offers job opportunities to non-artisans during slack seasons of agriculture and to other tertiary sector employees through selling the items in the state and outside the state. Today, the primary concern is that the sector is mostly dependent on age-old traditional tools, which are labour intensive and time-consuming.

The TPW is a circular wooden wheel, which is mounted on a porcelain cup (shown in Fig. 2.2). Necessary energy has to be imparted to the wheel using muscle power while working. To rotate the plate, the male potters use a bamboo stick, which is inserted in a hole on the plate. As shown in Fig. 2.2, the potter rotates the bamboo stick in a clockwise direction. It needs high muscle power, which is relatively difficult for the female artisans. That is why they use a smaller version of a pottery wheel, which is also rotated using muscle power. Workers sit on the ground with their legs folded to mould the clay on the wheel while imparting manual energy to spin the Wheel. Overall, the process is very time-consuming and tedious being a repetitive task that requires frequent bending movements. The prevailing work conditions in the sector strongly indicates the presence of task-related issues.

Fig. 2.2 Traditional *Chaak* used by male and female artisans

2.2.3 Investigating work-related health issues among artisans

This investigation covers work-related health issues in terms of pain relevance among Pottery artisans associated with clay moulding. Modified Nordic Musculoskeletal Questionnaire (NMQ) (Kuorinka, et al., 1987) was used to access the pain-related problems among the artisans in the last 12 months. Three hundred and sixty artisans were randomly selected from different parts of Assam, India, for this study. Only those artisans have participated in the study who volunteered to be part of this study. Socio-demographic and work-related details were also noted during the study.

2.2.3.1 Socio-demographic details

The socio-demographic and job details of Pottery artisans in Assam are presented in Table 2.2. The mean age of the participants is 38.3 years for the male with a standard deviation of 11.4 years and 34.6 years for female artisans with a standard deviation of 10.2 years. This study depicts that the level of education among artisans is not impressive as 22.8% of male Pottery artisans and 51.1% of the female artisan are illiterate.

2.2.3.2 Work-related details

Pottery is a household cottage industry in Assam. Hence, it is practiced as livelihood opportunities from one generation to another generation. As the survey result depicts, the participants have been associated with pottery making activities for 1- 38 years. The average working experience of male artisans in pottery making is 12.2 Years (standard deviation- 10.13 Years), whereas for female, it is found to be 10.4 years (standard deviation – 9.4 years). Children also participate in pottery activities to support their parents although this study considers only those artisans aged 18 to 60 years.

Interaction with artisans depicts that in addition to pottery activities, artisans are involved in other livelihood activities such as agriculture, daily wage labour, weaving etc. Artisans start their pottery works as early as 6 a.m. and continues up to late evening during peak seasons. They take a break of 30-45 minutes in every 1.30 -2 hour of working for relaxation and perform other day-to-day activities. Women are mostly responsible for cooking, washing clothes, looking after children etc. Male artisans work an average of 11.0 hours (SD – 9.1 hours) per

Table 2.2
Socio-demographic and work-related details of pottery artisans (n=360)

Sl. No.	Variables		Male (n=180)	Female (n=180)
1.	Age (year), µ (SD)		38.3 (11.4) Range: 18-60	34.6 (10.2) Range: 18-60
2.	Material status n (%)	Single	98 (54.4%)	79 (43.9%)
		Married	82 (45.6%)	101(56.1%)
3.	Education level, n (%)	Illiterate	41 (22.8%)	91(51.1%)
		Primary	86(47.8%)	42(23.3%)
		Secondary	44 (24.4%)	46(25.6%)
		Graduate	09 (05.0%)	0
4.	Years worked as a Pottery artisan, µ (SD)		12.2 (10.1) Range: 01 -38	10.4 (9.4) Range: 01 -33
5.	Daily working hours, µ (SD)		11.0 (9.1)	8.9 (7.9)
6.	Income level, n (%)	Low	82 (45.6%)	115 (63.9%)
		Moderate	66 (36.7%)	45 (25%)
		High	32 (17.8%)	20 (11.1%)
7.	Job satisfaction	Low	122 (67.8%)	96 (53.3%)
		Moderate	47 (26.1%)	78 (43.3%)
		High	11 (06.1%)	06 (03.3%)
8.	Monthly work loss due to health issues, µ (SD)		6 days (1.9)	8 days (1.4)
9.	Livelihood other than Pottery	Agriculture	120 (66.7%)	115 (63.9%)
		Daily wage labour	140 (77.8%)	54 (30.0%)
		Weaving	---	117 5.0%)

day, and female artisans wok an average of 8.9 hours (SD- 7.9 hour) per day. Work loss per month [for male: 6 days (SD-1.9 days) and female eight days (1.4 days)] due to health-related issues are found to be one primary concern which needs intervention.

2.2.3.3 Characteristics of musculoskeletal outcomes

Figure 2.3 presents the characteristic of musculoskeletal symptoms among the pottery artisans. As Fig. 2.3 depicts, all the artisans experienced musculoskeletal symptoms in at least one of their body regions at some time during the one year before this study. 100% of the male artisans reported being experiencing musculoskeletal symptoms in elbows and wrists/hands at some time during the last 12 months. More than 90% of male artisans reported musculoskeletal symptoms in wrists/hands, lower back, one or both hips/thighs/buttocks, one or both knees and

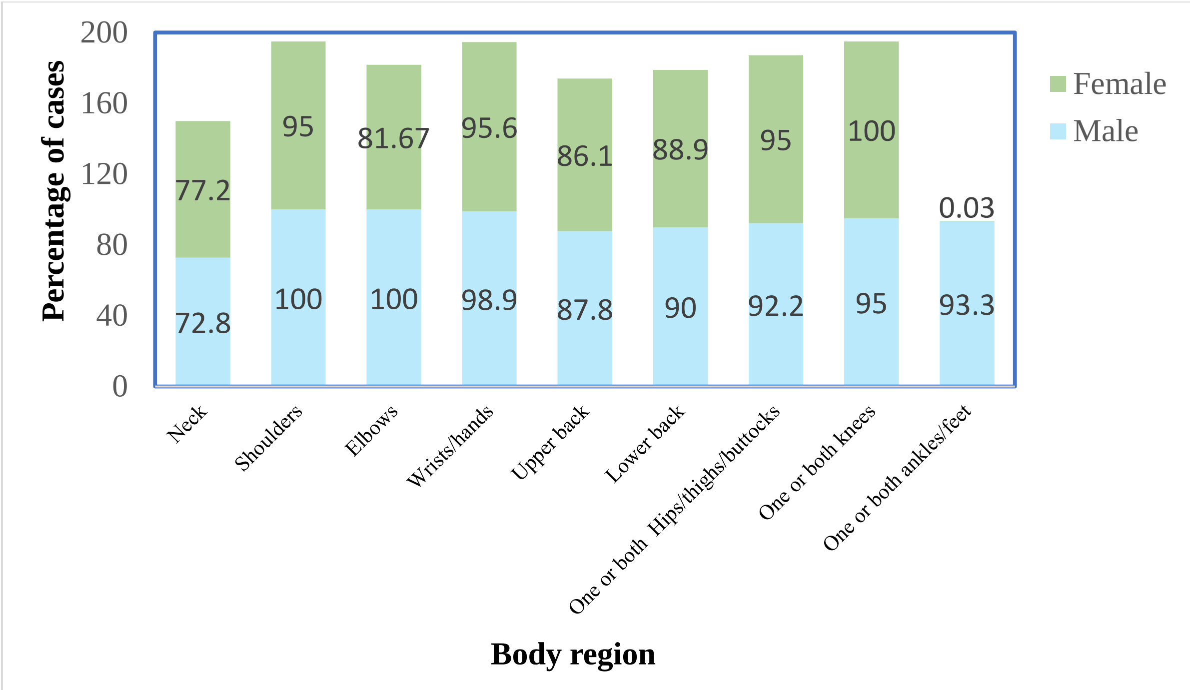


Fig. 2.3 Characteristics of musculoskeletal disorders among artisans in n different body regions

one or both ankles/feet. On the other hand, 87.8% of male artisans and 72.8% of female artisans reported musculoskeletal symptoms in the upper back and neck in the last 12 months. For male, ratings of severity of musculoskeletal symptoms are found to be between moderate and severe (3-4 on the scale of 0-5) for most of the body regions. The shoulder is reported to have a severe musculoskeletal symptom (greater than 4). Imparting energy to the wheel regularly for continuous movement of the TPW is supposed to be the main reason behind such severe musculoskeletal symptoms in shoulders.

For female, 100% of the artisans reported musculoskeletal symptoms in one or both knees. As depicted in Fig. 2.3, more than 90% of female artisans reported musculoskeletal disorder in shoulders, wrists/hands and one or both knees. 81.67%, 86.1%, and 88.8% of female respondents reported musculoskeletal symptoms in elbows, upper back and lower back, respectively. Similarly, 77.2% of female respondents reported musculoskeletal symptoms in Neck. Among female artisans, a significantly lower percentage of respondents reported musculoskeletal symptoms in one or both ankles/feet at some time during the one year before this investigation. For female, moderate musculoskeletal symptoms (greater than three on the scale of 3-5) for most of the body region is reported (shown in Table 2.3). Knees are said to have the highest severity (rating 3.9 on the level of 3-5) among all the body regions.

One of the primary reasons for health issues such as musculoskeletal pain and back pain among the pottery artisans is supposed to be because of wrong working postures viz., bent neck and back, and folded knees etc. (Chung et al., 2003; Chung et al., 2005; Jung and Jung, 2008). During the interactions with the artisans, most of the artisans revealed that they are regularly using painkiller and other medicine to get rid of the pain. Thus this investigation depicts a high prevalence of musculoskeletal symptoms among the artisans. To minimize these health-drudgery ergonomic intervention is imperative to improve their working conditions and reduce exposure to musculoskeletal risks. Keeping in mind the needs for technological intervention to tackle problems associated with the sector, an attempt has been made here for the design and development of Improvised Pedal-operated *Chaak* (IPC).

Table 2.3
Characteristics of musculoskeletal symptoms among pottery artisans; n= 360; n (male)=180, n (female)=180)

Body regions	**Prevalence of MSS**		**Severity of MSS (Scale 0-5)**	
	Male	**Female**	**Male**	**Female**
	n (%)	**n (%)**	**Mean (SD)**	**Mean (SD)**
Neck	131 (72.8)	139 (77.2)	2.9 (0.9)	3.1 (1.0)
Shoulders	180 (100)	171 (95)	4.1 (0.7)	2.8 (1.1)
Elbows	180 (100)	168 (81.7)	3.9 (0.8)	2.7 (0.9)
Hands/wrists	178 (98.9)	172 (95.6)	3.6 (0.8)	3.1 (1.0)
Upper back	158 (87.8)	155 (86.1)	3.1 (0.9)	2.9 (0.8)
Lower back	162 (90)	160 (88.9)	3.1 (0.9)	3.0 (1.1)
Hips/thighs/buttocks	166 (92.2)	171 (95.0)	3.3 (0.9)	2.9 (0.9)
Knees	171(95)	180 (100.0)	3.4 (0.8)	3.9 (0.8)
Ankle/feet	168 (93.3)	06 (0.03)	3.5 (1.1)	0.01 (0.1)

2.3 Shortcomings in pottery wheels available in the market and academic institutions

There is an endeavour to explore if available pottery wheels in the market, with the community and with academic institutions can cater to the needs of the Pottery artiness. Three variants of pottery wheel were studied as part of this study.

In Amingaon, a section of artisans is using electric-powered pottery wheel [shown in Fig. 2.4 (a)]. As informed by local artisans, this variant of Pottery wheel is developed locally using local resources. It requires an electric motor of 1 HP. As shown in Fig. 2.4 (a), the pottery wheel is prone to electric hazards. Besides, wrong working posture is a major issue in the pottery wheel.

SELCO, a rural energy-service company has developed a solar-powered Pottery wheel [shown in Fig. 2.4 (b)]. This machine is implemented in Goalpara pottery cluster of Assam, India. The major concern in the machine is low working height. Other concerns are electricity-powered, or solar-powered Pottery wheel is found to be ineffective in remote villages due to inadequate supply of electricity, unskilled workforce, and maintenance related issues.

Keeping in mind those concerns, Swabhiman, the NGO associated with the project opined that manual-powered Pottery wheel would better suit them. Based on their recommendations, pottery wheel developed by IIT Kharagpur (shown in Fig. 2.4 (c)) was field-tested in different locations of Assam, India.

Two major issues were identified in the Improvised Pottery wheel developed by IIT Kharagpur:

- Anthropometric dimensions of Assamese population does not match with anthropometric data of Kharagpur region. Hence, users find it difficult to operate the pottery wheel developed by IIT-Kharagpur.
- The modified pottery wheel is based on a bicycle pedalling mechanism where the artisans have to ride it to operate the machine. In doing so, a portion of the lower leg is exposed for female artisans, who ride the machine with their traditional dress (locally

(a)

(b)

(c)

Fig. 2.4 (a) Artisans working in a locally developed electric-powered Pottery wheel**;** (b) Solar powered Pottery wheel designed by SELCO; (c) Manually powered Pottery wheel designed by IIT Kharagpur

called as *mekhela-sador*). Inappropriate exposure of a small portion of their lower leg is not acceptable in the society due to strict social norms. Although it is not an issue for the urban context, the remote rural villagers are not ready to accept.

2.4 Motivation for the present study

Wok-related drudgery among the artisans in the TPW motivated to redesign it based on local people's anthropometric data.

2.5 Design statement

In-depth understanding of various aspects of traditional pottery works in Assam, India and knowledge gained from relevant literature on the subject help in enunciating following two design statements:

- Design and development of context-specific IPC coupled with a holistic knowledge and technology management mechanism are the basic need to rejuvenate the pottery industry of Assam.

- Local people's anthropometric data is essential for the successful design of technology considering the variation in anthropometric data with gender and ethnic diversity.

2.6 Research questions

Following research questions were enunciated for this study:

- Q_1: How could an understanding of knowledge on ergonomics and anthropometry contribute to the design and development of a new product?

- Q_2: How could design modification of TPW reduces health-hazards and improve the productivity of the artisans?

- Q_3: How can innovation be transferred to local fabricators so that it can reach the target-community and benefit the society?

2.7 Research design and outline: Scope and Methodology

The prime objective of this research is to redesign TPW and connect the new tool with artisans. The research framework adopted for the thesis is presented in Fig. 2.5. The structure of this thesis is as follows:

Chapter 1: Sustainability-orienting design approach for the bottom of the pyramid: In the first chapter, a brief introduction on design and delivery effort of *appropriate* *product/technology* is presented. Issues, ongoing research and the research gap on product/technology design, development and delivery in the context of BoP is discussed. Relevant literatures related to appropriate technology design and delivery at the BoP is reviewed in this chapter.

Chapter 2: Scope of present work and methodology: The second chapter outlines the motivation behind the study and rationale of this research are discussed. The existing problems in traditional Pottery wheel and the scope for ergonomic intervention are elucidated in this chapter.

Chapter 3: Anthropometric data generation considering gender and ethnic diversity of Assam, India: One major issue encountered while designing the improvised pedal-operated Chaak is the paucity of relevant anthropometric data of the target community. To overcome the hurdle, anthropometric data of five communities/tribes' of Assam, India *viz.*, Boro, Garo, Hira, Karbi, and Rabha communities/ tribes are collected and analysed. The results of the research findings are discussed in Chapter 3.

Chapter 4: Ergonomic design modification of pottery wheel: Step by step design details of IPC is discussed in this chapter.

Chapter 5: **Detailed product test, field validation and analysis**: The fifth chapter of this thesis covers the performance evaluation details of the IPC. The machine is field-tested at users' place. Field-testing results are discussed in this chapter.

Chapter 6: Localized manufacturing and distribution strategy for IPC: The technology transfer framework adopted for successful dissemination of the IPC is discussed in Chapter 6. Considering the Situated Learning Theory as an application lens, the technology transfer process is analysed.

Chapter 7: Conclusion, achievement, recommendations and scope for future work: Finally, the major inferences drawn from the research work carried out in this thesis along with the future scope of research is discussed in Chapter 7.

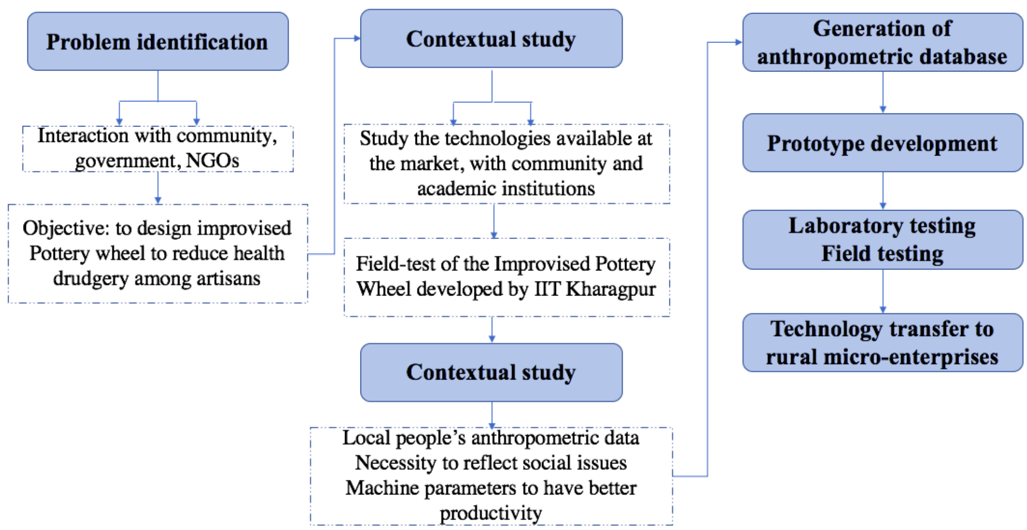


Fig. 2.5 Work flow diagram

2.8 Summary

In this chapter, the research gap identified from literature search and community dialogue/field-study, the research questions and hypothesis enunciated for this study, methodology followed during the study etc. are discussed. The next chapter presents the detail analysis of anthropometric data gathered from five different communities of Assam.

Chapter 3

Anthropometric data generation considering gender and ethnic diversity of Assam, India

3.1 Introduction

The previous chapter presented the research gap, objectives of this study and methodology followed during this study. Based on the research gap, the primary goal of this research work is enunciated as to redesign the TPW. As mentioned in the research gap, local people's anthropometric data needs to be incorporated in such design process such that ergonomic design is possible. The paucity of local people's anthropometric data was a significant hurdle. To tackle the issue, anthropometric data are collected from the target users. In this chapter, anthropometric data collection and analysis for its utility in design modification have been presented.

3.1.1 Importance of anthropometric data in designing new product

Work-related musculoskeletal disorders arise frequently in various occupational settings and are prevalent worldwide (Trevelyan and Haslam, 2001; Banerjee and Goswami, 2019; Stiernstrom, et al., 1998; Singh and Arora, 2010; Ghaderi, et al., 2014; Huysamen et al., 2018; Feyzi, et al., 2019; Candan, et al., 2019). Improper working posture and incompatibility between workers' anthropometric characteristics and the dimensions of the tools/machinery employed are some of the main reasons for the emergence of such problems (Iseria and Arslan, 2009; Botha and Bridger, 1998; Dewangan et al., 2008). Ergonomics is a multidisciplinary science that helps in optimizing the relationships existing among man, machine, and the environment. It helps to improve productivity, efficiency, safety, and comfort (Pheasant, 1998; Khadem and Islam, 2014). Although serious attention is necessary to this aspect, ergonomic principles do not receive much attention in the developing world, especially while designing tools and machinery for rural artisans, farmers, and weavers in their respective Nations (Jafry and O'Neil, 2000). Such negligence leads to frequent work-related injuries (Obi, 2016), operation-related difficulties (Sukadarin et al., 2014), and lower efficiency (Yadav et al., 1997), all of which need serious attention from the technology development groups. One major reason for such negligence is the paucity of relevant anthropometric data in several countries such as India, where the racial backgrounds of people vary from one state to another (Patel et al., 2016) and also within a state.

Therefore, modifying the existing workplace structure and redesigning the traditional tools/machinery employed in line with the scientific applications in relation to the fresh anthropometric data of the target-community is an alternative approach to minimize the health-related issues that arise because of these factors (Syuaib, 2015). Recent examples that relates to such developments include designing hand tools and equipment for the Indian agriculture sector (Dewangan et al., 2010), the designing of a combined harvester seat for the Iranian population (Ghaderi, et al., 2014), redesigning traditional tools that are used for rice farming (Syuaib, 2015), and workspace redesigning for the Indonesian Sundanese roof tile industries (Sutalaksana and Widyanti, 2016) etc. The application of anthropometric data to reduce work-related health problems has been recommended, especially for designing tools and machinery. This fact has been correlated by several studies conducted previously (e.g. Norrish and Wilson, 1995; Pheasant, 1998; Bolstad et al. 2001; Barroso, 2005; Klamklay et al., 2008; Iseria and Arslan, 2009; Hartono, 2018).

3.1.2 Brief review on anthropometric study related to India

In India, previous researchers (e.g. Sen, 1964; Sen et al., 1977; Gupta et al., 1983; Gite and Yadav, 1989; Gite and Singh, 1997; Yadav et al., 1997; Victor, et al., 2002; Dewangan et al. 2005; Fernandez *and* Uppugonduri, 2007; Dewangan et al., 2008; Gite et al., 2009; Dewangan et al., 2010; Vyavahare and Kallurkar, 2016) have made efforts to collect anthropometric data with regard to the Indian population. Such efforts were mainly concentrated on a specific region/community or for a particular requirement (Yadav et al., 1997; Mehta et al., 2008; Patel, et al., 2016). The most extensive collection of anthropometric data in India was performed as part of the project called "All India Coordinated Research Project on Ergonomics and Safety in Agriculture" (Patel et al., 2016). In this study, the anthropometric data of several north-eastern states of India, including Assam, are missing (Gite et al., 2009; Patel et al., 2016). In this regard, one can conclude that the available literature on anthropometric data of the Indian population is inadequate to formulate a clear idea regarding variations that exist in relation to gender and ethnicity for the designing of tools/machines (Patel et al., 2016).

A serious concern in this regard is in relation to the Indian micro, small, and medium enterprise (MSME) sector, especially cottage industries, which is still dependent on age-old traditional tools and methods. Due to the slogging associated with these systems, work-related disorders and health issues have been extensively reported in the sector (Nag and Nag, 2007; Unnikrishnan, et al., 2015; Sanjog, et al., 2019). The sector needs urgent intervention of ergonomics to improve the efficiency, safety, and comfort of the artisans associated with it. Thus, context-specific design intervention for these hand tools and traditional workplaces needs the inputs from newly conducted anthropometric studies that deal with target-users (Victor et al., 2002; Mugisa, et al., 2016). As mentioned above, the major hindrance for such intervention is the paucity of context-specific anthropometric data.

In a previous study, Dewangan et al., 2005 conducted a survey among male farmers belonging to one of the seven north-eastern states of India, with two districts of Assam also being included in the study. Thirty-three anthropometric dimensions were collected from the people belonging to these seven states, which are summarized in the study. Patel et al., 2016 collected anthropometric data of the male agriculture workers in the Kamrup district of Assam. Data were obtained randomly from the selected villages of the district. The district is inhabited by both ethnic people and those who have immigrated from outside the state. Because the anthropometric data vary from one region to another, from one ethnic group to another, or from one climatic condition to another (Chapanis, 1974; Sengupta, 1996), special care should be taken when considering such data for a specific group of people. Assam is inhabited by various ethnic groups with a high degree of ethnic diversity. Hence, characterization of the Assamese population into a particular race is inaccurate. In such a situation, an anthropometric study involving a mixed population may not give a true representation of the anthropometric characteristics of the state. Moreover, no relevant study has reported collecting anthropometric data from the female population in the state.

The female workforce plays a significant role in the rural economy of Assam. Knowledge related to the anthropometry of the female population is crucial for designing the tools/machinery used in the state. The existing anthropometric data are primarily concerned with people associated with agricultural activities. However, no serious attention has been given to the collection of the anthropometry data of people primarily associated with non-farm activities. Thus, a need was felt for a detailed investigation of the anthropometric data of the state considering the gender and ethnic diversity of Assam.

In view of the above, the anthropometric data of five communities/tribes of Assam, viz., Boro, Garo, Hira, Karbi, and Rabha are collected and summarized. Based on previous research findings, *viz.*, Lin et al., 2004; Dewangan et al., 2005; *İşeri* and Arslan, 2009; Sadeghi et al., 2015; Widyanti et al., 2015, an hypothesis enunciated for the study is that there exists a significant variation of the anthropometric dimension of the tribes/communities across genders and across ethnicities within the same gender. To examine whether the stated hypothesis is true, statistical t-test has been performed. People associated with non-farm activities, mainly people in the handicraft industries are considered for collection of the anthropometric data. The descriptive statistical values of the anthropometric dimensions have been estimated.

3.2 Procedure followed

3.2.1 Subjects

Five ethnic groups of Assam, viz., Boro, Garo, Hira, Karbi, and Rabha, are considered for the study. It may be mentioned that Boro, Garo, Karbi, and Rabha represent the tribal groups, whereas Hira represents the non-tribal community. Both male and female members have been considered in the study because the prime objective of the study is to design an improvised pedal-operated Chaak suitable for both male and female members of the communities. The districts where the particular community/ tribes are found in the majority have been considered for data collection. Five villages from each district have been selected based on available contacts in the specific district. Further, from each village, 10 to 20 households have been selected depending on the size of the population.

Table 3.1
Subject distribution (n= total number of subjects)

Tribes	Boro		Garo		Hira		Karbi		Rabha	
Gender	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
No. of subjects (n = 453)	65	44	50	44	50	44	50	44	50	13
Districts	Kamrup and Udalguri		Kamrup and Goalpara		Barpeta, and Kamrup		Karbi Anglong		Goalpara and Kamrup	

Only those individuals who were associated with the handicraft sector were considered for the study. Guidelines provided by the "All India Coordinated Research Project (AICRP) on Human Engineering and Safety in Agriculture (HESA), India" and cited by Dewangan et al., 2005 have been strictly followed during data collection. The village heads are consulted for the survey. The workers who volunteered have been considered as subjects for the study. The distribution of the participants of the study is presented in Table 3.1.

In the study, 265 male and 188 female members were included. To understand the relative accuracy of the study, the formula given by the British Standard, 2003 is adopted. The minimum sample size is calculated to be 112 as per the British Standard's (2003) formula: ($\propto \geq \frac{3.006 \times CV}{\sqrt{n}}$), (Shahida et al., 2015). In the aforementioned formula, $\propto$ = % of relative accuracy; n = sample size; and CV = coefficient of variation. Using the formula, (Hu et al., 2007) suggested that for 10% relative accuracy and CV value of 25, the minimum sample size should be 56 for both male and female. Because the study considered 265 male and 188 female, the sample size can be considered as statistically correct Thus, the study ensured the necessary accuracy level.

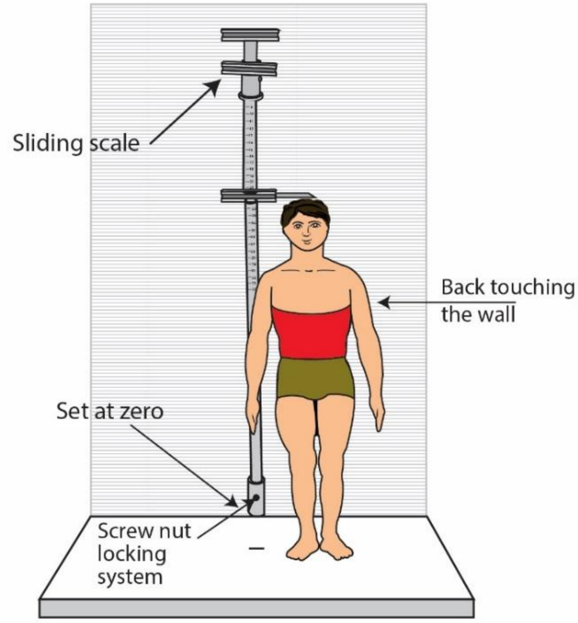
3.2.2 Body dimensions considered for this study

"AICRP on HESA, India" recommended 76 body dimensions, including age and body weight, as the determinants to be considered while designing agriculture machinery. All the dimensions suggested by "AICRP on HESA, India" except for grip diameter (outside) and middle finger grip diameter have been included in the present study. Standard terminologies as given by the Anthropometric Source Book (NASA, 1978) and cited by Dewangan et al., 2005 are followed in this study. To identify landmarks for different anthropometric measurements, instructions of Dewangan et al., 2008 have been followed. Thirty-seven measurements are taken when the subject is in a standing position, and 16 in a sitting position. Nineteen measurements are taken when the subject is in either a sitting or standing position. Moreover, three indices, namely body surface area (BSA), relative sitting height (RSH), and body mass index (BMI), are calculated using Eqn. (3.1), Eqn. (3.2) and Eqn. (3.3) respectively.

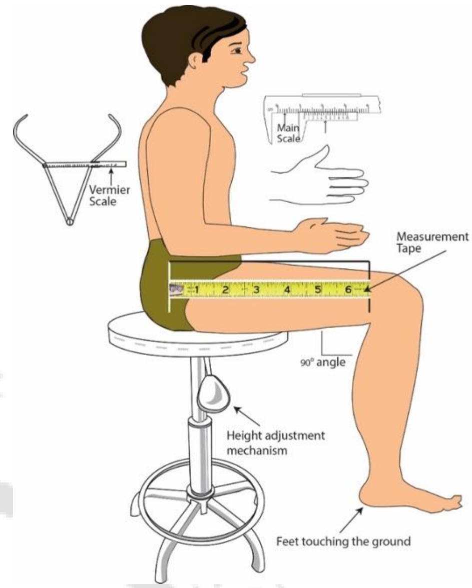
- BSA (m^2) = $\sqrt{\frac{Height(cm)\ X\ weight\ (kg)}{3600}}$ [3.1]
- RSH = $\frac{Sitting\ height}{Stature}$ [3.2]
- BMI (kg/m^2) = $\frac{body\ weight}{stature^2}$ [3.3]

3.2.3 Equipment and procedure

A commercially available anthropometer rod (SiberHegner and Co., Switzerland) has been used to measure most of the body dimensions, viz., height and length. A specially designed flat wooden surface (length = 65 cm; breadth = 45 cm) is used while taking measurements with participants in a standing posture. At the middle of the wooden structure, a locking system (screw nut locking) is added to erect the anthropometric rod. The necessary arrangement has been made to make the surface of the rod match the zero mark of the anthropometric rod. The detailed arrangement of the wooden structure is shown in Fig. 3.1 (a). The subjects have been asked to stand on the flat surface with their feet together and body erect. The sliding component of the anthropometer is adjusted to measure the height. Similarly, for measurements taken with the participants in a sitting posture, subjects are asked to sit over a height-adjustable stool with their body vertically erect. While measuring sitting dimensions, the subject are asked to keep their knees at a 90° angle. The schematic of the measuring sitting dimensions is shown in Fig. 3.1 (b). A commercially available portable weighing scale with a range of 0–-125 kg is used for measuring the body weight. The weighing scale is calibrated against the standard weights of 10–100 kg. Body mass is measured to the nearest 500 g. A Vernier caliper with a least count of 0.1 mm and a measuring tape with an accuracy 1 mm have been used while measuring the hand and foot dimensions.



(a)



(b)

Fig. 3.1 (a) Schematic diagram of the specially designed wooden structure to measure standing dimensions; (b) Schematic diagram of the height-adjusted stool used to measure sitting dimensions

The survey was conducted under the supervision of the RuTAG-NE, whose office is located at the Indian Institute of Technology (IIT), Guwahati. First, the village head was approached, and the objective and importance of the study explained to the village head, as well as the villagers. On attaining consent/ approval from the village head, the villagers who volunteered to participate were considered for further measurements. Due importance was given to ensure the good health and physical fitness of the participants. To reduce the margin of error during measurement, subjects were advised to be barefoot and wear light clothes during the survey. Two volunteers (one for the male participants and the other for the female participants) were trained for data collection.

Initially, volunteers were trained at the Indian Institute of Technology, Guwahati for handling of instruments so that manual errors that may arise during data collection would be reduced to a minimum. They were instructed regarding the theory that governs the anthropometric study. The members of the data-collection team were trained in measuring techniques and the selection of anthropometric landmarks for each dimension. People with adequate experience in anthropometric data collection provided training to the four members of the data-collection team. The online guidelines prepared by the Ergonomics Laboratory, IIT Guwahati under the banner of the National Program on Technology Enhanced Learning (NPTEL), Ministry of Human Resource and Development, Government of India were found to be a worthy resource during the training.

Preference was given to taking measurements on the right-hand side of the subjects. These data were measured to the nearest millimetre. To ensure the accuracy of the data collection process, periodical inspections were made on the site. The survey began in September 2017 and ended on April 2018.

Initially, a pilot study of 20 male and 20 female members was conducted at IIT Guwahati. Repeated measurements of all the anthropometric data of the same subjects were taken by both volunteers separately. The coefficient of reliability (R) was calculated. The R-values for both datasets were found to be greater than 95%. An R-value of greater than 95% ensured the accuracy of the data measuring technique (Ulijaszek & Kerr, 1999 and Patel et al., 2016).

3.2.4 Data Analysis

The statistical analysis was performed using a Microsoft Excel software package and STATA software package. The raw data for each dimension and subject was fed to the software package, which sorted the data in ascending order based on participants' stature. Outliers and unreasonable data caused by unaccountable error were identified and discarded to minimize the effects of human error. Outliers discarded included the data value that lies beyond three folds of the interquartile range (Q_3 – Q1) on both sides (i.e., quartile one (Q_1) and quartile three (Q_3) (Shahida, et al., 2015). Thus, minimum and maximum values considered in the study are as follows: Minimum value = Q_1 – 3 x interquartile range and Maximum value = Q_1 + 3 x interquartile range.

Skewness and kurtosis values for all the anthropometric variables measured were calculated. The descriptive statistical parameters, viz., minimum, maximum, mean, standard deviation (SD), standard error of mean (SEM), coefficient of variation (CV), and percentile values (5^{th}, 50^{th}, and 95^{th}) of all the body dimensions were also computed. In addition, three indices, namely BMI, RSH, and BSA, were determined for all the dimensions.

To examine how differently the dimensions are correlated, Pearson's correlation coefficient (r) values were estimated. Because the study involved a large number of variables, principal component analysis (PCA) and factor loading were conducted for dimension reduction and to extract the important factors. The factor analysis was performed using the STATA software package for male and female data separately. Within the same gender, anthropometric dimensions were divided into four groups for PCA and factor analysis. Thirty-six height-related body dimensions, which were measured while participants were in a standing position, were categorized in the first group. The second group comprised 16 anthropometric variables that were measured while participants were in a sitting position. Eight hand dimensions and seven foot dimensions were categorized in the third and fourth groups, respectively. Common factors were rotated using the Varimax rotation method and Promax rotation method. Such rotations were performed to make the loading values as distinct as possible (i.e., higher differences in loading values). Finally, least squares simple linear regression models were generated for dimensions that had correlation coefficients greater than or equal to 0.7. To examine the variation of different body dimensions across genders and ethnic groups, t-tests were performed using the STATA software package. Moreover, t-tests with a null hypothesis ($H_0 : \mu_1 = \mu_2$) and an alternate hypothesis ($H_a: \mu_1 \neq \mu_2$) were conducted for comparing the means of the two populations. Herein, μ_1 and μ_2 indicate the mean values of the two communities/tribes.

3.3 Results and discussion

The BMI distribution among the female and male of the sample population is shown in Table 3.2. As per WHO, 2014, the normal range of BMI values is 18.5-24.9. This study depicts that the majority of participants are in the normal range. However, 32.80% of the male and 35.47% of the female in the sample population are underweight. The study also depicts that overweight and obese individuals are uncommon in rural areas. However, as noted, a significant amount of the rural population lies in the underweight category, which demands serious attention by

Table 3.2.
Summary of BMI value

Category	BMI value (kg/m^2)	No. of subjects		Percentage of sample population	
	Male and female	Male	Female	Male	Female
Underweight	<18.5	62	94	32.80	35.47
Normal weight	18.5 to 24.9	108	154	57.14	58.11
Overweight	25 to 29.9	17	16	8.99	6.04
Obesity	>=30	3	01	1.07	0.38

the policymakers. The study was carried out among artisans associated with the rural handicraft industry. In general, they start their work early in the morning and continue into the late evening if the situation demands. In such a situation, one reason for the low average BMI among the artisans may be irregular food consumption.

The results for the descriptive statistics of all the measured anthropometric measurements of the female and male population are listed in Table 3.3. The results show that SD values for almost all the variables are relatively low. High SD values are recorded for weight and age among both the male and female. These high SD values indicate the maximum number of samples that deviate from their mean value. The SD values for hand and leg dimensions were found to be very low for both the male and female sample populations. The SEM values of all the anthropometric dimensions for both male and female are less than 1. Relatively low SEM values indicate that the data are spread to a lesser extent. It depicts the reliability of the data.

The CV values measure the relative variability of the data from the mean value. In this study, CV values were relatively low (i.e., less than 10) for most of the anthropometric dimensions. The CV value of lateral malleolus height for the female population was the highest among all the anthropometric dimensions. To check the normality of the data, skewness and kurtosis values were calculated for all the anthropometric dimensions, including those of the three indices mentioned earlier. For most of the anthropometric dimensions, skewness and kurtosis values were within the range of -1 to 1. Positive skewness indicates that anthropometric dimensions' tails extend more toward the positive side of its mean value; negative skewness indicates that anthropometric dimensions' tails extend toward the negative side of its mean value. Those anthropometric dimensions for which the kurtosis value is positive are expected to have a peak distribution, whereas a negative kurtosis value indicates a flat distribution.

Stature was found to be highly correlated ($r > 0.8$; $p < 0.01$) with a number of anthropometric dimensions. A high correlation of stature was found with the following dimensions: standing – vertical reach; vertical grip reach, eye height, acromial height, elbow height, olecranon height, iliocristal height, illiospinal height, trochanteric height, metacarpal III height, knee height, waist back length, span, span akimbo, sitting height, sitting vertical grip reach, sitting eye height, and sitting acromial height. The r-value for the correlation between bideltoid breadth and biacromial breadth was found to be relatively high. All correlation coefficients with high 'r' values are found to be statically significant at 1% ($p < 0.01$).

In the principal component analysis and factor analysis, Kaiser Criteria (Kaiser, 1960) was considered for solving the number of components. According to Kaiser's (1960) Criteria, a component with an eigenvalue greater than 1 is retained. However, screen test graph and proportion of variance accounted were also considered when deciding the number of components to be retained.

Factor loading matrices for female are shown in Table 3.4. Among female anthropometric dimensions in standing posture, 11 height-related variables could be predicted in factor 1. These are stature, vertical reach, vertical grip reach, eye height, acromial height, elbow height, olecranon height, iliocristal height, span, and spank akimbo. Three length-related variables, viz., thumb tip reach, shoulder grip length, and elbow grip length, from a standing posture could be predicted in factor 4. Four variables, viz., chest circumference, wrist circumference, waist circumference, thigh circumference, and calf circumference, have a high loading in Factor 2. Biacromial breadth and bideltoid breadth could be predicted with high factor loading in factor 3. Height-related variables in sitting position, viz., sitting height, vertical reach, eye height, and acromial height, have high factor loading in Factor 1. Two breadth-related variables in sitting position, viz., hip breadth and elbow-elbow breadth, could be predicted in factor 2 with a high loading value. Popliteal height, buttock-knee length, and buttock popliteal height have high factor loading values in factor 2. Thigh clearance height and elbow rest height have high factor loading variables in factor 4. Among the eight hand dimension variables, five variables have factor loading values greater than 0.5. These variables are maximum grip length and hand breadth at metacarpal III in factor 1; hand length, first phalanx digit III length, and palm length in factor 2. Variables related to female's hand dimensions with high factor loading values are medial malleolus height, lateral in factor 1; foot length and instep length in factor 2; and foot breadth (ball of the foot) and heel breadth in factor 3. As shown in Table 3.4, a total of 14 factors could be identified in the study.

Based on the criterion of an eigenvalue greater than 1, five dominant factors emerged in male's standing postures, which explained 89.70% of the data. Three dominating factors in each of the factor analyses of sitting position and foot dimensions emerged. Two dominant factors emerged for male's foot dimensions. The factor loading matrix for each factor is shown in Table 3.5. For male in a standing position, stature was found to have the highest factor loading (0.926). Seventeen variables related to height and length in a standing position could be predicted with factor loading greater than 0.5 in factor 1 and factor 2. Two variables, viz., bicromial breadth bideltoid breadth in the standing position, emerged as having high factor loading in factor 3. Variables related to circumferences measured in a standing position could be predicted with high factor loading in factor 4. Elbow grip length and forearm hand length emerged as having high factor loading values in factor 5. Similarly, when in a sitting position, male's anthropometric dimensions related to height and length have the greatest factor loading values in factor 1 and factor 2. A total of six variables related to sitting dimensions could be predicated in factor 1 and factor 2. Hip breadth, elbow-elbow breadth, and knee-knee breadth were found to have high factor loading values in factor 3. Thigh clearance height and elbow rest height could be predicted best in factor 4. Among the eight variables for hand dimensions, four were found to have factor loading values greater than 0.5. Six variables out of the seven variables for hand dimensions had high factor loading values. As shown in Table 3.5, a total of 15 factors could be identified in the study.

Score plots and variable loading plots for male and female anthropometric data are presented in Fig. 3.2. The prediction equations derived after regression are presented in Table 3.6. The study shows that height-related variables could be predicted mostly in factor 1. From this study, as well as from other references, it can be concluded that stature has the greatest influence over the other anthropometric dimensions. Measuring stature is restively easy. Hence, developing a regression model with stature as an independent variable will be helpful for easily predicting other dimensions.

Table 3.3

Summary of descriptive statistics of the anthropometric dimensions

SL. No.	Dimensions	Gender	Min	Max	Mean	SD	SEM	CV (%)	Percentile			Skewness	Kurtosis
									5th	50th	95th		
Standing													
1.	**Weight (Kg)**	F	28.0	97.0	48.4	9.9	0.72	20.45	35.0	47.8	65.7	1.09	2.81
		M	34.0	85.0	54.2	9.7	0.60	17.90	39.2	52.0	70.0	0.43	0.01
2.	**Stature**	F	129.5	166.6	153.5	6.2	0.45	4.04	143.3	153.9	163.2	-0.66	1.09
		M	148.2	189.5	165.3	7.1	0.44	4.30	154.2	164.8	178.1	0.31	0.32
3.	**Vertical reach**	F	170.0	216.3	193.9	7.6	0.55	3.92	181.1	194.8	205.4	-0.26	0.44
		M	183.2	231.0	207.1	8.2	0.50	3.96	193.0	207.0	220.0	-0.02	0.37
4.	**Vertical grip reach**	F	164.0	206.4	185.2	7.4	0.54	4.00	173.0	185.7	196.8	-0.09	0.33
		M	172.9	219.0	196.0	9.8	0.60	5.00	179.2	194.9	213.8	0.02	-0.32
5.	**Eye height**	F	118.5	157.0	143.0	5.8	0.42	4.06	133.6	143.6	152.1	-0.56	1.36
		M	128.6	176.2	154.2	6.6	0.41	4.28	143.3	154.2	164.0	-0.31	1.09
6.	**Acromial height**	F	112.0	143.1	127.3	5.3	0.39	4.16	118.2	127.3	134.9	-0.04	0.40
		M	108.1	157.2	136.3	7.2	0.44	5.28	124.8	136.3	146.9	-0.54	1.60
7.	**Elbow height**	F	83.1	108.7	97.1	5.1	0.37	5.25	88.8	97.0	105.6	-0.01	0.09
		M	82.4	120.5	104.2	5.9	0.36	5.66	96.0	104.5	112.6	-0.61	1.62
8.	**Olecranon height**	F	78.0	107.8	94.7	4.7	0.34	4.96	86.1	94.8	102.3	-0.29	0.82
		M	84.0	117.0	100.1	5.6	0.34	5.59	92.1	100.2	108.8	0.16	0.39
9.	**Iliocrystale height**	F	72.1	103.2	88.8	6.5	0.47	7.32	77.0	90.2	97.4	-0.41	-0.49
		M	74.0	106.0	94.2	6.1	0.37	6.48	83.1	95.3	102.2	-0.86	0.66
10.	**Iliospinal height**	F	70.0	97.3	79.9	4.3	0.31	5.38	74.4	79.8	86.3	1.13	3.22
		M	68.6	100.9	89.5	5.8	0.36	6.48	78.4	90.5	97.3	-1.00	1.35
11.	**Trochanteric height**	F	62.4	83.9	72.7	5.9	0.43	8.12	64.9	73.1	81.8	0.08	-1.25
		M	58.0	93.2	80.5	5.7	0.35	7.08	71.0	81.5	88.0	-0.86	1.52
12.	**Metacarpal height**	F	57.1	75.8	66.1	3.9	0.28	5.90	59.9	66.4	72.5	-0.15	-0.65
		M	54.4	83.5	70.3	4.9	0.30	6.97	62.3	71.0	76.9	-0.82	1.87
13.	**Knee height**	F	32.2	52.5	43.9	2.9	0.21	6.61	40.5	45.0	49.3	-0.40	1.83
		M	35.5	68.5	48.5	3.6	0.22	7.42	44.3	48.7	53.1	-0.51	1.13
14.	**Waist back length**	F	32.1	52.5	41.6	5.3	0.39	12.74	33.4	41.6	49.2	-0.03	-1.21
		M	33.0	53.5	45.0	4.6	0.28	10.22	36.2	46	51.3	-0.52	-0.19

Table 3.3 (continued)

15.	**Scapula to waist back length**	F	41.0	59.5	49.7	3.6	0.26	7.24	43.1	49.0	55.0	0.08	-0.17
		M	40.1	59.6	50.1	4.8	0.29	9.58	41.6	50.5	57.6	-0.17	-0.76
16.	**Wall to acromia distance**	F	7.0	15.2	10.0	1.7	0.12	17.00	8.0	9.8	13.6	0.95	0.65
		M	8.0	17.8	13.4	2.7	0.17	20.15	9.14	14.0	17.0	-0.32	-1.23
17.	**Arm reach from the wall**	F	63.4	84.4	74.7	4.0	0.29	5.35	67.4	74.5	81.0	-0.16	0.18
		M	67	90.5	79.7	4.6	0.28	5.77	71.6	80	87.4	-0.24	0.15
18.	**Biacromial breadth**	F	28.5	41.7	36.6	2.3	0.17	6.28	32.7	36.5	40.0	-0.28	0.15
		M	31.0	50.0	38.2	3.2	0.20	8.38	33.7	38.0	43.8	0.54	0.63
19.	**Bideltoid breadth**	F	33.0	45.0	40.2	2.7	0.20	6.72	35.2	40.5	44.0	-0.55	-0.12
		M	32.8	54.0	42.9	3.7	0.23	8.62	35.9	42.4	48.4	0.25	1.24
20.	**Chest breadth**	F	21.2	35.5	29.4	2.8	0.20	9.52	25.0	29.6	34.3	-0.03	-0.54
		M	18.2	38.0	29.1	3.1	0.19	10.65	24.0	29.1	33.8	-0.40	1.43
21.	**Chest depth**	F	15.4	28.0	22.4	2.8	0.20	12.50	17.9	22.5	27.0	-0.09	-0.52
		M	14.0	29.0	20.9	2.9	0.18	13.88	17.0	21.0	25.4	0.38	0.59
22.	**Inter-scye depth**	F	21.5	38.0	30.9	3.0	0.22	9.71	26.0	31.0	36.1	-0.07	-0.13
		M	23.7	42.5	32.2	3.9	0.24	12.11	27.0	31.5	39.6	0.54	-0.26
23.	**Waist breadth**	F	18.2	34.4	27.6	3.2	0.23	11.59	22.0	27.8	33.0	-0.18	-0.32
		M	18.0	34.5	28.8	2.7	0.17	9.38	24.0	29.0	33.0	-0.58	0.80
24.	**Hip Breadth**	F	24.0	38.5	32.7	3.1	0.23	9.48	25.3	32.0	36.4	-0.33	-0.03
		M	24.0	43.0	31.9	2.9	0.18	9.09	26.8	32.0	36.5	-0.05	0.77
25.	**Wall to lumbo Sacral joint distance**	F	2.0	5.7	4.2	0.7	0.05	16.67	2.9	4.4	5.4	-0.56	-0.16
		M	2.7	5.9	4.4	0.7	0.04	15.91	3.1	4.5	5.6	-0.10	-0.90
26.	**Abdominal extension to wall**	F	15.0	27.2	20.9	3.3	0.24	15.79	15.8	21.0	26.7	0.01	-0.94
		M	12.0	31.9	20.6	3.5	0.22	16.99	15.0	20.6	26.1	0.22	0.48
27.	**Chest circumference**	F	71.5	108.3	85.1	7.9	0.58	9.28	74.1	84.6	97.5	0.24	-0.85
		M	74.2	102.0	85.8	6.1	0.37	7.11	76.1	85.5	95.5	0.39	-0.38
28.	**Wrist circumference**	F	13.2	18.6	15.3	1.1	0.08	7.19	13.8	15.2	17.3	0.58	0.24
		M	14.0	22.0	16.5	1.3	0.08	7.88	15.0	16.2	18.9	1.18	2.72
29.	**Waist circumference**	F	63.5	95.5	77.0	8.0	0.58	10.39	65.0	76.0	89.4	0.22	-0.86
		M	59.5	92.2	75.2	7.5	0.46	9.97	64.0	75.0	86.9	-0.05	-0.79
30.	**Thigh circumference**	F	30.8	60.0	41.1	6.1	0.44	14.84	32.6	39.2	54.8	0.86	0.28
		M	33.2	56.0	44.7	4.9	0.30	10.96	36.1	45.0	53.0	-0.02	-0.57

Table 3.3 (continued)

31.	**Calf circumference**	F	22.1	46.0	32.1	4.2	0.31	13.08	27.0	32.0	40.8	0.98	1.52
		M	25.4	55.6	33.5	4.4	0.27	13.13	27.0	33.0	41.3	0.95	1.80
32.	**Thumb tip reach**	F	57.5	78.4	67.8	3.9	0.28	5.75	61.9	68.0	74.1	-0.15	-0.04
		M	61.8	85.3	74.7	4.7	0.29	6.29	66.6	74.9	82.5	-0.24	0.15
33.	**Shoulder grip length**	F	56.4	77.7	64.5	4.0	0.29	6.20	58.0	64.3	71.0	0.45	0.37
		M	57.3	81.9	70.4	4.8	0.29	6.82	62.5	70.9	78.1	-0.25	0.20
34.	**Elbow grip length**	F	27.4	41.3	33.1	2.5	0.18	7.55	30.0	33.0	38.1	0.67	0.60
		M	27.4	43.0	34.9	2.4	0.15	6.88	31.0	35.0	38.9	0.27	1.16
35.	**Forearm hand length**	F	31.5	47.0	41.4	2.5	0.18	6.04	37.4	41.7	45.1	-1.07	2.74
		M	35.2	51.0	42.9	2.5	0.15	5.83	39.0	43.0	46.6	0.18	1.06
36.	**Span**	F	135.0	173	155.5	6.5	0.47	4.18	145.0	156.0	165.7	-0.04	0.14
		M	141.3	188.5	167.2	7.5	0.46	4.49	154.5	167.0	179.9	-0.17	0.58
37.	**Span akimbo**	F	66.5	97.6	79.0	3.9	0.28	4.94	72.3	79.0	84.5	0.34	2.32
		M	62.4	98.2	85.0	4.7	0.29	5.53	77.6	85.0	92.9	-0.43	2.26
Sitting measurement													
38.	**Height**	F	68	89.6	79.9	3.5	0.26	4.38	75.0	80.0	86.1	-0.17	0.60
		M	65.7	95.0	85.2	4.9	0.30	5.75	76.6	85.4	92.4	-1.03	2.47
39.	**vertical grip reach**	F	97.9	130.8	116.8	6.1	0.44	5.22	106.4	117.2	126.6	-0.20	-0.28
		M	99.4	146.6	125.9	8.7	0.53	6.91	109.1	127.2	138.2	-0.63	0.64
40.	**eye height**	F	59.6	80.2	70.9	3.4	0.25	4.80	65.1	71.1	75.9	-0.43	0.35
		M	62.0	85.2	76.9	4.5	0.28	5.85	68.0	77.2	83.4	-0.83	0.82
41.	**Acromial height**	F	40.3	59.3	52.7	3.6	0.26	6.83	46.9	52.9	58.0	-0.69	0.76
		M	43.0	69.4	59.0	5.0	0.31	8.47	50.7	59.4	66.4	-0.37	-0.19
42.	**Popliteal height**	F	26.9	39.4	33.9	2.6	0.19	7.67	28.8	34.0	38.0	-0.46	0.11
		M	33.1	49.0	41.5	2.4	0.15	5.78	38.0	41.3	45.5	0.02	1.11
43.	**Knee height**	F	37.0	49.3	43.4	2.6	0.19	5.99	39.1	43.2	47.3	-0.13	-0.33
		M	38.5	59.7	51.3	2.7	0.17	5.26	47.4	51.3	55.8	-0.25	1.92

Table 3.3 (continued)

44.	**Thigh clearance height**	F	10.1	20.5	14.6	2.4	0.18	16.44	11.0	14.6	19.0	0.30	-0.75
		M	10.2	20.0	15.1	1.8	0.11	11.92	12.3	15.2	18.2	0.33	0.22
45.	**Elbow Rest Height**	F	15.9	32.0	23.5	2.9	0.21	12.34	18.4	23.5	28.2	0.17	0.66
		M	13.9	29.8	23.6	2.3	0.14	9.75	20.0	23.7	27.1	-0.65	2.12
46.	**Coronoid fossa to hand length**	F	23.0	53.9	36.5	3.1	0.23	8.49	33.0	36.4	40.2	0.33	1.8
		M	32.5	49.5	38.6	2.4	0.15	6.22	35.3	38.4	42.4	0.79	2.72
47.	**Abdominal depth**	F	14.1	28.8	20.5	2.9	0.21	14.15	15.5	20.9	24.9	0.03	-0.50
		M	14.5	30.5	19.7	3.0	0.18	15.23	15.8	19.5	24.6	0.94	1.45
48.	**Buttock Knee Length**	F	33.3	54.8	41.8	3.7	0.27	8.85	36.0	41.9	48.9	0.44	1.38
		M	41.8	60.2	52.8	3.2	0.20	6.06	48.0	52.8	58.0	-0.33	1.06
49.	**Buttock popliteal length**	F	31.3	47.9	38.5	5.8	0.42	15.06	33.5	40.2	46.4	-0.50	0.66
		M	32.9	52.0	41.9	2.9	0.18	6.92	38.1	41.8	46.3	-0.18	1.54
50.	**Hip Breadth**	F	24.0	43.3	30.7	3.6	0.26	11.73	25.3	30.0	38.3	0.61	0.06
		M	23.4	43.1	29.7	2.9	0.18	9.76	25.0	30.0	33.5	0.43	1.21
51.	**Elbow-elbow breadth**	F	29.3	49.6	38.9	4.2	0.31	10.80	32.7	38.3	46.1	0.31	-0.35
		M	30.0	50.1	39.1	2.8	0.17	7.16	34.6	39.1	44.2	0.34	0.97
52.	**Knee-knee breadth**	F	13.2	29.1	17.8	3.4	0.25	19.10	14.0	17.0	25.9	1.38	1.74
		M	14.0	30.0	17.5	2.1	0.13	12.00	15.0	17.1	21.2	1.6	1.02
53	**Functional leg length**	F	69.3	101.4	87.6	6.0	0.44	6.85	78.9	88.0	97.0	-0.11	-0.17
		M	77.0	111.3	92.9	5.7	0.35	6.14	84.2	92.4	102.2	0.24	0.52
Standing / sitting measurements													
54.	**Grip diameter (inside)**	F	3.5	7.3	5.0	0.6	0.04	12.00	4.0	5.2	6.2	0.05	-0.12
		M	3.8	8.4	5.5	0.7	0.04	12.73	4.3	5.4	6.7	0.39	0.71
55.	**Maximum grip length**	F	10.2	14.4	11.1	0.5	0.04	4.58	10.4	11.1	11.8	1.58	2.58
		M	7.2	18.7	14.2	1.9	0.12	13.38	10.0	14.5	16.7	-0.95	1.40

Table 3.3 (continued)

56.	**Hand length**	F	13.5	18.2	16.10	0.8	0.06	4.97	14.7	16.2	17.3	-0.33	0.51
		M	14.5	20.3	17.3	0.9	0.06	5.20	15.3	17.3	19.2	0.29	0.75
57.	**Hand breadth at metacarpal-III**	F	5.2	8.4	6.1	0.5	0.04	8.20	5.4	6.1	6.8	1.48	1.02
		M	5.1	10.0	6.7	0.2	0.01	2.99	5.8	6.7	7.4	0.67	1.63
58.	**Hand breadth across thumb**	F	5.5	10	8.31	0.6	0.04	7.22	7.43	8.3	9.5	-0.31	1.94
		M	7.3	10.5	9.0	0.7	0.04	7.78	8.0	9.1	10.1	0.18	-0.18
59.	**Hand thickness at metacarpal-III**	F	1.8	3.6	2.6	0.4	0.03	15.38	2.0	2.6	3.1	0.26	0.06
		M	2.1	4.5	2.9	0.2	0.01	6.90	2.3	2.8	3.6	1.01	1.8
60.	**First phalanx digit III length**	F	4.1	6.8	5.6	1.1	0.08	19.64	5.0	5.7	6.3	-0.82	1.43
		M	5.2	7.1	6.1	0.4	0.02	6.56	5.5	6.0	6.6	0.11	0.12
61.	**Palm length**	F	6.2	16.8	9.2	0.9	0.07	9.78	8	9.2	10	-1.44	1.9
		M	7.9	11.9	9.9	0.4	0.02	4.04	9.1	10.0	11.0	0.36	0.47
62.	**Foot length**	F	16.5	24.6	21.8	1.1	0.08	5.14	20.5	21.9	23.6	-1.10	-1.01
		M	20.0	27.6	23.4	1.3	0.08	5.56	21.2	23.4	25.5	0.34	0.60
63.	**Instep length**	F	12.0	19.8	17.4	1.2	0.09	6.90	15.5	17.6	18.6	0.21	0.25
		M	9.9	22.0	18.7	1.3	0.08	6.95	17.1	18.8	20.3	-1.23	1.40
64.	**Foot breadth (ball of the foot)**	F	7.0	10.2	8.4	0.6	0.04	7.14	7.4	8.4	9.3	-0.59	0.08
		M	6.8	11.0	9.2	0.9	0.06	9.78	8.2	9.1	10.2	-0.14	0.71
65.	**Heel breadth**	F	4.0	9.5	5.7	0.8	0.06	14.04	4.5	5.8	6.8	-0.20	-1.14
		M	4.5	8.4	6.5	0.6	0.04	9.23	5.7	6.5	7.2	-0.17	1.84
66.	**Medial malleolus height**	F	3.8	8.8	6.3	1.3	0.09	20.63	4.1	6.5	8.1	0.10	-1.24
		M	5.0	9.8	7.8	1.2	0.07	15.38	5.8	8.0	9.3	-0.41	-0.91
67.	**Lateral malleolus height**	F	4.0	9.4	6.1	1.4	0.10	22.95	4.3	6.4	8.2	0.24	-0.47
		M	4.0	9.3	7.0	1.1	0.07	15.71	5.1	7.2	8.5	-0.39	-0.75
68.	**Bimalleolar breadth**	F	6.0	8.0	6.8	0.5	0.04	7.35	6.0	6.8	7.4	-1.36	1.44
		M	3.0	7.0	4.2	0.8	0.05	19.05	3.3	4.1	5.2	1.31	1.40
69.	**Head length**	F	12.3	18.0	16.2	0.9	0.07	5.56	14.8	16.2	17.5	1.84	1.80
		M	14.5	19.3	16.8	0.9	0.06	5.36	15.2	16.8	18.3	-0.11	-0.49
70.	**Head breadth**	F	10.8	17.8	12.7	1.2	0.09	9.45	11.3	12.5	14.1	-0.82	1.74
		M	10.6	18.3	13.0	1.8	0.11	13.85	11.3	13.0	14.6	7.9	1.90

Table 3.3 (continued)

71.	**Menton to top of the head**	F	11.2	22.5	19.3	1.6	0.12	8.29	16.9	19.3	22.1	0.33	-0.84
		M	17.4	24.4	20.4	1.3	0.08	6.37	18.3	20.3	22.7	0.32	0.27
72.	**Age (year)**	F	18.0	60.0	36.1	11.6	0.85	32.13	20.0	35.0	55.7	0.34	0.90
		M	18.0	60.0	37.1	12.8	0.79	34.50	19.0	36.0	60.0	0.35	-1.06
Indices													
73.	**RSH**	F	0.45	0.62	0.52	0.02	0.001	3.85	0.49	0.52	0.55	1.05	1.50
		M	0.44	0.56	0.52	0.02	0.001	3.85	0.48	0.52	0.55	-1.27	2.32
74.	**BSA (m^2)**	F	1.02	2.06	1.43	0.1	0.01	6.99	1.19	1.42	1.72	0.39	0.08
		M	0.56	1.41	0.90	0.1	0.01	11.11	0.65	0.87	1.12	0.43	0.01
75.	**BMI (kg/m^2)**	F	12.95	41.90	20.49	3.8	0.28	18.55	15.63	19.93	26.83	0.46	0.56
		M	12.8	31.5	19.8	2.9	0.18	14.65	15.44	19.44	25.19	0.44	0.37

#Measurements are in cm, until otherwise specified; F = female, M = Male

Table 3.4

Coefficients for factor loading matrix for the anthropometric dimensions of female

Factor loading matrix for standing positions

Variables	Factor1	Factor2	Factor3	Factor4
Stature	**0.900***	-0.001	0.132	0.001
Vertical reach	**0.973***	-0.063	-0.066	-0.017
Vertical grip reach	**0.952***	-0.038	-0.066	-0.032
Eye height	**0.915***	-0.021	-0.017	-0.046
Acromial height	**0.940***	0.050	-0.032	0.005
Elbow height	**0.766***	0.024	0.079	0.003
Olecranon height	**0.763***	0.114	-0.002	0.079
Iliocrystale height	**0.748***	-0.052	0.069	-0.024
Iliospinal height	0.477	0.005	0.251	0.043
Trochanteric height	0.483	0.052	0.135	0.032
Metacarpal III height	0.444	0.146	0.029	0.119
Knee height	0.481	-0.005	0.115	-0.014
Waist back length	**0.616***	0.063	0.076	-0.039
Scapula to waist back length	0.197	0.058	-0.021	0.072
Wall to acromion distance	0.150	-0.029	-0.183	-0.036
Arm reach from the wall	0.126	0.0249	-0.169	0.108
Biacromial breadth	0.007	-0.067	**0.818***	0.048
Bideltoid breadth	0.032	-0.036	**0.740***	-0.075
Chest breadth	-0.054	-0.061	0.485	0.046
Chest depth	-0.060	-0.123	0.055	0.097
Inter-scye breadth	-0.022	0.166	-0.101	0.225
Waist breadth	0.060	0.168	0.260	-0.122
Hip breadth	-0.051	0.046	0.239	-0.166
Wall to lumbo sacral joint distance	0.193	0.107	0.001	-0.099
Abdominal extension to wall	0.199	0.104	0.30	0.126
Chest circumference	-0.017	**0.923***	-0.032	0.000

Factor loading matrix for sitting positions

Variable	Factor1	Factor2	Factor3	Factor4
Height	**0.833***	0.108	0.031	0.053
Vertical reach	**0.718***	0.136	-0.005	-0.001
Eye height	**0.798***	0.120	0.154	0.033
Acromial height	**0.506***	-0.054	0.089	-0.033
Popliteal height	0.334	-0.169	**0.600***	-0.077
Knee height	0.307	-0.060	0.468	-0.109
Thigh clearance height	-0.081	0.002	0.028	**0.678***
Elbow rest height	0.162	-0.002	-0.040	**0.707***
Coronoid fosaa to hand length	0.341	0.111	0.048	-0.125
Abdominal depth	-0.162	-0.106	0.231	0.316
Buttock knee length	0.159	0.422	**0.603***	0.127
Buttock popliteal length	-0.042	0.096	**0.747***	-0.002
Hip breadth	0.131	**0.849***	0.030	0.008
Elbow-elbow breadth	0.112	**0.734***	0.057	-0.054
Knee-knee breadth	0.079	**0.770***	0.034	0.009
Functional leg length	**0.591***	0.207	0.162	-0.074
Eigenvalue	4.04	2.22	1.84	1.67
TV (%)	25.28	13.89	11.53	10.43
CV (%)	25.28	39.16	50.69	61.34

Factor loading matrix for hand dimensions (female)

Variable	Factor1	Factor2	Factor3
Grip diameter (inside)	-0.021	0.328	0.221
Maximum grip length	**0.897***	0.016	0.004
Hand length	0.017	**0.811**	0.018
Hand breadth at metacarpal-III	**0.897***	0.016	0.00
Hand breadth across thumb	-0.051	0.325	-0.250

Table 3.4 (continued)

Wrist circumference	0.038	**0.655***	-0.022	0.009
Waist circumference	-0.014	**0.841***	-0.060	-0.019
Thigh circumference	-0.050	**0.6982***	-0.013	0.018
Calf circumference	-0.049	**0.663***	-0.020	-0.070
Thumb tip reach	-0.013	-0.090	0.016	**0.792***
Shoulder grip length	-0.001	0.033	-0.043	**0.790***
Elbow grip length	0.027	0.079	0.106	0.562
Forearm hand length	0.010	-0.097	-0.008	0.380
Span	**0.826***	-0.062	-0.174	0.003
Spank akimbo	**0.736***	-0.151	-0.092	-0.014
Eigenvalue	6.69	1.38	1.15	1.01
TV (%)	50.11	16.47	09.52	08.72
CV (%)	50.11	66.58	76.09	84.82

Hand thickness at metacarpal-III	-0.019	0.141	0.104
First phalanx digit III length	-0.024	**0.578***	0.093
Palm length	0.035	**0.764***	-0.109
Eigenvalue	2.49	1.93	1.01
TV (%)	31.26	24.21	12.49
CV (%)	31.26	55.37	67.86
	Factor loading matrix for hand dimensions		
Variable	**Factor1**	**Factor2**	**Factor3**
Foot length	-0.015	**0.856***	-0.048
Instep length	0.018	**0.770***	-0.013
Foot breadth (ball of the foot)	0.032	-0.071	0.665
Heel breadth	-0.023	0.019	0.665
Medial malleolus height	**0.911***	-0.032	0.029
Lateral malleolus height	**0.910***	0.033	-0.023
Bimalleolar height	0.063	-0.056	-0.113
Palm length	0.010	0.553	0.089
Eigenvalue	2.18	1.88	1.52
TV (%)	27.27	23.61	19.01
CV (%)	27.27	50.89	69.89

*Factor loading greater than 0.5

Table 3.5

Coefficients for factor loading matrix for the anthropometric dimensions of male

Factor loading matrix for standing positions

Variable	Factor1	Factor2	Factor3	Factor4	Factor5
Stature	**0.926***	-0.028	0.068	-0.004	-0.014
Vertical reach	**0.852***	0.129	-0.083	0.050	0.016
Vertical grip reach	**0.865***	-0.037	0.039	0.072	0.049
Eye height	**0.808***	0.1564	-0.013	0.024	0.016
Acromial height	**0.802***	0.0597	0.002	0.011	-0.017
Elbow height	**0.838***	-0.019	-0.005	0.016	-0.040
Olecranon height	**0.842***	-0.032	-0.036	0.091	-0.047
Iliocrystale height	**0.838***	-0.087	0.114	-0.002	-0.025
Iliospinal height	**0.871***	-0.131	0.124	-0.075	-0.015
Trochanteric height	**0.654***	0.015	0.038	-0.005	0.072
Metacarpal III height	**0.680***	-0.098	0.227	-0.111	0.011
Knee height	**0.643***	0.050	0.060	0.014	-0.075
Waist back length	**0.792***	-0.098	-0.020	-0.010	0.035
Scapula to waist back length	0.096	0.1055	0.163	-0.027	0.012
Wall to acromion distance	0.2410	-0.114	-0.393	0.068	0.122
Arm reach from the wall	0.0646	**0.858***	0.003	0.006	0.001
Biacromial breadth	0.192	0.047	**0.699**	-0.035	0.016
Bideltoid breadth	0.3025	0.001	**0.622**	-0.099	-0.025
Chest breadth	-0.160	0.0339	0.342	-0.001	-0.077
Chest depth	-0.100	-0.101	0.080	0.207	0.026
Inter-scye breadth	-0.107	-0.021	0.490	-0.076	0.042
Waist breadth	-0.120	0.0360	0.264	0.182	0.024
Hip breadth	-0.052	0.009	0.114	0.172	0.091
Wall to lumbo sacral joint distance	-0.017	0.032	0.015	0.157	0.120
Abdominal extension to wall	0.000	-0.085	0.217	0.176	-0.005
Chest circumference	0.1282	-0.030	-0.145	**0.840***	-0.084
Wrist circumference	-0.028	0.187	0.117	0.094	0.081
Waist circumference	-0.004	0.0555	-0.038	**0.787***	-0.055
Thigh circumference	0.001	-0.020	0.0406	**0.638***	0.069

Factor loading matrix for sitting positions

Variable	Factor1	Factor2	Factor3	Factor4
Height	**0.814***	0.189	-0.1814	-0.018
Vertical reach	**0.798***	0.180	0.011	0.024
Eye height	**0.819***	0.137	0.100	0.110
Acromial height	0.382	0.1857	0.117	0.078
Popliteal height	0.321	**0.750***	-0.060	0.049
Knee height	0.211	**0.661***	0.065	0.096
Thigh clearance height	0.005	0.096	0.050	**0.708***
Elbow rest height	0.121	0.035	0.074	**0.723***
Coronoid fosaa to hand length	0.375	0.445	0.176	0.029
Abdominal depth	-0.099	-0.057	0.113	0.024
Buttock knee length	0.391	0.338	0.257	0.062
Buttock popliteal length	0.1418	0.286	-0.007	-0.043
Hip breadth	0.1591	0.043	**0.821***	0.054
Elbow-elbow breadth	0.041	-0.022	**0.789***	0.020
Knoee-knee breadth	-0.0930	0.051	**0.509***	0.115
Functional leg length	**0.655**	0.505	0.072	0.055
Eigenvalue	4.65	2.11	1.54	1.22
TV (%)	29.04	13.24	0.10	0.08
CV (%)	29.04	42.28	51.94	60.00

Factor loading matrix for hand dimensions

Variable	Factor1	Factor2	Factor3
Grip diameter (inside)	0.3204	-0.097	0.196
Maximum grip length	0.160	0.039	-0.069
Hand length	**0.814***	0.047	0.015
Hand breadth at metacarpal-III	-0.025	**0.654***	-0.048
Hand breadth across thumb	0.066	**0.644***	-0.070
Hand thickness at metacarpal-III	0.046	-0.030	-0.263
First phalanx digit III length	0.005	0.243	0.360
Palm length	**0.843**	-0.047	-0.059

Table 3.5 (continued)

Calf circumference	-0.037	-0.045	0.303	0.427	0.043
Thumb tip reach	0.0551	**0.962***	0.015	0.004	-0.002
Shoulder grip length	0.0409	**0.963***	0.053	-0.017	-0.008
Elbow grip length	-0.013	0.0042	0.0062	-0.051	**0.893***
Forearm hand length	-0.0050	-0.010	-0.013	-0.049	**0.898***
Span	**0.628***	0.3889	-0.106	0.006	-0.005
Spank akimbo	**0.671**	0.2595	0.017	0.024	0.038
Eigenvalue	11.311	2.886	2.050	1.80	1.07
TV (%)	53.04	13.54	09.61	08.48	05.02
CV (%)	53.04	66.58	76.19	84.67	89.70

Eigenvalue	1.96	1.62	1.15
TV (%)	24.53	20.63	14.44
CV (%)	24.53	44.89	59.33
Factor loading matrix for foot dimensions			
Variable	**Factor1**	**Factor2**	**Factor3**
Foot length	0.042	**0.733***	0.150
Instep length	-0.031	**0.812***	-0.065
Foot breadth (ball of the foot)	-0.065	0.082	**0.519***
Heel breadth	0.016	0.105	**0.516***
Medial malleolus height	**0.869***	-0.002	-0.014
Lateral malleolus height	**0.869***	0.012	-0.006
Bimalleolar height	0.050	-0.039	0.332
Eigenvalue	1.31	1.95	1.01
TV (%)	33.02	27.96	14.45
CV (%)	33.02	60.98	75.43

*Factor loading greater than 0.5

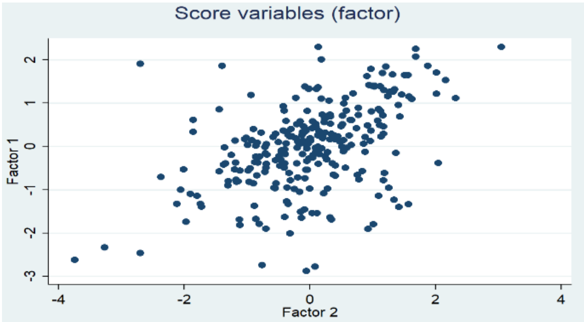
Table 3.6

Regression equations for prediction of certain body dimensions (cm)

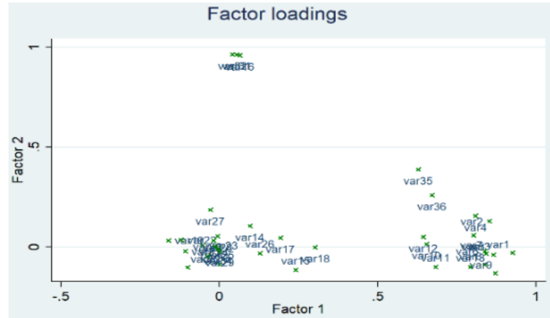
	Female				Male			
Variable	Equations	F- ratio	R^2	SEE	Equations	F- ratio	R^2	SEE
Vertical reach	1.05 x ST+ 33.52	489.16***	0.72	4.01	0.97 x ST + 45.98	611.1***	0.69	4.51
Vertical group reach	0.96 x ST + 37.03	354.58***	0.66	4.35	1.15 x ST + 5.62	566.35***	0.68	5.54
Eye height	0.77 x ST + 24.63	415.14***	0.69	3.21	0.03 x ST + 26.86	579.31***	0.69	3.66
Acromial height	0.75 x ST + 12.93	561.09***	0.75	2.67	0.79 x ST + 5.62	387.20***	0.59	4.61
Elbow height	0.64 x ST - 0.71	271.14***	0.59	3.28	0.63 x ST -1.08	344.45***	0.56	3.93
Olecranon height	0.57 x ST +7.14	232.12***	0.56	3.17	0.57 x ST +5.71	281.60***	0.52	3.89
Iliocrystal height	0.84 x ST - 40.57	345.80***	0.65	3.84	0.64 x ST – 11.65	319.47***	0.54	4.10
Span	0.81 x ST +31.22	268.86***	0.59	4.19	0.45 x ST +9.09	231.12***	0.46	3.45
Span akimbo	0.38 x ST + 20.63	104.51***	0.36	3.16	0.47 x ST +6.74	216.49***	0.45	3.69
Bideltoid breadth	0.79 x BB + 11.38	150.84***	0.45	2.01				
Shoulder grip length	0.70 x TTR + 16.94	159.54***	0.46	2.92				
Vertical grip reach (sitting)	1.13 x SH + 16.94	131.31***	0.41	4.68	0.38 x SH + 28.46	295.41***	0.53	3.15
Sitting Eye height	0.66 x SH + 0.9 x SVR + 6.52	161.25***	0.64	2.02	0.18 x SH + 35.10	17.73***	0.12	4.72
Buttock knee length (sitting)	0.42 x BPL + 21.5	134.70***	0.42	2.84				
Hip breadth (sitting)	0.36 x EEB + KKB x 0.52 + 7.16	174.54***	0.65	2.15	0.54 x EEB +29.74	52.94***	0.67	2.56
Instep length	0.82 x FL -1.33	210***	0.53	0.89	0.66 x FL + 3.23	272.12***	0.51	0.74
Heel breadth	0.71 x FB -0.73	80.13***	0.30	0.66	0.31 x FB +3.66	50.03***	0.16	0.44
Medial malleolus height	0.88 x LMH + 1.823	635.17***	0.78	0.64	0.98 x LMH + 1.00	2930.35***	0.91	0.33

***** *Significance ($p < 0.01$); SEE = standard error of estimate*

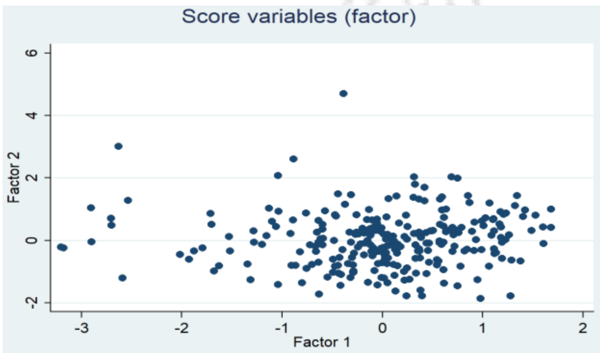
ST = stature, CC = Chest circumference, BB = Bicromial breadth, TTR = Thumb tip reach, SH = sitting height, VR = sitting vertical grip reach, BPL = Buttock popliteal length, EEB = Elbow-elbow breadth, KKB = knee-knee breadth, FL= foot length, FB = foot breadth, LMH = lateral malleolus height



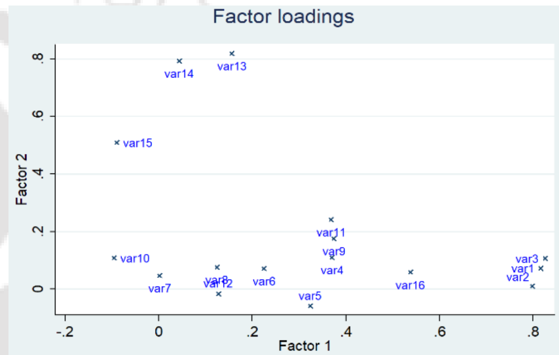
(a) Score variables for male standing position



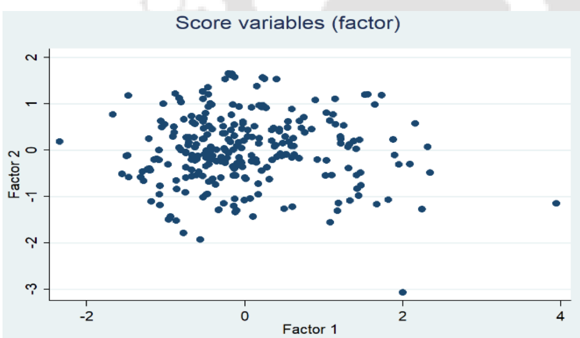
(b) Loading plot for male standing position



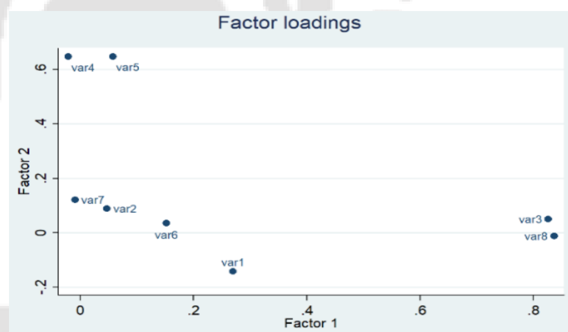
(c) Score plot for male sitting position



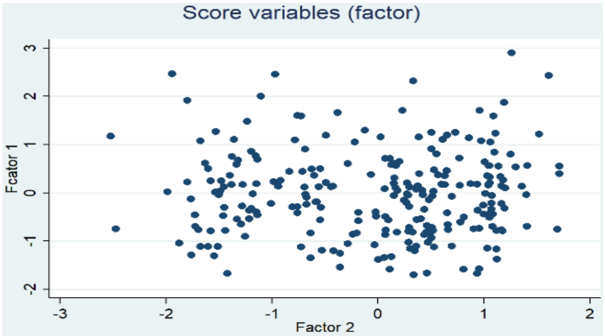
(d) Loading plot for male sitting position



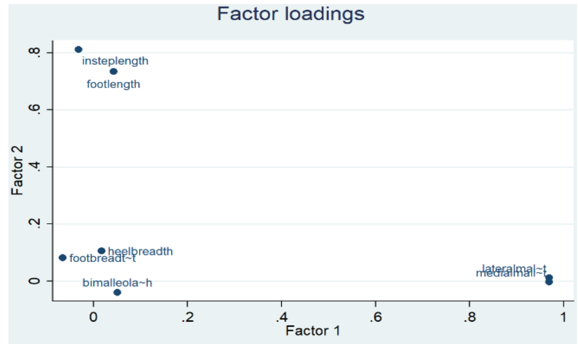
(e) Score plot for male hand dimensions



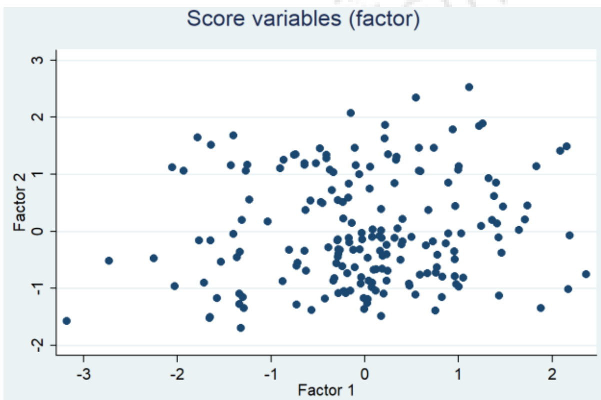
(f) Loading plot for male hand dimensions



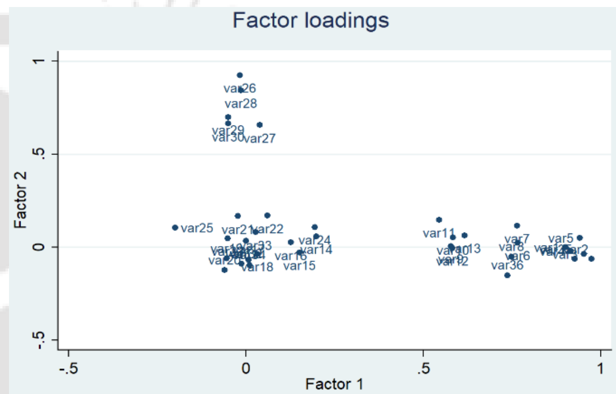
(g) Score plot for male foot dimensions



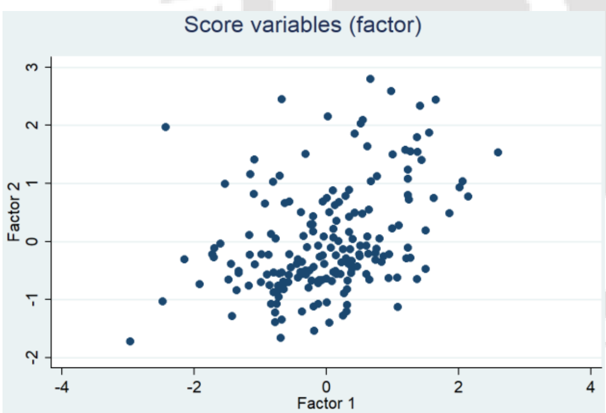
(h) Loading plot for male foot dimensions



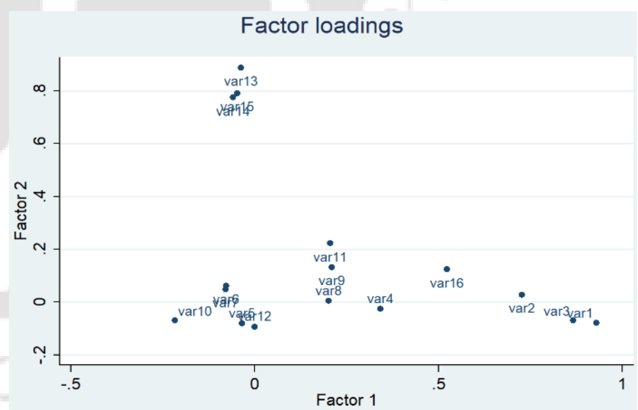
(i) Score plot for female standing dimensions



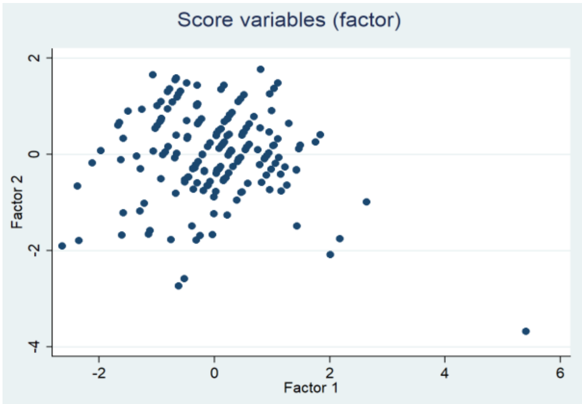
(j) Loading plot for female standing dimensions

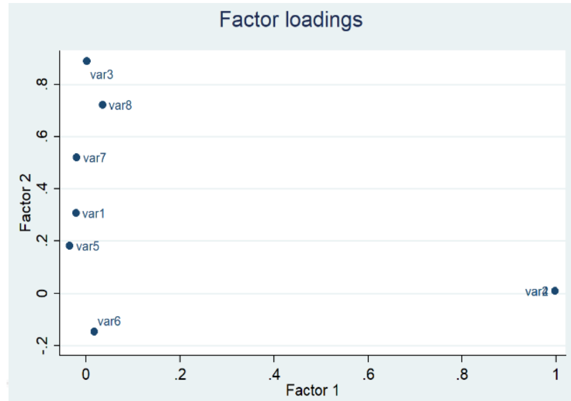


(k) Score plot for female sitting dimensions



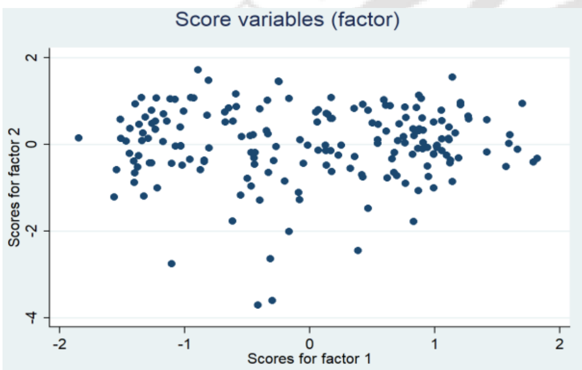
(l) Loading plot for female sitting dimensions

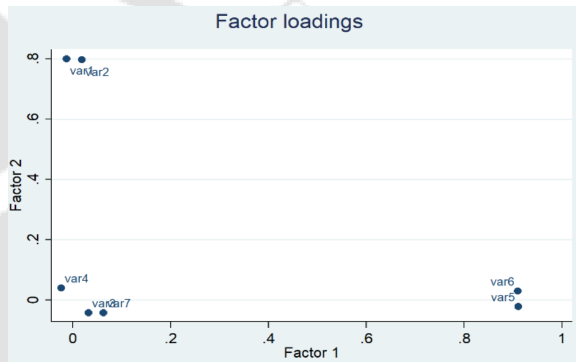




(m) Score plot for female hand dimensions

(n) Loading plot for female hand dimensions





(o) Score plot for female foot dimensions

(p) Loading plot for female foot dimensions

Fig. 3.2 Score plot and loading plot generated after PCA analysis of anthropometric data

3.3.1 Comparison of anthropometry results across ethnic groups

Separate statistical data (mean and standard deviation) for some of the important anthropometric dimensions in all five communities are presented in Table 3.7 and Fig. 3.3. The results indicate that all the anthropometric dimensions of male members of the Hira community are less in comparison to the male members of the other communities. The stature value for male of the Boro community was found to be 167.3 cm (standard deviation- 6.5 cm) which is the highest among the five ethnic groups; those of the Hira community have the smallest stature which is found to be 161.6 cm (standard deviation-6.8 cm). Similarly, the sitting height value of the male Boro population was found to be 87.48 cm (standard deviation- 3.5 cm) which is the highest value among the five ethnic groups, and the male Hira population have the lowest sitting stature which was found to be 81.7 cm (standard deviation-3.6 cm).

Considering the female population, the Boro community was again found to have the greatest stature values (154.6 cm, standard deviation-78 cm) among the five ethnic groups, with the Hira community people having the lowest value (150.7 cm with standard deviation-6.3 cm). Similarly, the sitting height value of the female population of the Boro community was found to be the highest (81.7 cm, standard deviation-3.6 cm) and that of the Hira community female population the lowest (78.5 cm, standard deviation-.4.1cm).

Like stature and sitting height, all the anthropometric dimensions of the Hira community were found to be lower than the anthropometric values of other communities. This reveals that when designing tools/machinery for the rural population, special care must be taken to accommodate dimensional variation. Designing tools/machinery separately for each ethnic group may not be economically feasible. Hence, it is advised to incorporate adjustable features whenever possible.

Table 3.7

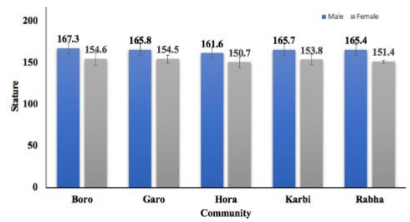
The mean and SD value of some of the important anthropometric dimensions of the five communities

	Boro		Garo		Hira		Karbi		Rabha	
	M (65)	F (44)	M (50)	F (44)	M (50)	F (44)	M (50)	F (44)	M (50)	F (13)
Standing										
Weight (Kg)	58.9 (13.2)	54.7 (11.3)	54.1 (4.8)	48.3 (6.4)	48.8 (9.3)	46.0 (10.5)	57.3 (8.9)	47.3 (8.5)	50.4 (9.78)	44.2 (1.8)
Stature	167.3 (6.5)	154.6 (7.8)	165.8 (7.3)	154.5 (4.4)	161.6 (6.8)	150.7 (6.3)	165.7 (7.1)	153.8 (5.9)	165.4 (6.5)	151.4 (1.8)
Vertical reach	208.4 (8.2)	194.7 (7.2)	208.8 (7.9)	195.3 (5.8)	203.4 (7.8)	191.0 (8.4)	208.0 (8.9)	193.2 (8.1)	206.9 (7.1)	190.8 (2.3)
Eye height	156.9 (5.8)	144.4 (6.3)	154.5 (5.2)	143.4 (4.2)	149.0 (7.8)	140.6 (5.8)	154.8 (5.8)	142.9 (5.5)	154.6 (5.8)	141.2 (1.7)
Acromial height	138.1 (5.6)	127.5 (7.1)	137.7 (5.6)	128.2 (3.8)	132.6 (6.7)	125.7 (5.5)	137.0 (2.1)	126.6 (7.50	136.2 (2.1)	124.4 (5.2)
Elbow height	105.4 (0.6)	98.6 5.4)	104.4 (1.7)	97.6 (3.3)	101.9 (1.1)	96.5 (4.6)	104.9 (1.6)	92. 9 (5.5)	103.7 (0.8)	93.5 (4.7)
Olecranon height	101.5 (3.2)	96.4 (4.9)	101.3 (4.2)	94.5 (4.1)	97.8 (3.7)	94.6 (5.2)	101.6 (0.6)	92.9 (5.5)	99.7 (0.7)	93.5 (4.7)
Knee height	48.8 (2.3)	43.8 (2.8)	49.1 (2.5)	45.8 (2.4)	47.1 (4.6)	44.6 (3.5)	48.8 (2.8)	45.6 (2.9)	48.7 (4.8)	44.5 (0.45)
Arm reach from the wall	80.8 (0.5)	76.3 (3.5)	78.9 (0.5)	74.3 (5.1)	77.1 (2.9)	74.2 (4.3)	79.9 (0.5)	73.7 (3.5)	81.1 (0.5)	74.7 (3.5)
Span	168.5 (1.1)	157.1 (6.4)	168.8 (0.8)	155.3 (5.1)	162.7 (1.7)	153.2 (3.9)	167.7 (1.0)	155.5 (6.9)	167.2 (0.8)	152.8 (6.7)
Span akimbo	86.5 (3.7)	79.5 (3.8)	84.6 (4.5)	78.6 (3.1)	81.9 (1.8)	79.2 (3.9)	85.5 (0.6)	78.9 (3.9)	84.3 (0.4)	76.8 (0.96)
Sitting										
Height	87.48 (3.5)	81.7 (3.6)	86.1 (3.2)	80.7 (2.6)	81.2 (6.7)	78.5 (4.1)	86.1 (3.2)	79.5 (2.7)	84.7 (4.1)	79.2 (1.1)
vertical grip reach	127.0 (0.8)	121.5 (6.4)	127.9 (0.8)	119.4 (5.7)	124.2 (4.5)	117.5 (3.1)	130.1 (2.3)	122.2 (4.9)	130.5 (3.3)	118.4 (3.1)
Eye height	77.1 (3.7)	72.4 (3.6)	78.9 (4.1)	72.1 (2.5)	72.2 (5.2)	69.2 (4.1)	78.7 (3.0)	72.1 (2.3)	77.8 (3.9)	69.2 (0.9)
Acromial height	61.3 (3.5)	57.4 (8.2)	61.0 (3.5)	56.4 (5.3)	60.5 (3.7)	54.8 (9.7)	61.7 (3.0)	56.0 (5.1)	60.9 (5.3)	55.9 (2.1)
Popliteal height	41.3 (1.8)	36.5 (2.1)	42.4 (2.8)	38.7 (1.8)	38.2 (2.8)	38.1 (2.7)	41.4 (3.5)	38.9 (1.9)	42.0 (1.6)	39.2 (3.1)
Elbow Rest Height	24.5 (3.6)	26.4 (4.4)	24.2 (3.6)	23.8 (2.7)	20.8 (2.0)	22.9 (6.5)	24.6 (1.8)	23.7 (1.9)	22.9 (3.1)	25.1 (2.6)
Coronoid Fossa to Hand length	38.8 (2.0)	37.7 (4.2)	39.5 (3.3)	35.9 (2.8)	37.6 (2.6)	35.9 (3.0)	38.5 (2.0)	36.7 (1.9)	38.2 (1.7)	36.4 (1.8)
Buttock Knee Length	51.5 (4.4)	50.5 (4.6)	52.9 (2.9)	49.1 (2.9)	51.1 (3.2)	52.7 (3.5)	53.8 (5.9)	5.6 (3.5)	53.8 (2.6)	51.6 (3.5)
Buttock popliteal length	42.3 (6.4)	40.7 (4.1)	41.9 (3.4)	41.1 (3.8)	41.6 (2.8)	43.6 (4.3)	41.7 (6.4)	41.9 (1.9)	42.2 (2.7)	39.9 (2.3)

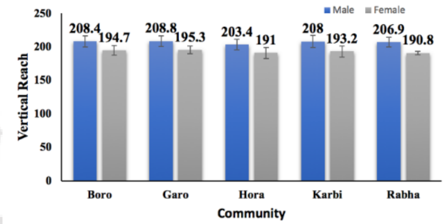
Table 3.7 (continued)

Hip breadth	32.6 (2.56)	31.3 (3.27)	32.8 (2.04)	32.7 (2.5)	28.7 (2.7)	30.6 (3.1)	33.7 (2.3)	33.8 (2.9)	31.1 (2.3)	31.2 (0.56)
Functional leg length	93.3 (5.1)	88.8 (5.7)	95.2 (5.9)	84.9 (4.9)	89.7 (5.6)	87.8 (6.5)	92.2 (6.0)	87.6 (4.4)	93.5 (4.3)	81.7 (1.3)
Standing / sitting										
Grip diameter (inside)	5.4 (0.9)	5.5 (0.8)	5.3 (0.7)	4.8 (0.7)	4.2 (0.6)	4.8 (0.7)	5.5 (0.6)	5.2 (0.5)	5.5 (0.5)	5.3 (0.7)
Hand length	17.6 (0.9)	16.1 (0.9)	17.6 (0.9)	15.5 (0.8)	16.2 (1.0)	16.0 (0.6)	17.5 (0.9)	16.4 (0.8)	16.9 (0.9)	15.9 (0.8)
Hand breadth across thumb	9.0 (0.6)	8.3 (0.7)	9.2 (0.5)	8.3 (0.6)	8.5 (0.7)	8.2 (0.5)	8.9 (0.4)	8.2 (0.7)	9.0 (0.6)	8.2 (0.6)
Palm length	10.0 (0.9)	9.1 (1.4)	10.0 (0.6)	8.9 (0.9)	8.7 (1.0)	8.9 (1.1)	10.2 (0.6)	9.3 (0.6)	9.8 (0.6)	9.3 (0.5)
Foot length	23.5 (1.0)	21.6 (1.4)	23.9 (1.2)	20.7 (1.2)	22.7 (1.5)	20.9 (1.4)	23.7 (1.9)	21.8 (1.1)	23.2 (1.2)	21.8 (0.9)
Indices										
RHS	0.52 (0.05)	0.53 (0.02)	0.52 (0.72)	0.52 (0.09)	0.50 (0.03)	0.52 (0.02)	0.51 (0.04)	0.51 (0.03)	0.51 (0.80)	0.54 (0.04)
BSA	1.65 (0.18)	1.52 90.18)	1.58 (1.25)	1.43 (0.10)	1.47 (0.5)	1.36 (0.15)	1.62 (0.02)	1.41 (0.14)	1.52 (0.5)	1.36 (0.12)
BMI	20.99 (3.23)	22.94 (4.97)	19.73 (4.40)	20.27 (0.37)	18.64 (3.05)	19.69 (3.68)	20.85 (0.53)	19.91 (3.09)	18.29 (2.67)	19.26 (2.43)

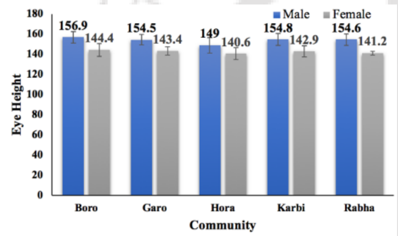
#Measurements are in cm, unless otherwise specified; n = number of subjects; M = male, F = female



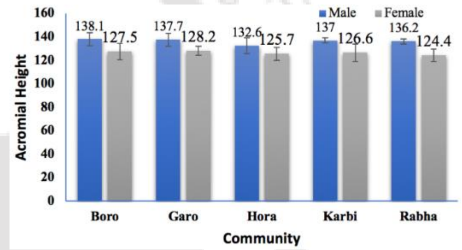
(a) Stature



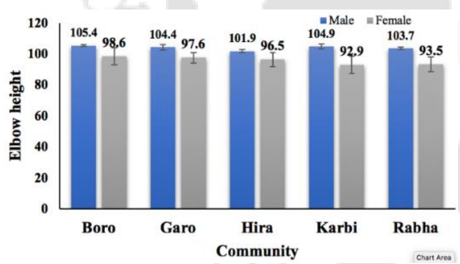
(b) Vertical reach



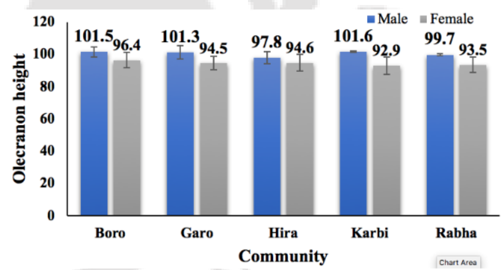
(c) Eye height



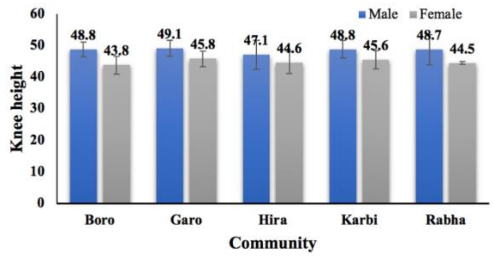
(d) Acromial height



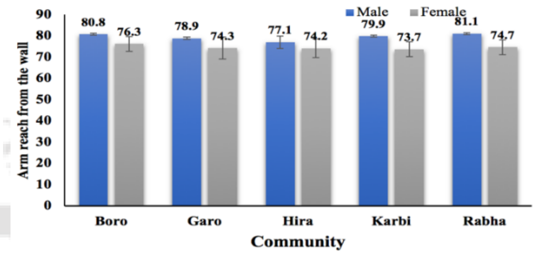
(e) Elbow height



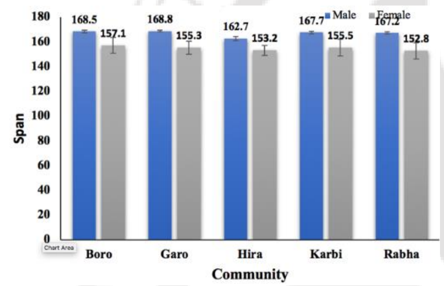
(f) Olecranon height



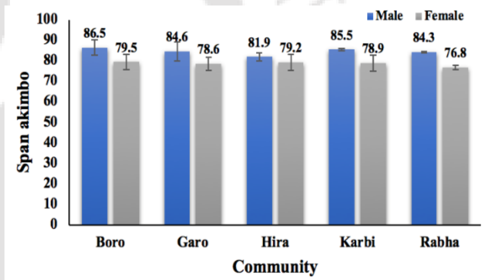
(g) Knee height



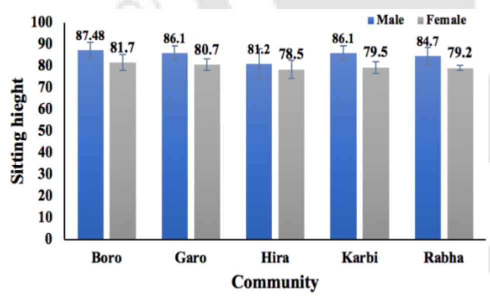
(h) Arm raech from the wall



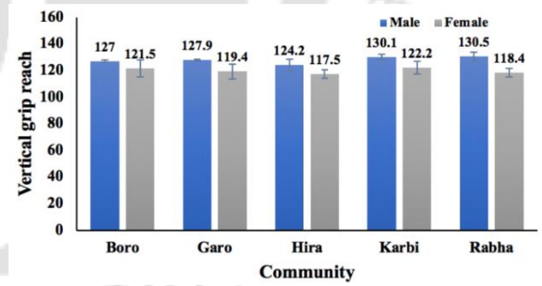
(i) Span



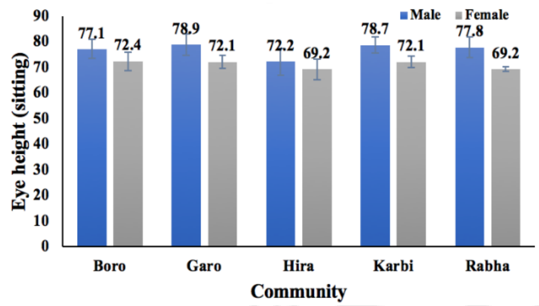
(j) Span akimbo



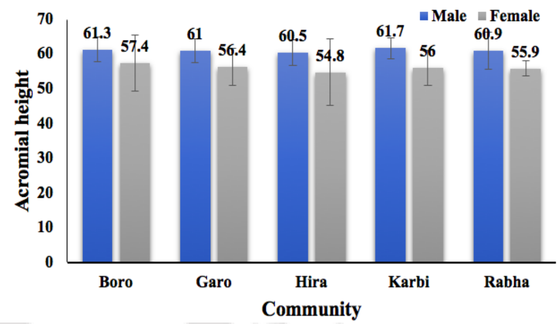
(k) Siting height



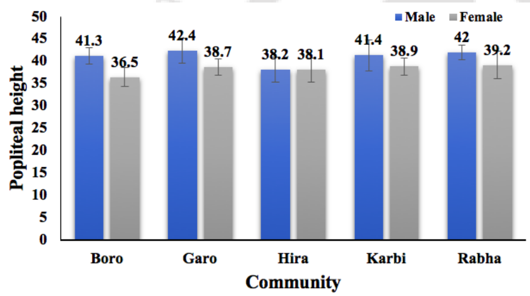
(l) Vertical grip raech (sitting)



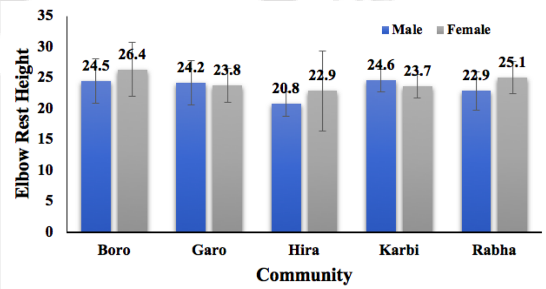
(m) Eye height (sitting)



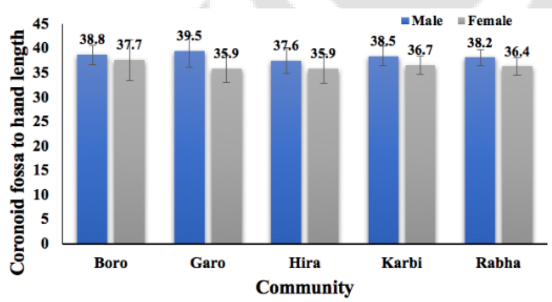
(n) Acromial height (sitting)



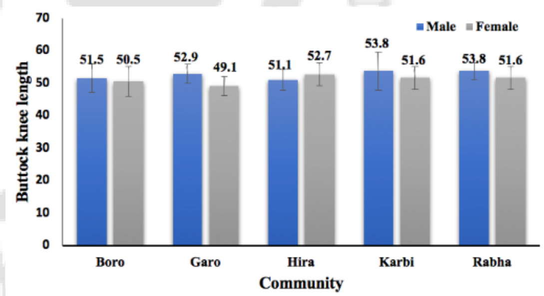
(o) Popliteal height (sitting)



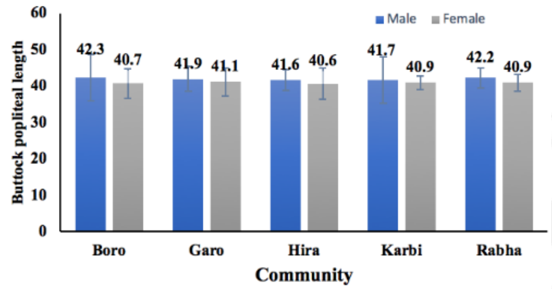
(p) Elbow rest heigt (sitting)



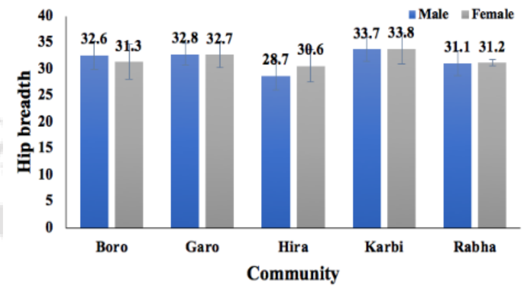
(q) Coronoid fossa to hand length



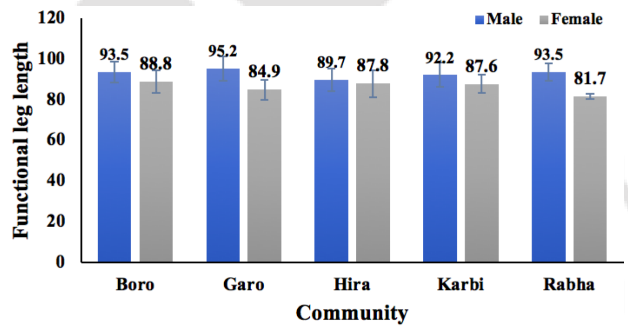
(r) Buttock knee length



(s) Buttock popliteal length



(t) Hip breadth



(u) Functional leg length

Fig. 3.3 Showing the variations of some of the important anthropometric dimensions (in cm) based on geneder and ethinicity

3.3.1.1 Statistical t-test result

Statistical t-tests results comparing the statistical significance of variance of anthropometric data (stature and sitting height) across genders for mean values of the total sample population of male and female anthropometric dimensions are presented in Table 3.8. All the anthropometric data except spank akimbo, sitting elbow rest height, grip diameter (inside), and BMI values were found to be significantly different ($Pr < 0.01$) for male and female sample populations.

Moreover, t-tests were carried out to verify the statistical significance of the variations of two important anthropometric dimensions, namely stature and sitting height, across ethnic diversity within the same gender; the results are presented in Table 3.9. Within-gender variations in stature values when comparing the Hira community members with the Boro, Garo, Karbi, and Rabha populations were found to be statically significant. The results depict that within-gender variations in stature values of Boro vs. Garo, Boro vs. Karbi, and Garo vs. Karbi are not statistically significant. Significant outcomes are observed between sitting height values of different communities across the same gender. Statistically significant variations were seen in the sitting height values of the following groups: Boro vs. Hira (female), Boro vs. Hira (male), Boro vs. Karbi (female), Boro vs. Rabha (male), Garo vs. Hira (female), Garo vs. Hira (male), Hira vs. Karbi (female), Hira vs. Karbi (male), Hira vs. Rabha (male), and Karbi vs. Rabha (male). Due to a limitation of data, the female Rabha group was not considered.

Some important anthropometric dimensions from this study were compared with those of two previous studies viz., (Dewangan et al. 2005 and Patel et al. 2016). Almost all the height-related important anthropometric dimensions of this study were found to be higher in comparison to the stature values reported in the other two studies.

This study validates findings from previous studies (e.g. Launer and Harris, 1996; Lin et al., 2004; Klamklay et al., 2008; Iseri and Arslan, 2009; Syuaib, 2015), which have shown that anthropometric dimensions vary across occupations, genders, geographical locations, and ethnicities. In Assam, machinery is outsourced from southern or northern Indian states. Agriculture machinery (e.g., power tillers, threshers, etc.) are also outsourced from these states. Because the anthropometric data of the five communities studied here differ from those of other groups, special care is necessary in such technology intervention initiatives. Otherwise, due to anthropometric dimension mismatches, accident, injuries, drudgery, or other health-related issues may arise among machine operator.

Table 3.8

t-tests results for comparing mean values of some of the anthropometric dimensions based on gender (male vs. female)

	t	Pr.	Df	Statistical significance		t	Pr.	df	Statistical significance
Standing					**Sitting**				
Weight (kg)	-6.224	0.000***	372	Significant	Height	-11.168	0.000***	372	Significant
Stature	-16.730	0.000***	372	Significant	vertical grip reach	-9.001	0.000***	372	Significant
Vertical reach	-15.496	0.000***	372	Significant	eye height	-12.151	0.000***	372	Significant
Eye height	-16.375	0.000***	372	Significant	Popliteal height	-11.560	0.000***	372	Significant
Acromial height	-14.086	0.000***	372	Significant	Elbow Rest Height	1.238	0.217	372	Not significant
Elbow height	-11.497	0.000***	372	Significant	Coronoid Fossa to Hand length	-8.439	0.000***	372	Significant
Olecranon height	-10.640	0.000***	372	Significant	Buttock Knee Length	-5.640	0.000***	372	Significant
Knee height	-10.262	0.000***	372	Significant	Buttock popliteal length	14.497	0.000***	372	Significant
Arm reach from the wall	-9.051	0.000***	372	Significant	Hip Breadth	2.917	0.037***	372	Significant
Span	-15.52	0.000***	372	Significant	Functional Leg Length	-9.871	0.000***	372	Significant
Span akimbo	0.000	1.000	372	Not significant					
Sitting									
Grip diameter (inside)	0.714	0.475	372	Not significant	RHS	2.615	0.009***	372	Significant
Hand length	-9.23	0.000***	372	Significant	BSA	-9.069	0.000***	372	Significant
Hand breadth across thumb	-9.544	0.000***	372	Significant	BMI	1.535	0.125	372	Not significant
Palm length	-5.707	0.000***	372	Significant					
Foot length	-12.250	0.000***	372	Significant					

*# Represents Statistical significance: at the ***Pr< 0.01; **Pr<0.05; *Pr< 0.1*

Table 3.9

t-test result based on ethnicity

		Stature					Sitting height			
Sl. No		t	Pr	df	Significance		t	Pr.	Df.	Significance
1.	Boro Vs Garo (female)	0.4409	0.66	78	Not significant	Boro Vs Garo (female)	1.5337	0.1287	88	Not significant
	Boro Vs Garo (male)	0.8391	0.4034	98	Not significant	Boro Vs Garo (male)	1.5854	0.1161	98	Not significant
2.	Boro vs Hira (female)	2.6308	0.0103**	78	Significant	Boro vs Hira (female)	3.7150	0.0004***	88	Significant
	Boro vs Hira (male)	4.1716	0.0001***	98	Significant	Boro vs Hira (male)	5.5523	0.0000***	98	Significant
3.	Boro Vs Karbi (female)	0.8346	0.4065	78	Not significant	Boro Vs Karbi (female)	3.3212	0.0013***	88	Significant
	Boro Vs Karbi (male)	0.9609	0.3390	98	Not significant	Boro Vs Karbi (male)	1.6484	0.1025	98	Not significant
4.	Boro Vs Rabha (male)	1.2219	0.2247	98	Not significant	Boro Vs Rabha (male)	3.2535	0.0016***	98	Significant
5.	Garo Vs Hira (female)	3.0783	0.0029***	78	Significant	Garo Vs Hira (female)	2.7165	0.0079***	88	Significant
	Garo Vs Hira (male)	3.0409	0.0030***	98	Significant	Garo Vs Hira (male)	4.6172	0.0000***	98	Significant
6.	Garo vs Karbi (female)	0.6146	0.5406	78	Not significant	Garo vs Karbi (female)	2.0831	0.0401**	88	Significant
	Garo vs Karbi (male)	0.1067	0.9153	98	Not significant	Garo vs Karbi (male)	0.0732	0.9418	98	Not significant
7.	Garo Vs Rabha (male)	0.3053	0.7608	98	Not significant	Garo Vs Rabha (male)	1.8974	0.0607*	98	Significant
8.	Hira Vs Karbi (female)	-2.1587	0.0340**	78	Significant	Hira Vs Karbi (female)	-1.1238	0.0042***	88	Significant
	Hira Vs Karbi (male)	-2.9527	0.0039***	98	Significant	Hira Vs Karbi (male)	-4.5629	0.0000***	98	Significant
9.	Hira Vs Rabha (male)	-2.8928	0.0047***	98	Significant	Hira Vs Rabha (male)	-3.1246	0.0023***	98	Significant
10.	Karbi Vs Rabha (male)	0.1954	0.8455	98	Not significant	Karbi Vs Rabha (male)	1.8251	0.0710*	98	Significant

*# Represents Statistical significance: at the ***Pr< 0.01; **Pr<0.05; *Pr< 0.1*

3.4 Testing the hypotheses

In section 3.2.4, a null hypothesis (H_0 : $\mu_1 = \mu_2$) and an alternate hypothesis (H_a: $\mu_1 \neq \mu_2$) are proposed where, μ_1 and μ_2 indicate the mean values of anthropometric dimension of the two communities/tribes. T-Tests results discussed in previous sections prevails the statistical significance of the variations of anthropometric dimensions across ethnic diversity within the same gender. Similarly, within-gender variations in stature values when comparing the Hira community members with the Boro, Garo, Karbi, and Rabha populations were found to be statically significant. Similarly, significant outcomes are observed between sitting height values of different communities across the same gender. Also, statistical t-tests results comparing the statistical significance of variance of anthropometric data (stature and sitting height) across genders for mean values of the total sample population of male and female anthropometric dimensions depicts that all the anthropometric data except spank akimbo, sitting elbow rest height, grip diameter (inside), and BMI values were found to be significantly different ($Pr < 0.01$) for male and female sample populations. These findings validates that anthropometric dimensions vary across occupations, genders, geographical locations, and ethnicities. Thus we could not reject the null hypothesis.

3.5 Summary

This study reports anthropometric data of five communities/tribes in Assam with gender and ethnic diversity. Seventy-two anthropometric body dimensions, including age and body weight, of 453 people from different districts of Assam, India are summarized in this study. The sample included 265 male and 188 female from the state of Assam within the age ranging between 18 and 60 years. Hand tools are extensively used in the region for various day-to-day activities. Hence, the newly presented anthropometric data in the study should be helpful in redesigning other tools and machinery for the five communities of Assam, India.

Statistically significant variations in anthropometric characteristic across genders and ethnic diversity within genders are observed. The most prominent variation existed between the anthropometric dimensions of tribal people and the non-tribal people of the region. Most of the anthropometric dimensions of the Hira community, the only non-tribal community considered in this study, were found to be smaller than those of the other four tribes. One reason for such a variation is that the tribal people of the state are Mongoloid, whereas the Hira people are non-Mongoloid. The female population is found to be shorter than the male population. The results indicate that the null hypothesis has been rejected for the Hira population in comparison with other tribes. The outcomes of the study will add knowledge to the anthropometric data differences among the different native groups from a small geographical space.

In the next chapter, design and development process of the IPC is discussed. Anthropometric data presented here is used while determining dimensions of the IPC.

Chapter 4

Ergonomic design modification of pottery wheel

4.1 Introduction

The paucity of anthropometric data of target-users was a major problem at the start of the design of the IPC. To overcome the hurdle, target-users' anthropometric data is collected and analyzed which is reported in the previous chapter. Anthropometric data collected during this study is used in deciding different dimensions of the IPC to make fit it to the said communities. The design and development effort of IPC is discussed here.

4.1.1 Morphology of design

The overall design process of the IPC is followed by seven sequential stages of design also known as the morphology of design propagated by Morris Asimow (Das, 2007). Sequential steps can be mentioned as follows: feasibility study, preliminary design, detailed design, planning for production, planning for distribution, planning for consumption, and planning for retirement.

As per the morphology of the design process discussed here, before initiating the design process, a primitive need must be identified. The need for an IPC is already discussed in chapter 2. In the following sections, detail analysis of feasibility study, preliminary design, detailed design are presented. Details about planning for production, planning for distribution, and planning for retirement are discussed in chapters 6 and 7.

4.1.2 Feasibility study

To understand the feasibility of the need of IPC, the issue was discussed with stakeholders. Indian Institute of Enterprise Guwahati has been implementing a project for the socio-economic improvement of pottery artisans in the Dhubri district of Assam, India. Expert opinion is collected from the officials associated with the project. Financial involvements are also considered as economic feasibility is imperative for the sustenance of any technology. Officials involved with RuTAG project ensured financial support.

4.1.3 Identification and formulation of the design matrix

Walsh, et al., 1992 defined product design as "*the activity in which ideas and needs are given physical form, initially as a solution, concepts and then as a specific configuration or arrangement of elements, materials, and components*". It stresses three actions: exploration, reflection, and interaction i.e. listening, interpreting and addressing (Verganti, 2003). Going through these phases, while developing a new product help in integrating product language, users' need/aspiration and technological development.

Needs of target-users may be tangible (utility and functionality) and/or intangible (emotional and socio-cultural needs). Right combinations of product features assist in attaining desired users' needs. Attaining a right combination of features in a product through design activity necessitates understanding the complex and dynamic behavior of the society and community. An in-depth understanding of the needs/aspirations of the poor people and analyze those needs/aspirations from the perspectives of target-users' social-economical condition is essential. Hence, to have a better understanding of target-users' needs/aspiration regarding new technology, at the beginning of the design process, target-users' feedback were collected to understand the users' opinion.

A total of 360 artisans (180 male and 180 female) were interviewed during the ideation stage of technology development to understand how the needs/aspirations/constraints of the artisans vary from one context to another. Important factors that need attention in the process of designing the technology were identified from the survey. The findings of the user's survey can be disused in the following subheadings.

- Technological needs are context-specific and vary from one location to another within a small geographical distance. Hence, in deciding different technical features, special attention is necessary so that it can satisfy the maximum people.

- Finance and physical infrastructure is a major issue in remote villages. Villagers, especially higher aged people prefer manual-powered tool/machine with simple working procedure.

- In the household cottage industry, female members play an important role. So their requirement should be reflected in deciding technical features.

Following design criteria is considered based on the understanding of the users' need:

- To prioritize manual power so that it can cater to the needs of the target-users from remote villages.

- To select an easy to operate mechanism so that unskilled manpower can easily handle the machine.

- To design the machine in such a way that the same machine can be used by both male and female artisans

- To avoid parts/components/mechanisms where complex manufacturing is needed so that it can be manufactured in the village level without extra investment to micro-enterprises.

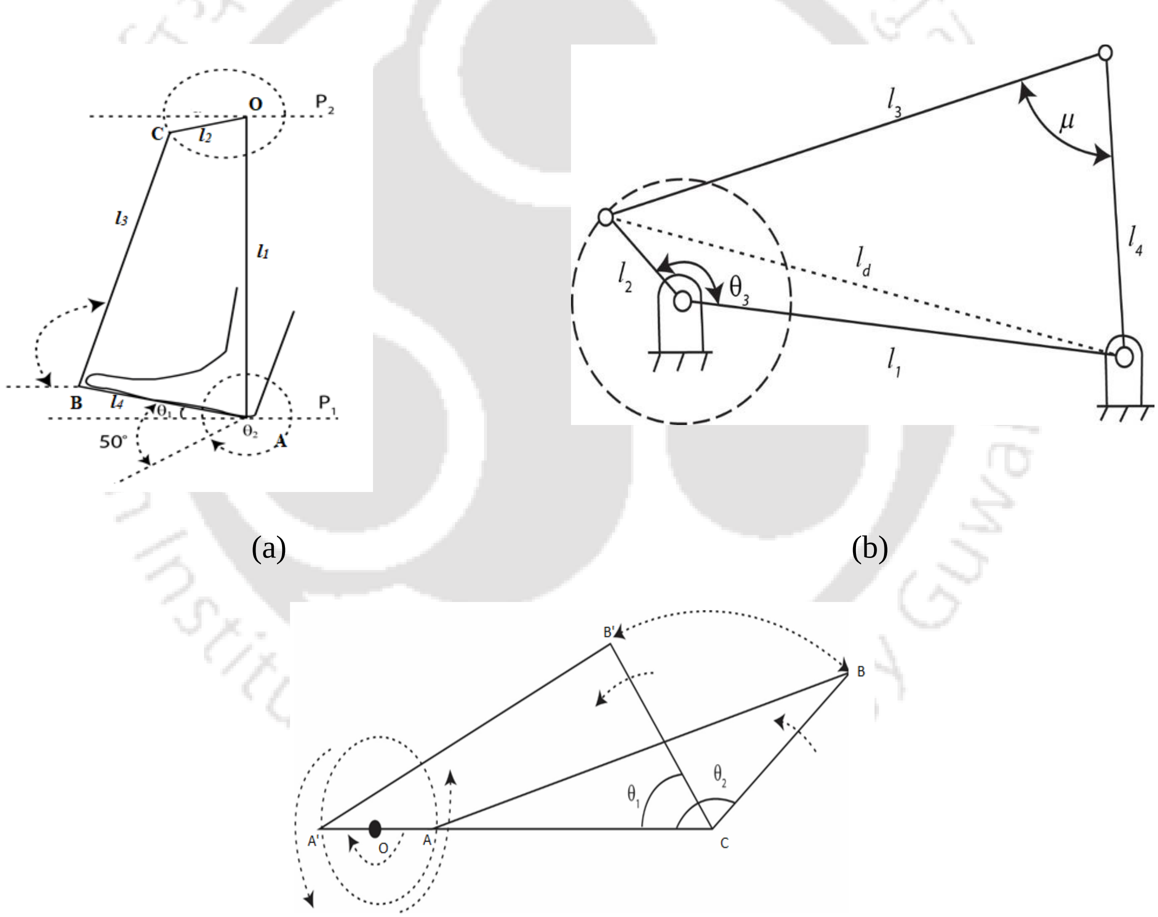
- To avoid parts/components where frequent maintenance is prevalent

- Cost of the machine should be as low possible.

4.2 Preliminary design

Pottery artisans are accustomed to the manual-powered sewing machine. During interaction with artisans, they propose that the operation mechanism of the new machine should be like a *Treadle Mechanism* used in sewing machine. Leg muscles are considered stronger than arm muscle (Tsai, et al., 2008), and hence pedaling is supposed to generate more power than hand cracking (Tiwari, et al., 2011). Leg powered mechanism is also considered to be ergonomically better. Hence, the treadle mechanism used in a sewing machine is skillfully adapted in the IPC.

A four-bar planner crank-rocker mechanism is constructed (shown in Fig. 4.1). The operator will apply an ankle-powered manual force on the pedal as shown in Fig. 4.1 (a). The Pedal will act as a rocker arm. As shown in Fig. 4.1 (b) and Fig. 4.1 (c), it will facilitate the rotation of the crank. Based on experimental verification, it is assumed that one can provide a full rocker movement per second. This motion is transmitted to a bigger pulley through the provision of a four-bar planner crank-rocker mechanism (shown in Fig. 4.2 (a)). Thus the rotation of bigger pulley is 60 rpm. The bigger pulley is again connected to a smaller pulley by a belt- drive system. The diameter ratio between the bigger pulley and smaller pulley is considered as 5:1. This belt-drive arrangement will transmit the motion from the bigger pulley into the smaller pulley. Theoretically, the rotation of the smaller pulley will be 300 rpm. One



(a)

(b)

(c)

Fig. 4.1 (a) Showing the four-bar pedaling; (b) Showing the four-bar mechanism; (c) Showing extreme two angles

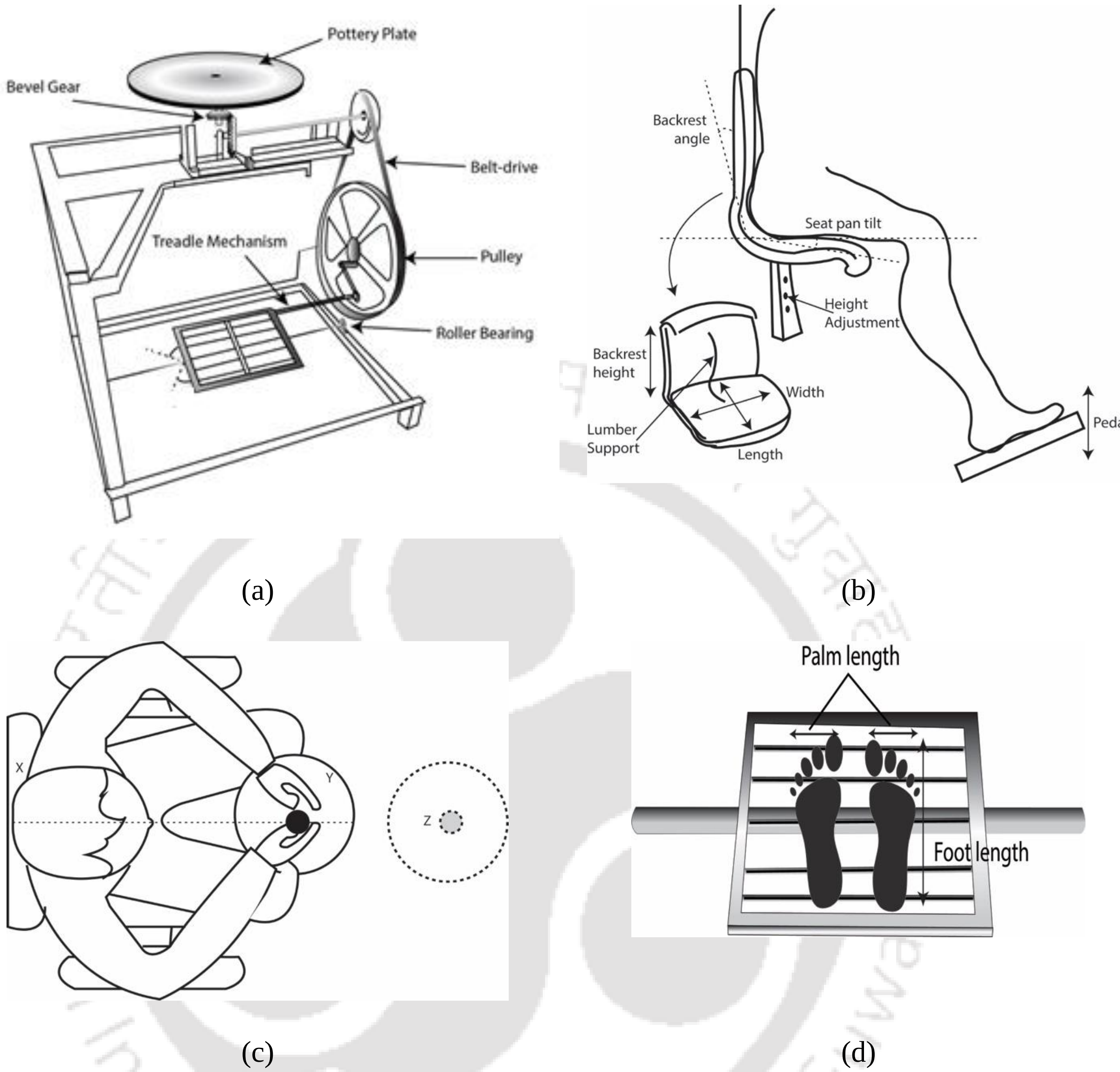


Fig. 4.2 (a) Working mechanism of the IPC (b) Chair details of the IPC (c) Side view showing work surface reach; Y and Z represent work surface position for maximum and minimum distance, respectively (d) Showing the dimensions of the pedal

end of the shaft connected with the smaller pulley is again connected to a bevel gear system. The pottery plate (*Chaak*) is connected to the shaft connecting the bevel gear. Such an arrangement facilitates the successful conversion of linear motion into rotatory motion in the *Chaak*. The gear ratio considered for the bevel gear system is 2:1. Hence, 300 x 2 = 600 rpm (theoretically) is obtained at the *Chaak*.

Finally, an ergonomically correct sitting arrangement is designed using fresh anthropometric data of the target-users (shown in Fig. 4.2 (b)). In deciding different parameters of the four-bar planner crank-rocker mechanism, anthropometric data of the target-users are considered.

4.3 Detail design

4.3.1 Crank-rocker four-bar mechanism design

Different linkages and extreme angle positions of the crank-rocker mechanism (OABC) are illustrated in Fig. 4.1. Here, OA= fixed length, OC = crank length, BC= coupler, and AB= rocker length. Here rocker length refers to the pedal (crank) length. Two extreme limit angle positions formed by (OA, AB) and (OA, AB') are mentioned as θ_2 and θ_1 respectively (Fig. 4.1 (c)). The range of rocker motion is the range between θ_1 and θ_2 which is referred here as $\beta = (\theta_2 - \theta_1)$.

The fixed length (l_1) is considered to be 300 mm. It is decided based on the anthropometric data of the target community (as discussed in Chapter 3). Here, rocker arm length (l_4) is the pedal length. Now, based on the foot length of the target-community, the rocker arm length (l_4) is considered as 180 mm. The determination of the rocker length (l_4) is discussed in section 4.3.2.7. To evaluate the other two dimensions i.e. Crank length (l_2) and coupler length (l_3), the law of cosines (shown in Eqn. (4.1) and Eqn. (4.2)) is used here.

Now, considering the operators' comfort during the pedalling of the crank, two extreme angles (θ_1 and θ_2) are considered in the design process. Based on experimental verification, it is supposed that the operator can move the pedal 40^0 above the plane P_1 and 10^0 below the plane P_2. Putting the values of l_1, l_4, θ_1 and θ_2 in Cosines law presented in Eqn. (4.1) and Eqn. (4.2), the other two dimensions viz., l_2, and l_3 can be calculated.

$$q_1 = \cos^{-1}\left[\frac{(l_2 - l_3)^2 - l_1^2 - l_4^2}{2l_1l_4}\right] \qquad [4.1]$$

$$q_2 = \cos^{-1}\left[\frac{(l_2 + l_3)^2 - l_1^2 - l_4^2}{2l_1l_4}\right] \qquad [4.2]$$

$$\mu = \cos^{-1}\left[\frac{l_3^2 + l_4^2 - l_1^2 - l_2^2 + 2 l_1 l_2 \cos\theta_3}{2 l_3 l_4}\right] \qquad [4.3]$$

Thus, the length of the crank (l_2) = 70.3 mm and the length of the coupler (l_3) = 303 mm.

As per the requirement of the system, the crank (l_2) needs to rotate 180^0. Hence, the angle of rotation of the crank (θ_3) as 180^0. Using the Eqn. (4.3), the transmission angle is calculated as 88.6^0. According to Yan, 1998, a comfortable transmission angle range should be in between 45^0 and 135^0. Therefore, the transmission angle of 88.6^0 can be considered as an effective design for comfort.

Finally, the dimensions of the link of the four-bar mechanism satisfy the Grashof's criteria: Bigger link + smaller link < sum of the other two links.

4.3.2 Application of anthropometric data in deciding different dimension of the machine

In this section, a discussion is presented on how different dimensions of the IPC is decided based on anthropometric data of the target-community using ergonomic principles.

Correct sitting posture is the basic requirement for productivity and comfort. Ideally, the thigh and calves should be at an angle of 90^0. Similarly, the upper and lower arms should form an angle of 90^0. As mentioned by Rebiffe,1969, the basic requirement while deciding the important dimensions of workstation/ machine involve important angles to be considered, which are as follows: back angle, trunk/thigh angle, knee angle, ankle angle, upper arm angle, and elbow angle. The geometrical parameters that need serious attention in designing a seat are as follows: lumbar support, backrest slope angle, seat width, seat length, seat height, seat pan angle, etc. In designing the machine, necessary attention is given for providing important joint angles at a neutral range so that tissue stress may be minimized (Keegan, 1953), thus providing a comfortable and controlled sitting posture. The basic requirement in a workstation

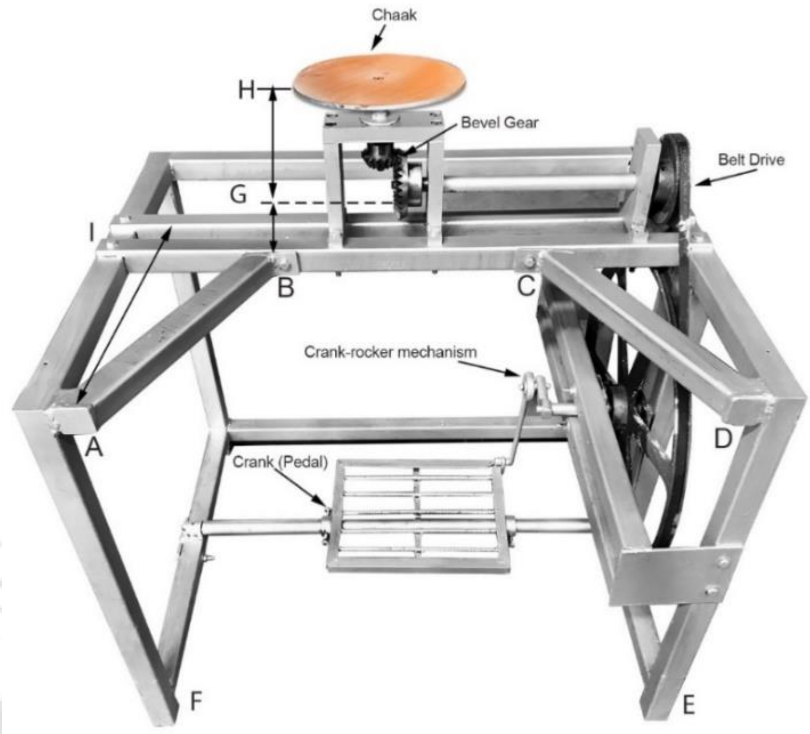


Fig. 4.3 Showing the four-bar mechanism in the fabricated model of the machine

design for attaining healthy operator posture as poised by Konz, 1967; Khalil 1972; Tichauer 1975; Das and Grady, 1983; Eastman Kodak Company 1983; Corlett, 1988; Yu, et al., 1988; Konz, 1995; and Corlett and Clark, 1995 are followed in designing the IPC.

To achieve an effective and efficient man-machine interaction, several parameters need to be optimized (Mehta et al., 2007). Shao and Zhou, 1990 suggested a horizontally and vertically adjustable sitting arrangement for comfort. Hence, the seat was not integrated with the machine, thereby enabling the operator to adjust the distance between the artisan and work surface as per her/his comfort. To make the pottery works comfortable for both male and female artisans, height adjustment chair was proposed. In this case, the popliteal height of the artisan was taken as the determining criteria (Das and Sengupta, 1996). Since the popliteal height of female is found to be lesser as compared to male's popliteal height, minimum chair height is determined based on the 5th percentile value of female popliteal height. The maximum chair height was determined based on the 95th percentile value of the male population. Hence, Minimum chair height = 5th percentile value of female popliteal height + 5 cm = 28.8 + 5 =

33.5 cm (~ 34 cm); Maximum chair height = 95th percentile of male popliteal height + 5cm = 45.5 + 5 = 50.5 cm (~51); clearance value of 5 cm is considered. Because the rural population is not accustomed to sophisticated products, the screw and nut mechanism was preferred for height adjustment instead of an air-pressure mechanism.

In pottery works, artisans need to give serious attention to the job while imparting the required shape for the product. That is the reason why the artisan tilts his/her head/neck forward in the traditional process. To accommodate the same, the following measures are proposed in the design intervention: i) the seat is given a U-shaped curvature (as shown in Fig. 4.2 (b)) so that the artisans get the necessary hip support, ii) necessary open space is maintained (A-B-C-D as shown in the Fig. 4.3) so that the artisans can move the chair as per his/her necessity and comfort. This will facilitate the operator to keep the trunk/thigh angle and knee angle at 90^0 while pedalling. Hip support by the U-shaped seat and free movement due to the opening A-B-C-D are expected to minimize the forward tilt of the head/neck. Besides, the vertical distance AF and DE (Fig. 4.3) is kept at a distance higher than the 95^{th} percentile value of male popliteal height (sitting). In the present case, 95^{th} percentile value of male popliteal height (sitting) is found to be 45.5 cm. Hence, the vertical distance AB is proposed as 50.5 cm (~51 CM), where 5 cm is kept as clearance value. Knoz, 1967 from an experimental result concluded that the work surface height should be 2.5 cm below the elbow height (sitting). However, Das and Grady (1983) opined that working height can be varied several centimetres up or down without any impact on the comfort. In this study, since the machines are being designed as suitable for both male and female, hence ideally adjustable work surface height will suit better. Such an arrangement is not possible due to the belt-drive pulley mechanism employed in the proposed design. Thus the work surface height GH is kept fixed to 20 cm.

Another important dimension that is considered while designing the machine is work surface reach, i.e., the horizontal distance XY (as shown in Fig. 4.2(c)). In determining the distance XY, thumb tip reach has been considered as the determining criterion (Das and Sengupta, 1996). According to this criterion, the artisans should be able to easily reach the pottery plate while seated. As shown in Fig. 4.2(c), if the design is set for position Z, then person with a shorter thumb tip reach will not be able to work comfortably. If it is designed based on the anthropometric value of shorter thumb tip reach (position Y), then people with both short and long thumb tip reaches will be able to work comfortably. In the present case, due to the opening A-B-C-D the artisan can easily adjust the position of the chair as per her/ his comfort. The dimension 'AD' is kept 20 cm higher than the seat pan width of the chair. The details about the calculation of seat pan width of the chair is shown in section 4.3.2.1. A lower value of AI (as shown in Fig. 4.3) is better for easy reach of the work surface. The distance between A and I of 25 cm is determined based on the requirement of the four-bar mechanism. Thus, the artisans will get enough scope for working in the machine without any forward tilt of head/neck.

4.3.2.1 Seat pan width

To determine the width of the chair, hip breadth is considered as the determining criterion (shown in Fig. 4.2 (b) (Mehta et al., 2008). Because of the hip breadth of the female population, in general, is found to be greater in comparison to the hip breadth of male, in order to accommodate maximum populations, the 95th percentile of female hip breadth is considered in the study.

Seat pan width = 95th percentile of female hip breadth + 5 cm = 38.3 + 5 = 43.5 cm. ~ 45cm. (5 cm is considered as a clearance value).

4.3.2.2 Seat length

The seat length (Fig. 4.2 (b)) is generally determined based on the buttock popliteal length of the female population (Mehta et al., 2008). The depth of the chair should be determined in such a way that the necessary buttock support is confirmed without the worker's lower legs touching the seat. If the chair length is designed for maximum dimensions, shorter people will not be able to sit properly. If the seat is designed for the shortest length, then the users with higher buttock popliteal length will not able to apply the necessary force on the treadle. Hence, the length of the chair is determined based on the mean value of the female buttock–popliteal length.

Chair depth = Mean of female buttock-popliteal length + 5 cm = 38.50 + 5 = 43.5 cm. (5 cm is considered as a clearance value).

4.3.2.3 Seat backrest height

In deciding backrest height, necessary attention must be paid to the fact that the operator's back gets the necessary support and, at the same time, full mobility to the arm and shoulder is not blocked (Mehta et al., 2008; Ghaderi, et al., 2014). The 5th percentile value of sitting acromial height is 46.9 cm and 50.7 cm for male and female populations, respectively. To have a free movement of the shoulder, the backrest height is considered as 35 cm.

4.3.2.4 Seat backrest inclination

As per the standard norms, a backward inclination of 95^0–105^0 from horizontal is recommended for operators' lower back and sacrum support. In this study, high back inclination is not recommended as the operators need to operate the pedal and at the same time concentrate on the job. Hence, a small inclination of just 95^0 from the horizontal is suggested in the study.

4.3.2.5 Seat pan tilt

Mehta et al. 2008 recommended 5^0 to 7^0 backward seat tilt for the tractor operators. However, keeping in mind the nature of work, a flat seat pan is recommended in this study.

4.3.2.6 Lumbar support

Based on the findings of (Carecone and Keir, 2007) and (Guo et al. 2015), a lumbar support thickness of 10 mm is suggested.

4.3.2.7 Pedal dimensions

The dimensions of the pedal, i.e., the pedal, is decided based on the 95th percentile value of palm length and foot length for the male population. The 95th percentile value of the male's foot length is 25.5 cm. Thus the breadth of the pedal = foot length + clearance value = 25.5 + 10 = 35.5 cm (~ 36 cm). For determining the length of the crank, twice the 95th percentile value of male palm length is considered. Besides, a clearance value of 20 cm is considered to facilitate space between the feet and on both sides of the foot. Details are shown in Fig.4.2 (d).

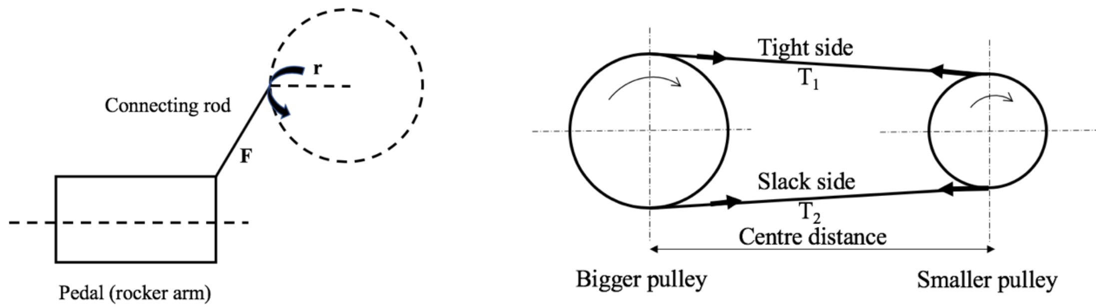


Fig. 4.4 (a) Showing how actuating force rotating the crank; (b) Pulley-belt system

Thus the length of the crank = 2 × 95th percentile value of male's palm length + 20 cm = 2 ×11.0 + 20 cm = 44 cm. The position of the pedal is decided based on the requirement of the gear-belt drive system. This cannot be changed due to the constraints imposed by the belt-drive system.

4.3.3 Calculation of force system

At the beginning of the design, it is assumed that the machine needs to be designed for a maximum value of actuating force (pedal-force) of 150 N. Such an assumption is supported by previous design work reported by Patel, 2015, where the leg force of Assamese people is reported. The force system is shown in Fig. 4.4 (a) and Fig. 4.4 (b). Using the Eqn. (4.4), the torque to be produced due to application of a force of 150 N at the paddle is calculated as 10.95 N-m. If F_1 is the tension on the tight side of the belt and F_2 is the tension on the slack side of the belt, then by using the Eqn. (4.5), F_1 and F_2 is calculated as 54.75 N and 273.75 N respectively. In Eqn. (4.5), *d* is the diameter of the output pulley, which is 100 mm in the present case. In case of V-belt, the ratio between the force on the tight side and on the slack side is usually assumed to be 5; $F_1 = 5F_2$. Considering the no slip condition, the velocity of the belt is calculated using the Eqn. (4.6) as 1.57 m/s. Here, r_1 is the radius of the driver pulley and r_2 is the radius of the driven pulley. Similarly, ω_1 and ω_2 are their corresponding angular velocities. Then, using the Eqn. (4.7), the power needs to be transmitted to the gear drive through the shaft connecting the driven (output) pulley and the gear drive is calculated as 343.83 w. Next, we need to design the shaft for transmitting this power.

$T = F.r$ [4.4]

$T = (F_1\text{-}F_2)\,\frac{d}{2}$ [4.5]

$V_b = r_1\,\omega_1 = r_2\,\omega_2$ [4.6]

$P = (F_1\text{-}F_2)\,v_b$ [4.7]

4.3.3.1 Calculation of bending moment

The force ($F = F_1 + F_2$) that tends to bend the shaft at the pulley end is 328.5 N. Thus, using Eqns. 4.8, 4.9, 4.10, the forces on the bevel gear have been calculated as, tangential component W_t =304.17 N, axial component, F_a = 99.02 N, and the radial component, F_r = 49.52 N.

Tangential component: $W_t = \frac{2T}{d_m}$ [4.8]

Axial competent: $F_a = W_t \tan\phi \sin\alpha$ [4.9]

Gear ratio: $m_G = \tan\phi = 2$ [4.10]

The loading diagram of the force system commanded by the gear, pulley and supported by the bearings can be drawn as shown in Fig. 4.5. Considering the equilibrium in the y direction and taking moment about C, vertical reaction forces can be calculated as R_{bv} = 52.1 N. and R_{cv} = 325.9 N. Form the above forces, maximum bending moment is calculated as M = 24.8 N-m. Calculation details of bending moment is presented in Annexure A.

4.3.3.2 Calculation of shaft diameter

Based on the availability of the material in the local market and machining facility available with local fabricators, AISI 1018 hot rolled steel is considered as the shaft material. Corresponding Yield strength and Shear strength are 370 MPa and 185 MPa respectively. Assuming a factor of safety of 3, allowable shear stress is 61.67 MPa.

Now, considering the Tersca Criterion for solid shaft, stress due to bending moment and torsion can be expressed as given in Eqn. (4.11):

$$\tau_{all} = \frac{16}{\pi d^3}\sqrt{(C_{bm}M)^2 + (C_t T)^2} \qquad [4.11]$$

Here, C_{bm} is bending factor and C_t is torsion factor. For gradually applied load; $C_{bm} = C_t = 1$. Hence, Eqn. (4.11) can be written as:

$$\tau_{all} = \frac{16}{\pi d^3}\sqrt{M^2 + T^2} \qquad [4.12]$$

Now, using the value of M and T at the critical location i.e. at D as 24.8 N-m and 10.95 N-m respectively in Eqn. (4.12), the minimum diameter can be calculated as 13.04 mm. Thus any diameter greater than 13.04 mm is considered to be safe. To make the design safe, shaft diameter is considered as 20 mm.

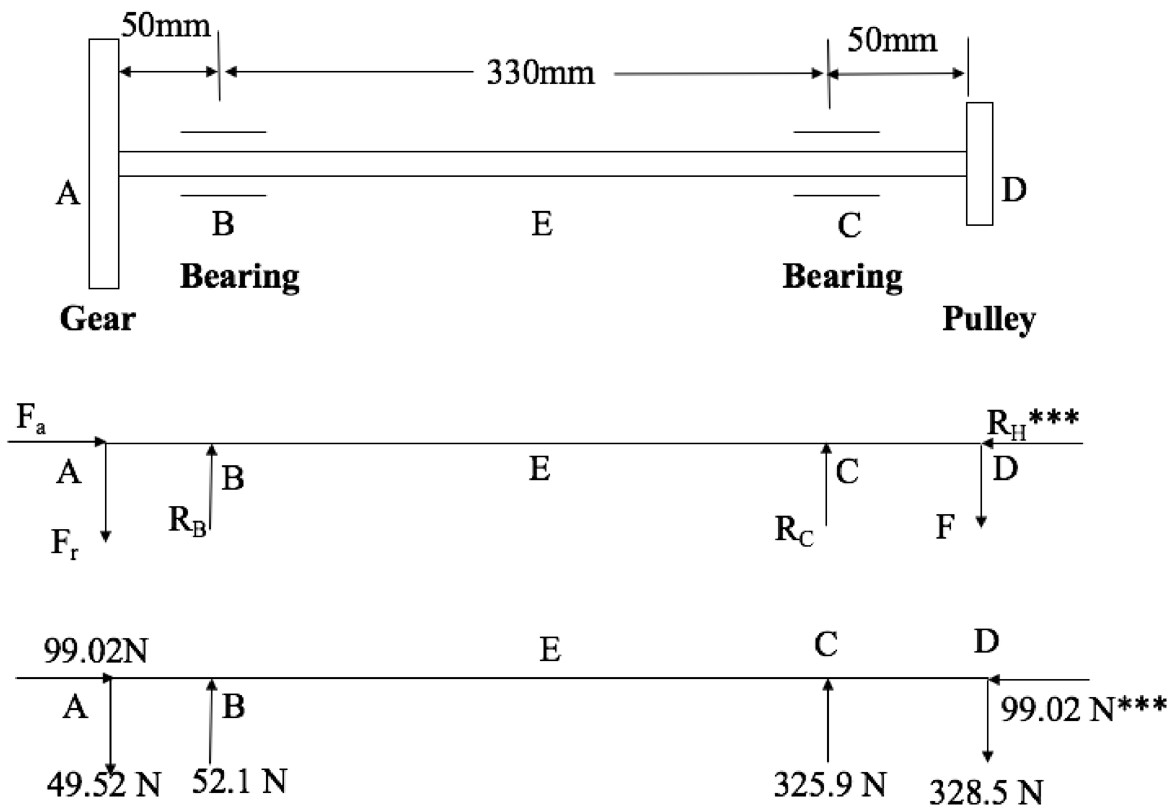


Fig. 4.5 Showing the force system in the shaft (the horizontal force F_a is counter balanced by pulley and belt-drive system)

4.3.4 Selection of Bearing

The ball bearings were selected for reduction in friction between the bearing parts and the shafts. The equivalent load on the bearings can be expressed as:

$$P = XF_a + YF_a \qquad [4.13]$$

The life of the bearings can be expressed as:

$$L = \left(\frac{C}{P}\right)^3 \qquad [4.14]$$

As Fig 4.5 depicts, there are two bearings with $R_B = F_{r1} = 52.1$ N and $R_C = Fr_2 = 325.9$ N. In both cases, the thrust load (F_a) is equal to 99.02 N.

Now, $\frac{F_a}{F_{r1}} = 1.90 < e$ and $\frac{F_a}{F_{r2}} = 0.30 < e$. Hence, X = 1 and Y = 0 is considered.

Thus, using Eqn. (4.13), P_1 and P_2 can be calculated as: at the position B: $P_1 = 52.1$N; at the position C: $P_2 = 325.9$ N. Considering the service of the gear for 3 years with 56 hours per week, no of cycles can be calculated as15.72 x 10^7 cycles. Thus putting the value in Eqn. (4.14), the dynamic load capacity is calculated as: C_1= 27821N and C_2 = 134852N. Using SKF catalogue for the above dynamic load capacities, the bearing for 20 mm diameter shaft is considered as SKF6404.

4.3.5 Design of the Belt drive

Considering the anthropometric data of the target-users, the centre distance between the bigger pulley and smaller pulley is considered as 400 mm. This design constraint arises due to the required frame height. Based on the requirement of frame height and considering the availability of standard pulley in the market, the diameter of the bigger pulley is considered as 560 mm. To maintain a diameter ratio of 5:1 between the bigger pulley and smaller pulley, the dimeter of the smaller pulley should be 112mm. However, the nearest standard size of smaller pulley available in the local market is 125mm. Thus a smaller pulley of 125mm is selected here. As a result the diameter ratio obtained in the process is 4.48 which is near to 5.

Using Eqn. (4.15) belt length is calculated as 1997.65 mm (~78.65 inch). To avoid loose contact the belt length is considered as 78 inch (~1981.2 mm). Thus A78 V-belt is considered here as V-belt lasts longer, gives better performance, less slip and dampen vibration.

$$L = 2C + 1.57(D + d) + \frac{1}{4C}(D - d)^2 \qquad [4.15]$$

$$\sin a = \frac{d_2 - d_1}{2L} \qquad [4.16]$$

$$q = 180^0 - 2 \times a \qquad [4.17]$$

Now, using the Eqn. (4.16) and Eqn. (4.17), inclination angle and wrapping angle can be calculated as 6.36^0 and 167.39^0 respectively.

4.3.6 Selection of Bevel Gear

Considering the material properties and availability in the market, Steel EN8, 080M48 (Young's modulus: 1.90 x 10^9 Pa) is considered as material for the Bevel gear. As mentioned earlier, the gear ratio is assumed as 2.1. Considering the pressure angle as 20^0, the minimum no of teeth to avoid interference is calculated using the Eqn. (4.18) as 14.56, whereas the nearest value us 16. Thus a 16 tooth pinion with a 32 teeth gear is considered here. The twisting moment is calculated as 14.23 x 10^3 N-m. Using Eqn. (4.19) cone distance (R) is calculated as 47 mm. Other parameters of the bevel gear is presented in Annexure B.

$$n_1 = \frac{2k}{(1+2m)\sin^2\phi}\left(m + \sqrt{m^2 + (1+2m\sin^2\phi)}\right) \qquad [4.18]$$

$$R = \psi_y \left[\left(\sqrt{i^2+1}\right) \sqrt[3]{\left(\frac{0.72}{(\psi_y - 0.5)[\sigma_c]}\right) \left[\frac{E(M_t)}{i}\right]} \right] \qquad [4.19]$$

Fatigue due to repeated bending stresses results the tooth breakage. Hence, the induced bending stress of the gear when transmitting a torque should be lesser than the allowable bending stress. The induced bending stress and allowable bending stress is calculated using Eqn. (4.20) and Eqn. (4.21) as 0.96 MPa and 29.56 MPa respectively. Thus design is said to be safe.

Induced bending stree, $\sigma_b = \frac{R\sqrt{i^2+1}\left[M_t\right]}{(R-0.5b)^2 \times b \times m_t \times y_{v1}}$ x $\frac{1}{\cos\alpha}$ [4.20]

Allowable bending stress, $\sigma_b = \frac{K_{b1}}{nK_s}\sigma_0 = \frac{1.4}{n}\frac{K_{b1}}{K_s}\sigma_{-1}$ [4.21]

To avoid the surface failures of the tooth profile like pitting, surface abrasion, seizure, etc., and to have the satisfactory life, gear should have the wear resistance. i.e., the induced crushing stress should be lesser than the allowable crushing stress ($\sigma c \leq [\sigma c]$). Using Eqn. 4.22), the induced crushing stress is calculated as 49.6 GPa which is lesser than the allowable crushing stress of 105 GPa. Hence, the design is considered as safe.

Induced crushing stress, $\sigma_c = \frac{0.74}{(R-0.5b)}\left(\frac{\sqrt{\left(i^2+1\right)^3}}{i \times b} \times E_{eq}\left[M_t\right]\right)^{\frac{1}{2}}$ [4.22]

4.3.7 Design for frames

Considering the total weight of the bevel gear system and the four horizontal columns the vertical column needs to be designed for axial compressive load of maximum 147.2 N. That 147.2 N load will effectively act on the four columns of the frame. Thus, the load to be carried by one column is 36.8N. The Euler's Buckling formula is expressed by Eqn. (4.23).

$$P_{cr} = \frac{\pi^2 EI}{L_e^{\,2}} \quad [4.23]$$

The column is fixed-free in both x- and y-directions. For a fixed-free column, the effective length is L_e = 2l. The column may buckle about the x- or y- axis. The Moment of Inertia for a rectangle is: $I = \frac{bh^3}{12}$; where breadth (b) = depth (h) = 40 mm; The length of the column (l) = 760 mm and Youngs' Modulus (E) = 205 GPa. Thus the Euler's Buckling load can be calculated as: 186.53 KN.

Now, considering a factor of safety equal to 2, the allowable load can be calculated as: 93.26 KN.

Thus, allowable stress = $\frac{load}{area}$ = 116.58 MPa.

The actual load on the column $= \frac{36.8N}{0.04 \times 0.04m^2}$ = 23 KN ≤ allowable load of 93.26 KN.

Since the load acting on a column is less than Euler's Buckling load, the design is considered to be safe.

The technical details of IPC is summarized in Table 4.1, Fig. 4.6 and Fig. 4.7.

4.4 Summary

In this chapter the design process of the IPC is presented. The engineering design process is carried out with a number of assumptions, which are also mentioned above. To validate the design process, full-scale models are manufactured. The machines are distributed among artisans and their feedbacks have been collected. Field-testing results are discussed in the next chapter.

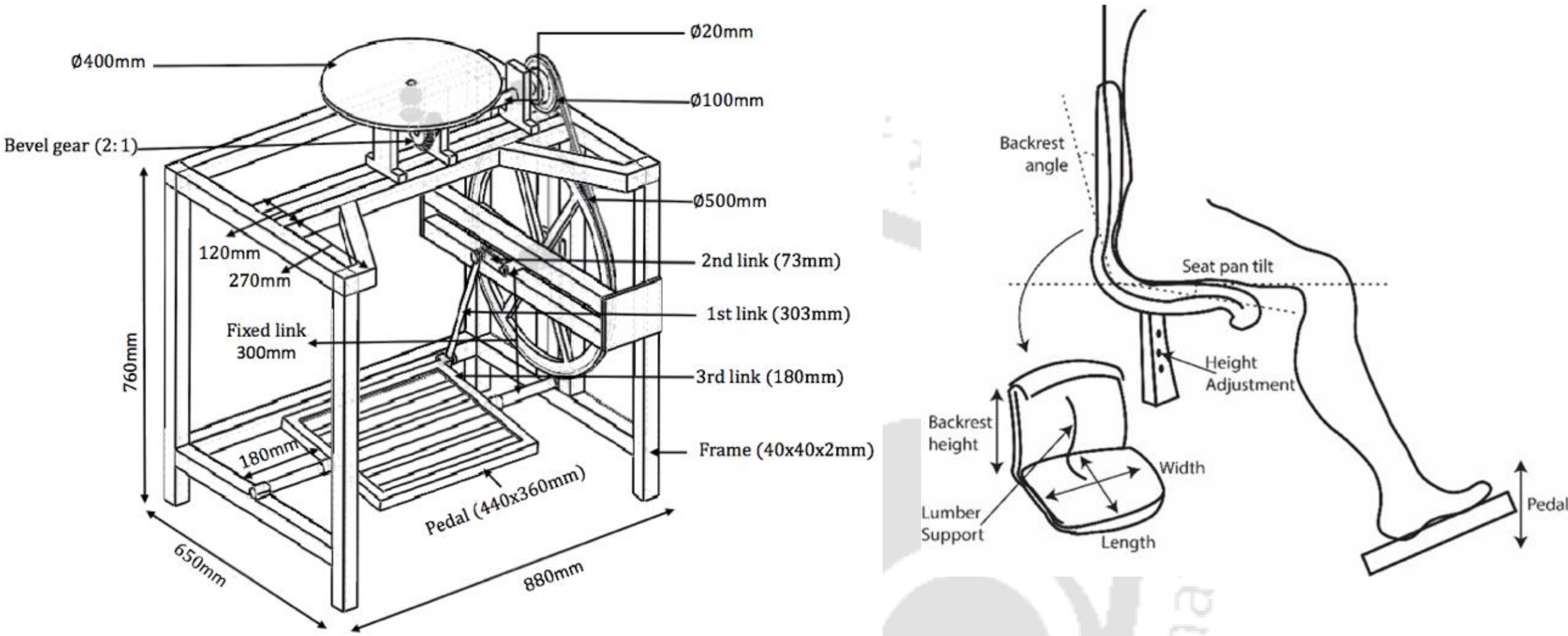


Fig. 4.6 Dimension details of IPC

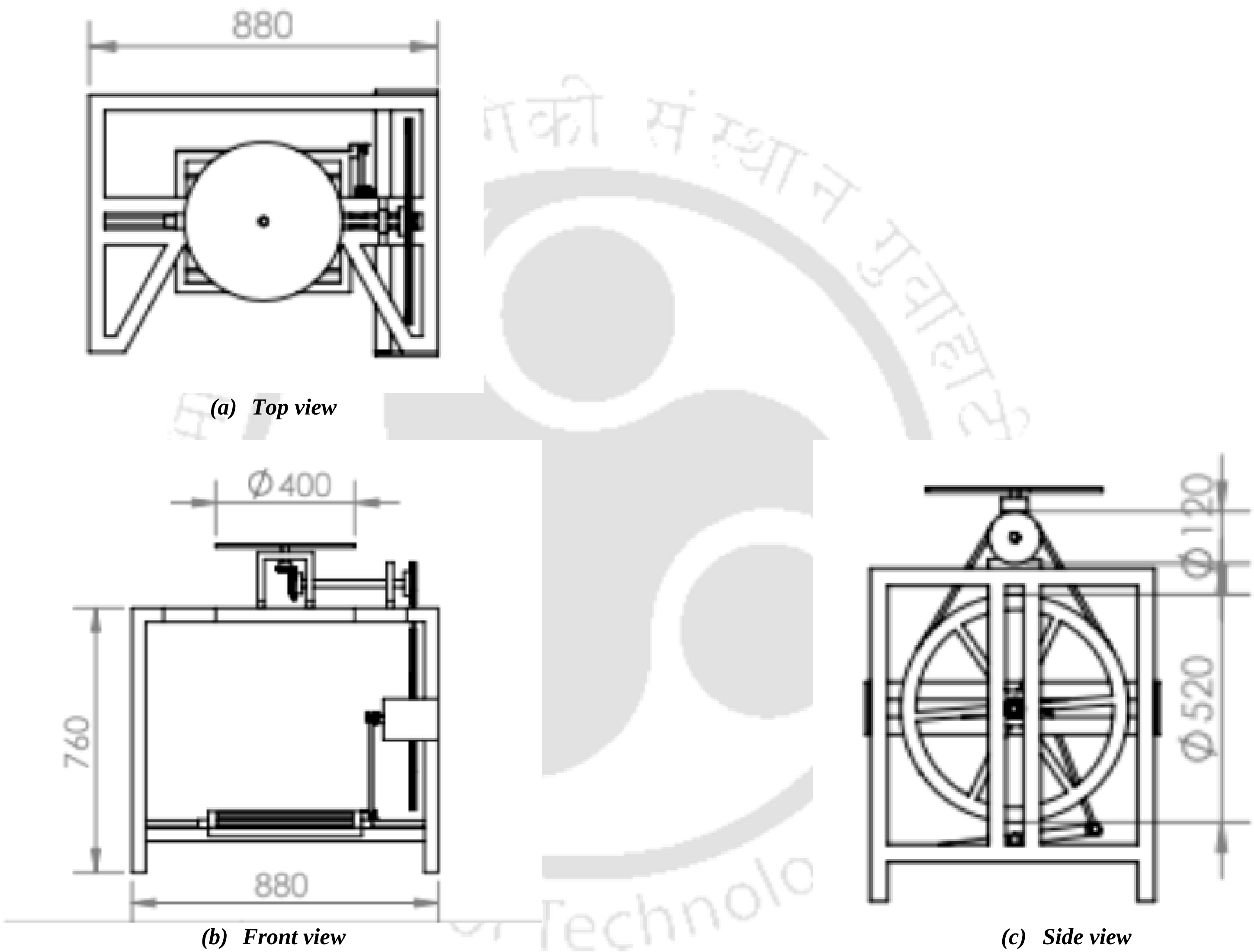


Fig. 4.7 Two-Dimensional sketch reprenting the top view, front view and side view of IPC

Table 4.1

Technical Details of IPC

Details of parts procured from the market	
1. Nut and Bolt:	M6 and M8
2. Bevel gear	Material: Steel EN8, 080M48 Pinion: Pitch: 3MOD; Pressure angle:20^0; Bore diameter: 14mm; Distance to apex: 65 mm; Face width: 18mm; Hub diameter: 36mm; Hub length: 14mm; Outside diameter: 55mm; Overall length: 34.34mm; Pitch circle diameter: 48mm; Recess depth: 3mm. Gear: Bore diameter: 14mm; Distance to apex: 55mm; Face width: 18 mm; Hub diameter: 20mm; Outside diameter: 97.88mm; Overall length:40.12mm; Pitch circle diameter: 96mm.
3. Roller Bearing	SKF6404
4. V-belt	A-78
5. Pulleys	Diameter: 500mm and 100mm
6. Height-adjustable chair	Minimum height: 35cm; Maximum height 55cm; Seat pan width: 45cm; Seat Depth: 45cm; Backrest height: 35 cm; Lumbar support: 10mm
Details of parts manufactured locally	
Material: AISI 1018 hot rolled steel	
1. Frame	Dimension: 40x40x2mm
2. Pedal	L shaped cross-section of dimension (25 x 5 mm) is used; shaft diameter: 20 mm
3. 4-bar mechanism	Shaft of diameter 10 mm is used
4. Shafts	Shaft connecting the smaller pulley and bevel gear: length: 360, diameter: 20mm Shaft connecting the bigger pulley to 2^{nd} link of the 4-bar mechanism: length:145.5mm, diameter: 20mm Shaft connecting the bevel gear and pottery plate: length: 80mm, diameter:20mm
5. Bearing housing	Square plate of dimension (80x80mm), width:14mm

Table 4.1 (continued)

6.	Support plates for bevel gear shaft	Rectangular section (60x120mm) and (120x20mm); thickness:20mm
7.	Circular plate (Pottery plate)	Diameter: 400 mm; thickness: 10mm

Chapter 5

Detailed product test, field validation and analysis of IPC

5.1 Introduction

In the previous chapter, design details of the IPC was presented. To evaluate the performance of the new machine, it has been field-tested in a Pottery cluster in Nalbari district of Assam, India (shown in Fig. 5.1). In this chapter, performance evaluation results are discussed.

(a) (b)

Fig. 5.1 (a) Artisan working in the IPC; (b) Photo showing medium-sized items produced by artisans using the IPC

5.1.1 Subject characteristics

The performance evaluation of IPC is carried out with a sample of thirty male artisans and thirty female artisans. Two criteria are considered during selection of participants: i) artisans should have working experience of more than 5 years, ii) they must have used the IPC for more than 3 months, and iii) age range: 20-45 years based on the criteria forwarded by Mc Ardle et al. 2001. Two methods of pottery works are examined, viz., moulding earthen pots using TPW and IPC. Necessary precautions have been taken so that only physically fit artisans participate in the field-testing activities. The dominate hand for all the participants are the right hand.

5.2 Measurement of force

To understand the biomechanics of physical efforts required while operating the IPC, leg-force requirement during pedaling the IPC is measured. Here, the nature of force is dynamic. To measure the actuating force and working force, SHIMPO MF-100 Mechanical Force Gauge (shown in Fig. 5.2) is used. Three readings for each participant are recorded. Then the average of the three readings are noted for that particular artisan. Finally, the average of all the participants' readings are considered to calculate the actuating force and working force for the IPC.

Fig. 5.2 Showing the SHIMPO MF-100 Mechanical Force Gauge

The actuating force (Kg, mean ± standard deviation) is found to be 3.5 ± 0.7 Kg. Similarly, the working force was measured as 1.1±0.2 Kg. During the experimental investigation, the artisans expressed that they can easily exert this amount of force without any discomfort. This force could not be compared with the traditional process, as in the traditional system the wheel is rotated by exerting manual hand power. Patel, 2015 reported that average isometric muscular strength of Assamese people as:

Male: 32.43± 7.68 kg for right leg and 26.02±8.07kg for left leg

Female: 24.48±8.71 kg for right leg and 19.54±6.80 kg for left leg.

The actuating force and working force required to operate IPC are much less than isometric muscular strength of the Assamese people as reported by Patel, et al., 2015. Therefore, this design of the machine is considered to be comfortable for the artisans.

5.3 Productivity

To evaluate the productivity of the IPC, the average numbers of items produced by artisans in one hour is recorded for both male and female. Experimental results are presented in Table 5.1. Figure 5.3 demonstrates that the new intervention is successful in enhancing the productivity for both male and female artisans. Male artisans' average productivity is found to be almost 1.7 times higher in the case of IPC than that of the TPW. Similarly, female artisans' average productivity is found to be almost 1.8 times higher in case of IPC than that of the TPW. Due to the use of IPC, the average production of small-sized items per hour for female artisans is found to be enhanced from 62.3 number to 110.1 number and for male, from 98.6 to 168.4 number. Using STATA software, t-test is carried out to examine the statistical significance of the variations of productivity of the two machines i.e. TPW and IPC for male and female separately. The result as presented in Table 5.3 depicts that differences of productivity in case of TPW *vs*. IPC is statistically significant ($p < 0.01$) for both male and female. T-Test result is presented in Table 5.2.

In the traditional process, artisans need to rotate the wheel in an interval of 2-3 minutes. It hampers the moulding process which results in reduction of overall productivity of artisans.

Such issues are rectified through new design intervention in the IPC. That is also one of the reasons for better productivity of the artisans using IPC.

Table 5.1
Comparison of number of items produced per hour using TPW and IPC

Sl. No	Gender	TPW		IPC	
		Male	**Female**	**Male**	**Female**
1.	Production (unit/hour) (SD)	96.8 (6.4)	62.3 (5.3)	168.4 (5.8)	110.1 (7.2)

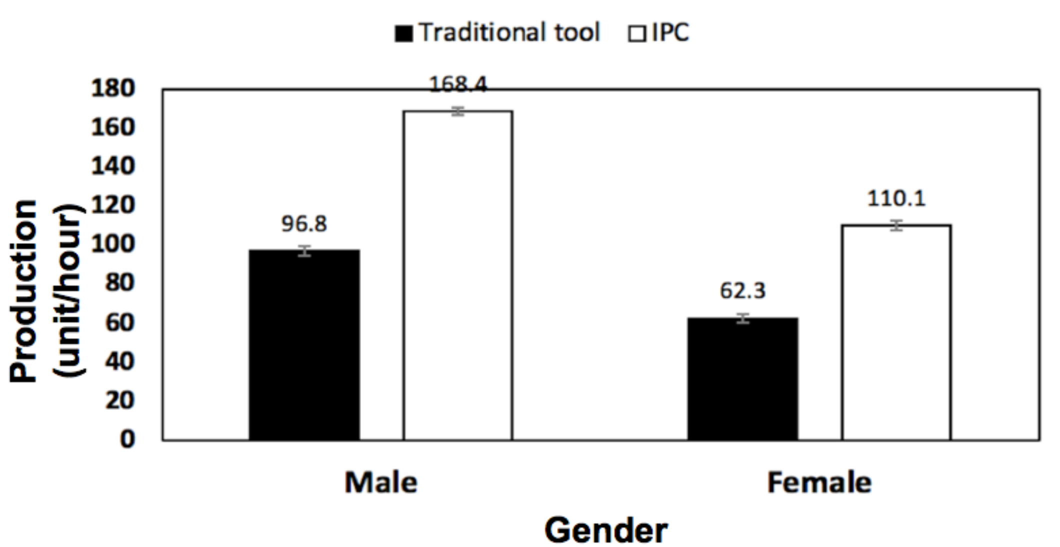
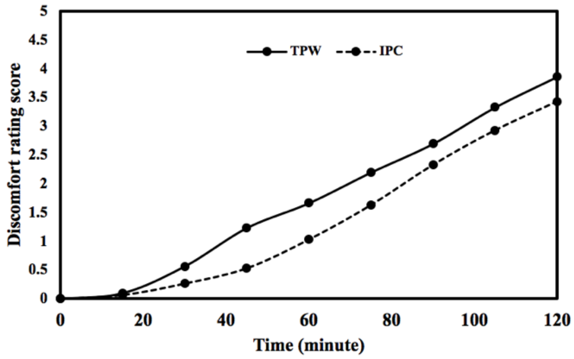


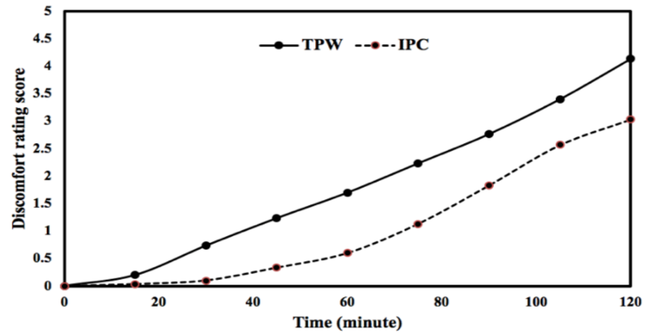
Fig. 5.3 Comparison of average productivity of IPC with the TPW

Table 5.2
t-test result for productivity mean value (TPW vs. IPC)

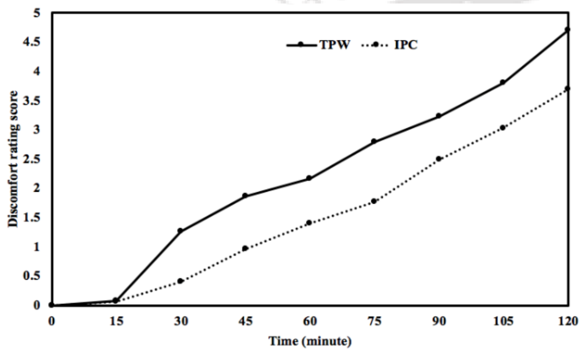
Sl. no	particulars	Degree of freedom (df)	t-test statistics (***Pr<0.01)
1.	TPW *vs*. IPC (male)		2.04***
2.	TPW *vs*. IPC (female)	29	1.33***



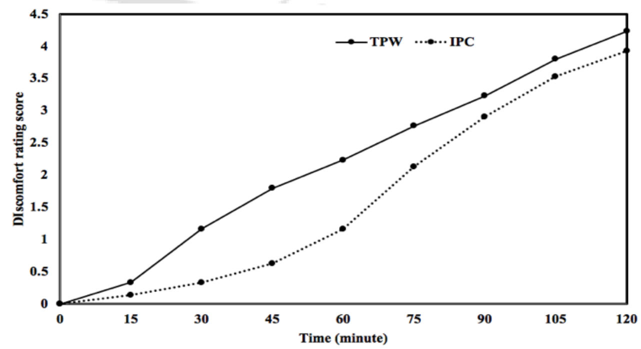
(a) Discomfort rating score for neck (male)



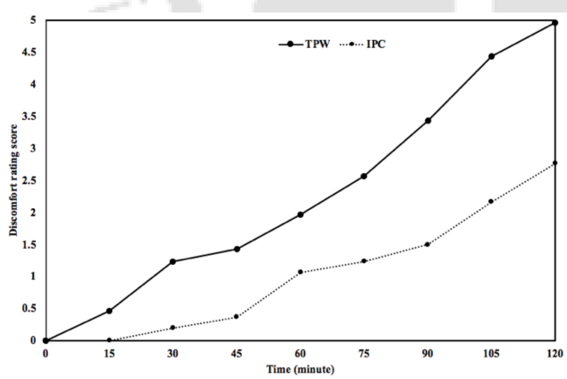
(b) Discomfort rating score for neck (female)



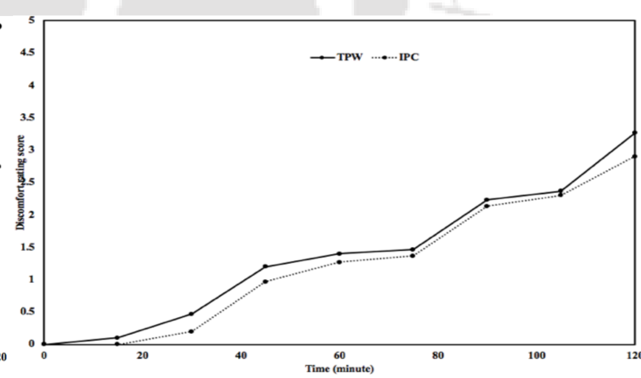
(c) Discomfort rating score for shoulders (male)



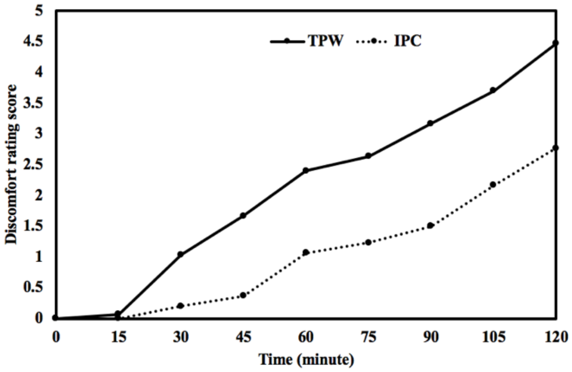
(d) Discomfort rating score for shoulders (female)



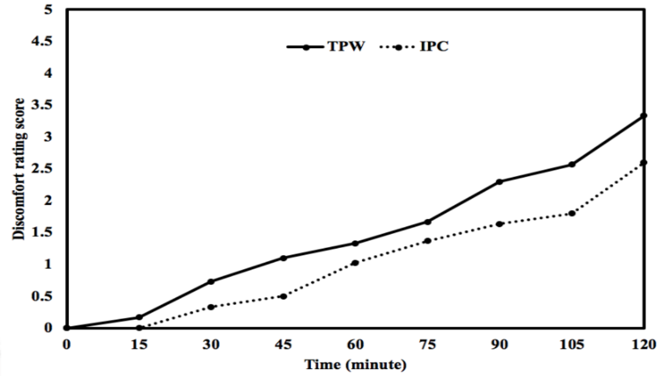
(e) Discomfort rating score for elbow (male)



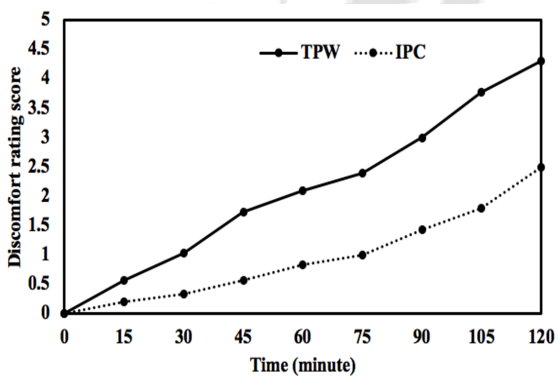
(f) Discomfort rating score for elbow (female)



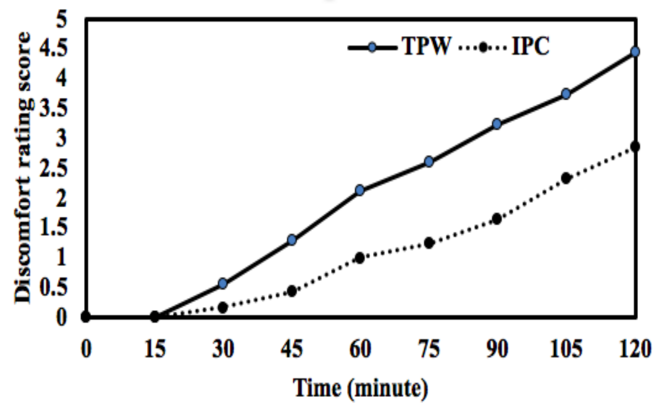
(g) Discomfort rating score for hand wrists (male)



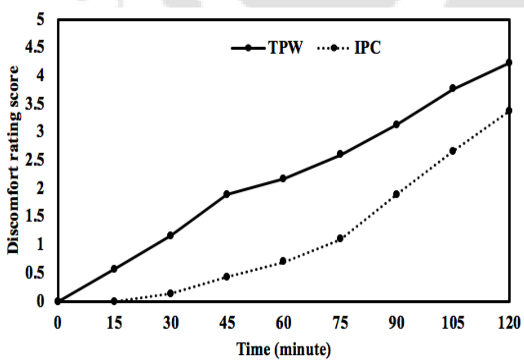
(h) Discomfort rating score for hand wrists (female)



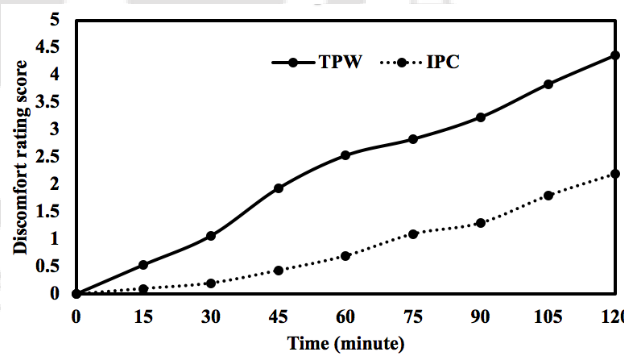
(i) Discomfort rating score for upper back (male)



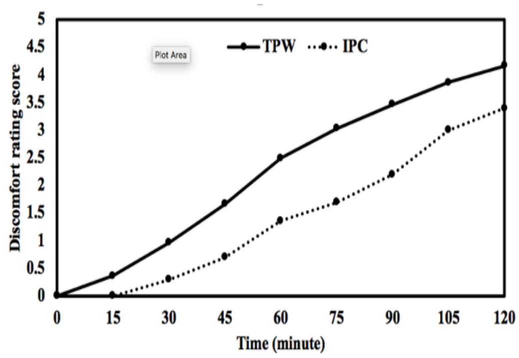
(j) Discomfort rating score for upper back (female)

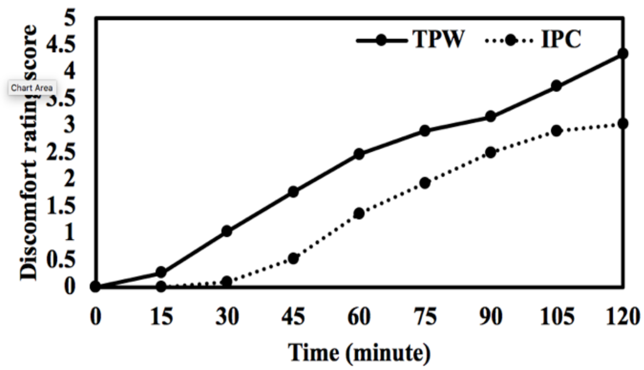


(k) Discomfort rating score for lower back (male)



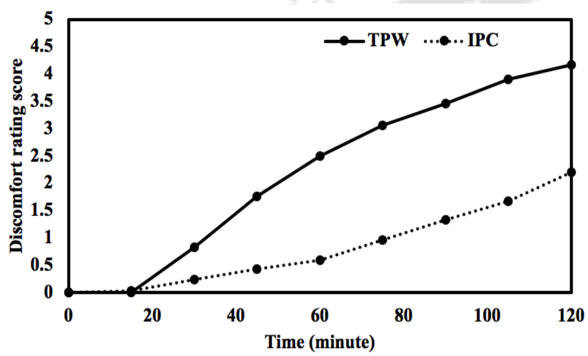
(l) Discomfort rating score for lower back (female)

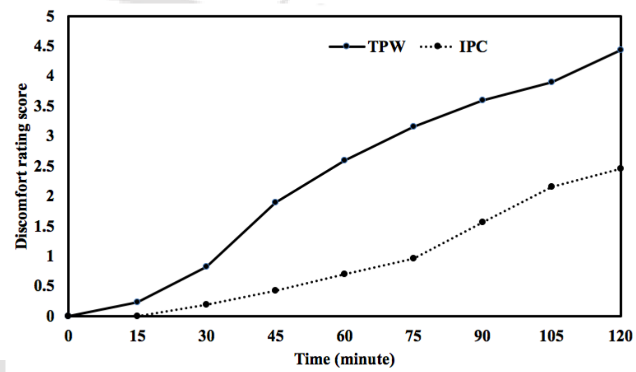




(m) Discomfort rating score for buttock (male)

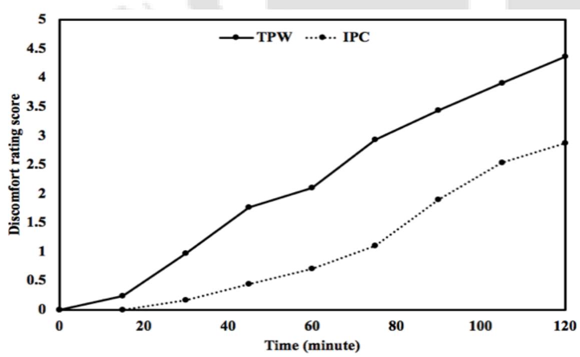
(n) Discomfort rating score for buttock (female)

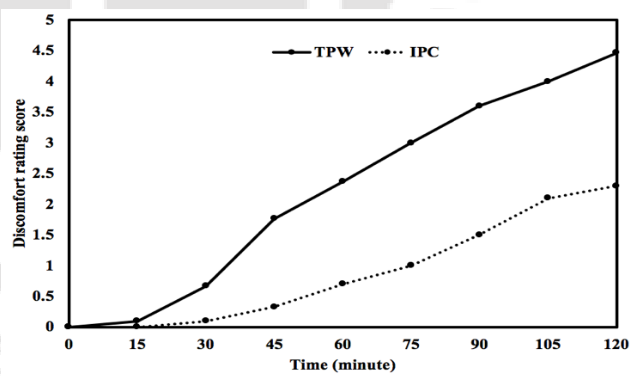




(o) Discomfort rating score for thighs (male)

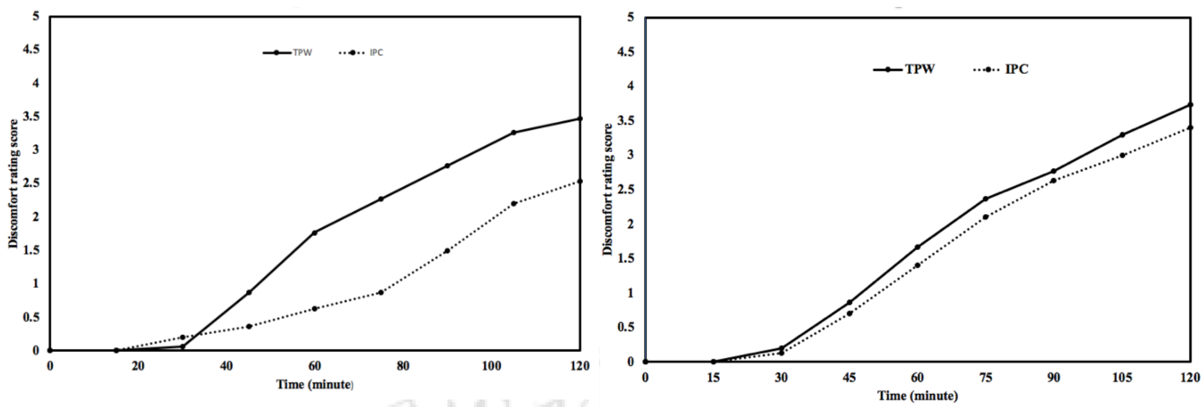
(p) Discomfort rating score for thighs (female)





(q) Discomfort rating score for knees (male)

(r) Discomfort rating score for knees (female)



(s) Discomfort rating score for calves (male)   (t) Discomfort rating score for calves (female)

Fig. 5.4 Comparison of discomfort rating score (TPW vs. IPC)

5.4 Evaluation of prevalence of pain in different body parts

To evaluate the prevalence of pain in different body parts, first, the artisans are asked to work in the TPW for 2 hours without any break. Localized discomfort or pain at different body regions are recorded in every 15 minutes. To express qualitative data into quantitative data, a scale of 0-5 was used where 0 denotes no pain and 5 denotes extreme pain. It is allowed to adjust their body postures as per their comfort during the work. The next day, they are asked to work in the IPC. Similar to traditional tool, artisans' discomfort or body pain was recorded.

The results of discomfort rating score as expressed by the artisans are presented in Fig. 5.4 (a) to (t). An examination of Fig. 5.4 depicts that the physical discomfort is reduced after the introduction of IPC. The discomfort rating score is lower in case of IPC if it is compared with the discomfort rating score of TPW. Bending posture and wrong sitting arrangement is the major issue in traditional process. The results depict that introduction of new sitting arrangement is successful in reducing discomfort in majority of the body parts viz., neck, upper back, lower back, knees, thigh buttock. Similarly, the new arrangement of rotating the wheel by leg-power instead of hand-power, discomfort is reduced in body parts viz., shoulders, elbow, hand wrists, claves.

5.5 Muscular fatigue

To examine muscular fatigue of artisans during the work, hand grip strength is accessed. Jamar Handgrip Dynamometer (Sammons Preston Inc., Boling-brook, IL, USA) as shown in Fig. 5.5 is used to record isometric muscular strength. The instrument has 5 gripping positions and a dial. Strength in terms of force (0.5-90 kg scale) exerted can be seen in the dial. The handgrip strength is recorded in standing position for both dominant and opposite hands. During the recording of handgrip strength, the participant remained standing with arms hanging straight downward. To achieve maximum strength, trunk and wrist are kept in neutral position.

Handgrip strength is recorded in every 15 minutes for 2 hour while working in IPC and TPW separately. Strength data of both dominant hand and opposite hand are collected. A rest of ~3 minutes between two readings is considered. The descriptive statistical values for both male and female are presented in the Table 5.3.

Before the start of the work, for male, mean value of handgrip strength is found to be 32.5 ± 2.1 Kg and 28.2 ± 2.3 kg for dominant and opposite hand respectively. After two hours of working in the TPW, the mean value of handgrip strength is found to be 29.9 ± 2.1kg and 25.8 ± 2.2 kg for dominant and opposite hand respectively. Similarly, after two hours of working in the IPC, average handgrip strength is measured as 31.0 ± 2.2 kg and 26.5 ± 2.1 Kg for dominant and opposite hand respectively.

Fig. 5.5 Illustration of grip posture

For female, the mean value of handgrip strength before working are found to be 23.1 ± 2.1 kg and 18.2 ± 2.0 kg for dominant and opposite hand respectively. After two hours of working in the TPW, the mean value of handgrip strength is found to be 20.2 ± 2.3 kg and 14.8 ± 2.0 kg for dominant and opposite hand respectively. Similarly, after two hours of working in the IPC, average handgrip strength is measured as 21.9 ± 2.4 kg and 16.7± 1.8 Kg for dominant and opposite hand respectively.

The decrease in muscular strength during work is due to fatigue and muscular activity. The results in Table 5.3 establishes the fact that the design intervention is successful in reducing the decrease of muscular strength with time. The change is statistically significant ($p<0.01$) for both right and left hands of the female artisans. For male, the change in the right hand is statistically significant ($p<0.01$).

5.6 Monitoring the heart rate

The heart rate is considered as the major tool for quantification of workload and energy expenditure. To examine the impact of design modification of TPW on physical workload and energy expenditure, heart rate (beats per minute) of the artisans is measured. As shown in Fig. 5.6, a PULSE OXIMETER is used to examine the heart rate of artisans. The PULSE OXIMETER is fixed in the index figure of the artisan to record the heart rate of the artisan.

Table 5.3

Artisans' muscle strength at rest and after work

Gender	Particulars	At rest (kg)	IPC at work (kg)	TPW at work (kg)	Percentage change due to design intervention (IPS vs. TPW)
Male	Right hand	32.5 (2.1)	31.0 (2.2)	29.9 (2.1)	3.6* (t-value: 2.04)
	Left hand	28.2 (2.3)	26.5 (2.1)	25.8 (2.2)	2.5 (t-value: 2.10)
Female	Right hand	23.1 (2.1)	21.9 (2.4)	20.2 (2.3)	8.0*** (t-value: 2.0)
	Left hand	18.2 (2.0)	16.7 (1.8)	14.8 (2.0)	11.3*** (t-vaue:1.9

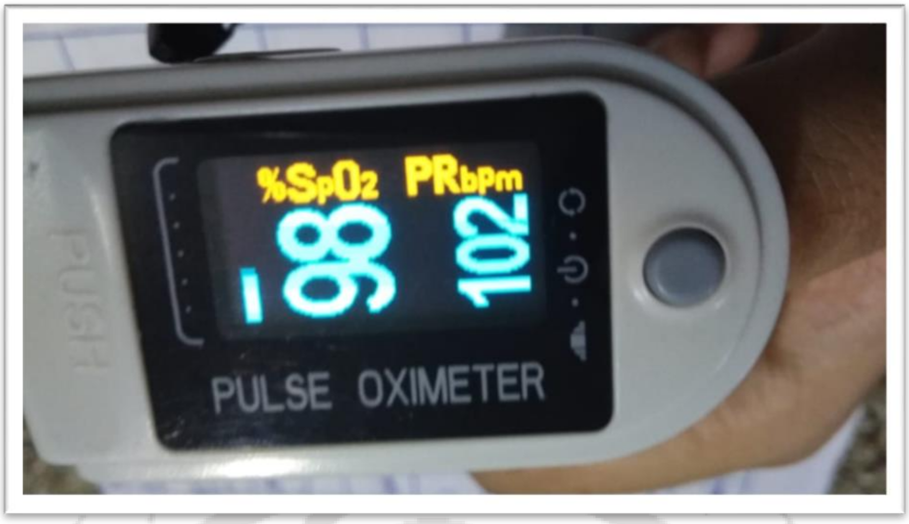


Fig. 5.6 PULSE OXIMETER showing the heart rate of an artisans

In the morning, before artisans start their work, subjects are given sufficient rest and their heart rate is noted. Thus, heart rate at rest (HR_{rest}) is Heart rate before the start of the work. A total of three readings for each artisans are considered. Then, they start their work for one hour in the traditional process (TPW). Then their heart rate is noted in between 100th to 110th minute of work for each subject. Average of the three readings is considered for this study. This is noted as heart rate at work (HR_{work}). The average of HR_{rest} and HR_{work} is calculated which is called as average working heart rate (AWHR). Again, maximum heart rate (HR_{max}) is calculated using the general relation as follows: 220−age of the subject [Singh et al., 2008].

Similarly, the oxygen consumption rate (OCR) and energy expenditure rate (EER) are calculated based on measured heart rate using the general equations Eqn. (5.1) and Eqn. (5.2) given by Singh *et al.* 2008:

$$OCR = 0.0114 \times \text{heart rate} - 0.68 \quad [5.1]$$

$$EER = OCR \times 20.93 \quad [5.2]$$

For male, as shown in the illustrative graph (Fig. 5.7) the AWHR during work with TPW and IPC are found to be 110.7 beats/minute and 104.5 beats per minute with corresponding average work pulse (ΔHR) was 71 beats/min and 58.5 beats/minute respectively. The results depicts that the AWHR has increased 47.2% above the resting heart rate for the TPW compared to 38.8% increase for the IPC. Similarly, the average oxygen consumption rate are 1.36 litre/minute and 0.85 litre/min for TPW and IPC respectively. The average energy expenditure rate are found to be 28.62 kJ/minute and 17.68 kJ/minute for TPW and IPC respectively.

For female, as shown in the illustrative graph (Fig. 5.8), the average working heart rate during work with TPW and IPC are found to be 102.7 beats/minute and 99.8 beats per minute with corresponding work pulse (ΔHR) to be 59.5 beats/min and 53.8 beats/minute. The results depicts that the AWHR has increased 40.7% above the resting heart rate for the TPW compared to 36.9% increase for the IPC. The average oxygen consumption rate is calculated as 1.17 litre/minute and 0.77 litre/min for TPW and IPC respectively. The energy expenditure rate are found to be 24.57 kJ/minute and 16.01 kJ/minute for TPW and IPC respectively.

Thus, the works related to moulding pots using TPW can be put in the category of ‘heavy’ work but with the use of IPC it can be categorized as ‘moderate’ work (Nag *et al.* 1980). Thus the ergonomic modification of the pottery wheel is found to be successful in reducing health drudgery of the artisans.

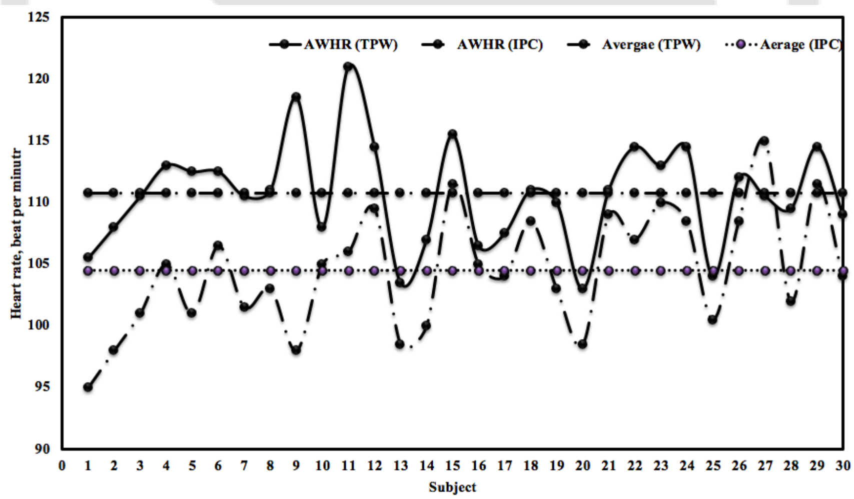


Fig. 5.7 Comparison of heart rate response while using TPW and IPC by male artisans

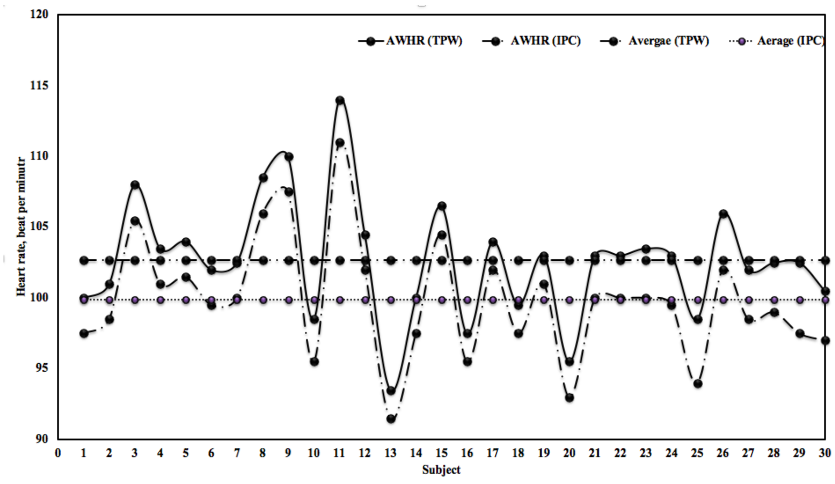


Fig. 5.8 Comparison of heart rate response while using TPW and IPC by female artisans

Finally, based on quantitative data received from the participants, a radar diagram is drawn (Fig. 5.9). Other parameters, viz. cost, maintenance issue, and product quality are also evaluated while preparing the radar diagram. The product quality is found to be almost the same in both TPW and IPC. The production cost of the IPC is found to be around Rs. 15,967.2 (~ 16,000). The calculation details of cost of the IPC is presented in Annexure-C. The cost of the TPW is around Rs. 12,000. However, added productivity and health benefits suffice for the differences in price. As shown in Fig. 5.9, the area covered by the solid line (IPC) is greater than the area covered by the dotted line (TPW). It depicts that the improvised model is better than the traditional one.

5.7 Summary

The experimental investigation clearly demonstrates that the design intervention is successful in reducing the health-discomfort and energy expenditure besides reduction in increase in heart rate. The design intervention also improves the productivity of the artisans. The next step of the innovation by design cycle is to bring the product (i.e. IPC) to the target-users. In the next chapter, the product distribution strategy is discussed.

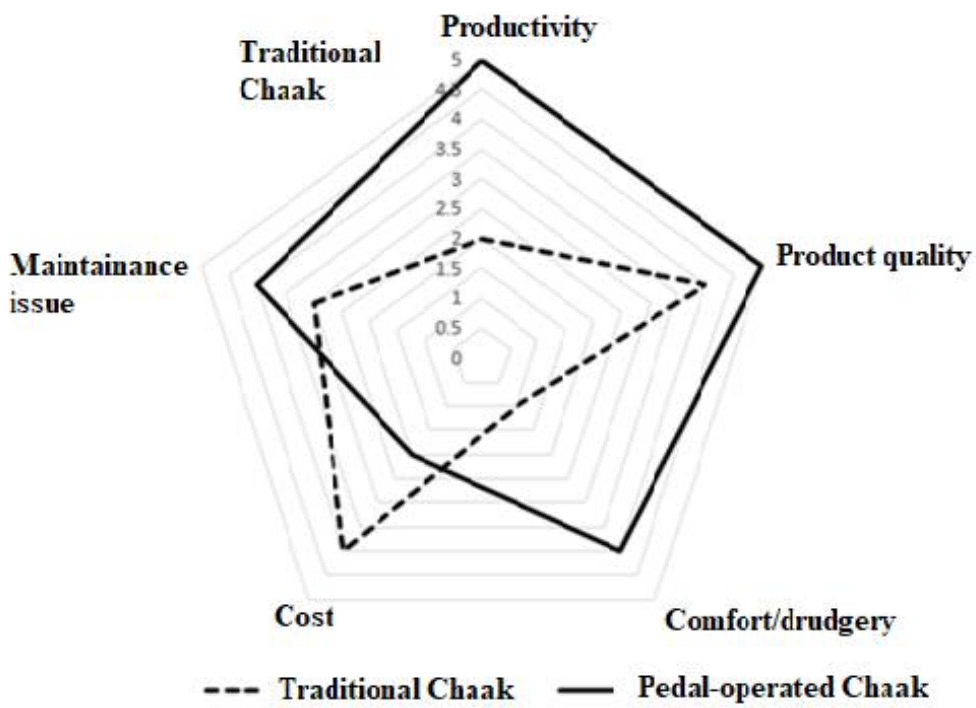


Fig. 5.9 Comparative assessment of the IPC with the IPC based on quantitative data obtained from field-test

Chapter 6

Localized manufacturing and distribution strategy for IPC

6.1 Introduction

In the previous chapter, field-testing results of IPC are discussed. In this chapter, remaining components of the innovation process *viz.*, planning for production and distribution strategy are discussed in details. The market-centric approach is not suitable in rural technology planning and management due to low scale of economies, institutional voids etc. Hence, a localized technology transfer planning is appreciated here.

Initially, a qualitative case study analysis is carried out to have wider knowledge on the ways in which different stakeholders should act for the accumulation of resources and knowledge and bridging the institutional voids to enable technology transfer in a rural developing economy context. As mentioned in the research gap, there is a shortage of knowledge related to practical negotiation process of novel product design and delivery in rural Indian context. Hence, RuTAG's innovation model (an orguware enunciated by the Office of the principle Adviser to Government of India) are analysed to apprehend how RuTAG is bridging the void. Knowledge gathered from this case study is adopted in planning the localized technology transfer strategy for the IPC.

Knowledge gathered from the case study analysis and localized technology transfer strategy for the IPC are discussed in following sections.

6.2 Case study analysis on RuTAG

Qualitative case study methodology proposed by Yin, 2016 is followed here. As a part of the study, opinions from all the stakeholders associated with RuTAG-IIT Guwahati projects are collected and analysed to have an in-depth knowledge on how RuTAG is bridging the institutional voids to deliver technology at the BoP. Workshops/ idea-sharing sessions were organized to have a wider dialogue with expertise from different background associated with academia, government, development-based projects/ rural technology transfer initiates, etc. In such meetings, participants include RuTAG-IITG officials, RuTAG- IITG Project Appraisal Committee Members, members from civil society, Government officials associated in Science Technology Intervention in North Eastern Region (STINER) project. The outcomes of those meetings enrich the knowledge on design and delivery in the rural India context. Outcomes gathered during multi-method approach research tools viz., workshops, opinion collection, idea sharing sessions are used as the inputs for developing the technology transfer framework.

6.2.1 Brief introduction about RuTAG

In India, premier technical institutions and laboratories typically lack action groups for the dissemination of technologies suitable for the rural community (Das, 2007). Therefore, the RuTAG mission is enacted by the Office of the Principal Scientific Adviser to create a technical pool in premier technical institutions of the country who can devote time and effort for development and dissemination of demand-driven technology for the rural community. A participatory model design and innovation system is emerging under RuTAG initiative.

As shown in Fig. 6.1 and Fig. 6.2, RuTAG is acting as an interface between academia (technical institutes), Government, and NGOs. The roles played by different actors of the system are as follows: NGOs for problem identification and technology transfer; academia (technical institutes) for design and development of technology; and Government for necessary funding arrangements, etc. RuTAG is trying to empower the community through strengthening village-based institutions. As shown in Fig. 6.3, RuTAG ensures elaborate consultations with NGO officials, community members, and other stakeholders before taking up a particular problem of technology intervention. Community meetings are organised in different parts of the country where the needs and constraints are identified. In addition, an NGO official can communicate directly with the RuTAG team for technological needs of the individuals or communities. RuTAG officials visit villages, identify problems, and verify the villages' needs and constraints. Again, for the design and development of technology, RuTAG collaborates with technical institutions. Since all the RuTAG centres are working under administrative control of an Indian Institute of Technology (IIT), RuTAG can avail of the excellence in such institutions. Once the technology is ready for dissemination, it is the responsibility of the NGO to take the technology to the community through its available resources. In such cases, RuTAG encourages the NGO to collaborate with different funding agencies. Capacity-building exercises, such as exposure visits for artisans and training in selected institution/organisations, are also organised from time to time.

Such an arrangement facilitates a common platform for co-creation of knowledge, which is essential to reflect marginalized people needs and aspirations in a new product/technology. The end-users are placed at the heart of the design process in RuTAG. It facilitates the inclusion of local people's knowledge and experience in the design process. Extensive user-orientation during the ideation stage helps in gathering knowledge on both the tangible and intangible socio-technical factors of the target-community. In traditional design activities, the participation of NGOs/VOs is mostly appreciated in the post-development of technology, whereas they play a passive role during the ideation process. Here, the NGOs/VOs/end-users receive the central stage in the whole innovation effort. NGOs/VOs works as the mediator during the information sharing, data generation, collection of user feedback, etc.

The design team (technical) constructed extensive discussions with other stakeholders in various stages of the design. In deciding different technical and non-technical dimensions of the design and delivery process, suggestions and opinions from the stakeholders are seriously valued.

One significant learning of the case study analysis is that technology transfer at the BoP necessitate initiatives to improving the absorptive capacity of both the rural micro-enterprises and the target users. Such capacity-building activities have two objectives: (i) to improve the knowledge of the community about the new technology, so that they don’t face problem in migrating from traditional practices into new technology and (ii) to improve the skill of the technology manufacturer, so that they can manufacture the product per demand and provide necessary maintenance service to the community. In doing so, stress is given for improving the understanding about the technology (i.e., market, finance, economy etc.), so that the community/supplier of the technology can make necessary changes if the situation demands in the long run.

Instead of just delivering a piece of technology, stress should be given for minimizing the cultural and geographical distance between the technology developers and technology recipients. It is empowering the bottom actors to take part as a positive performer in the technology transfer efforts. Catalysing the events by RuTAG through their R&D efforts and connecting government for financial support also help to activate the other stakeholders to perform positively.

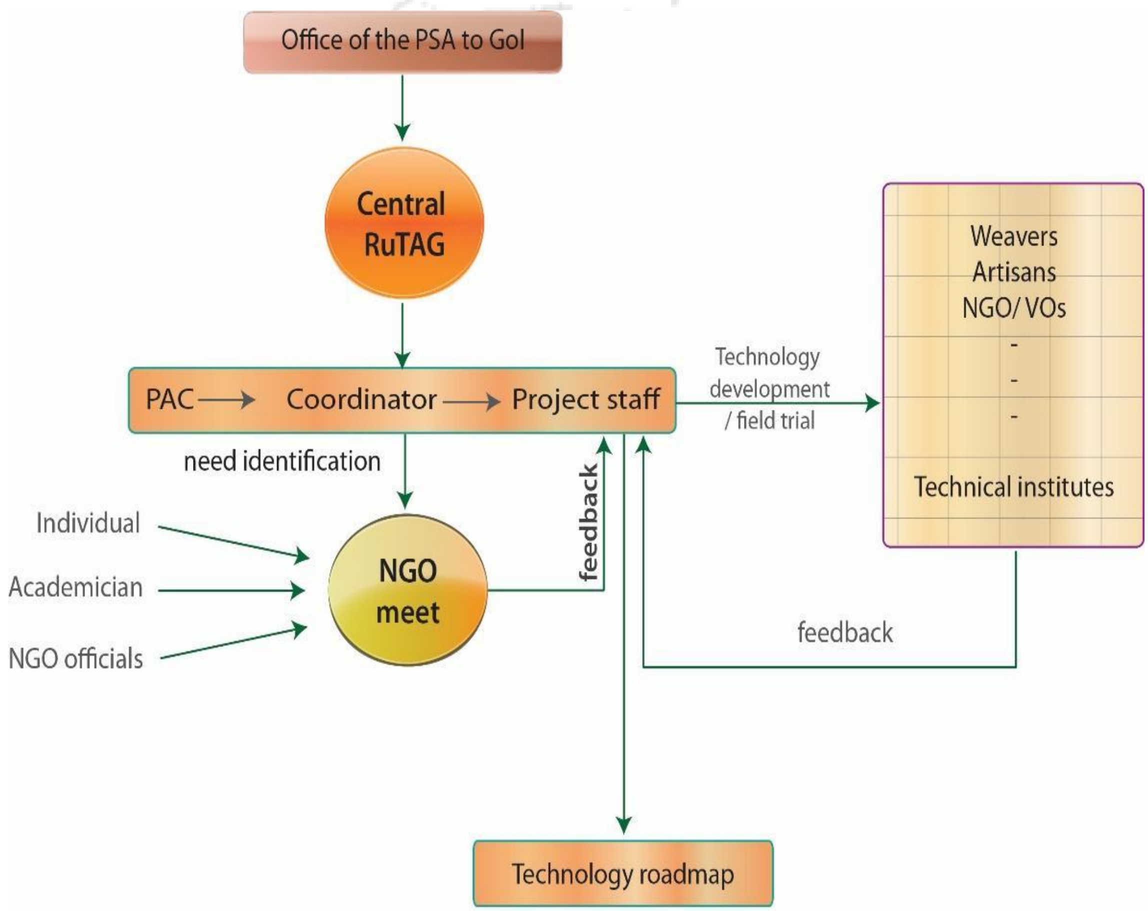


Fig. 6.1 Feedback mechanism for appropriate technology development and dissemination

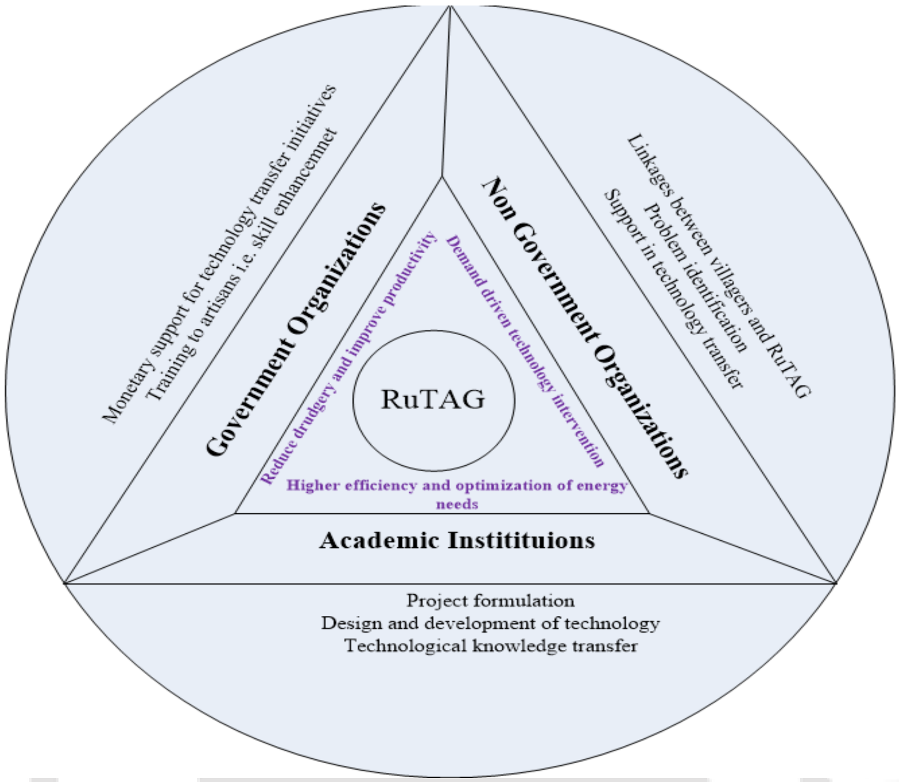


Fig. 6.2 Role to be played by different actors of RuTAG

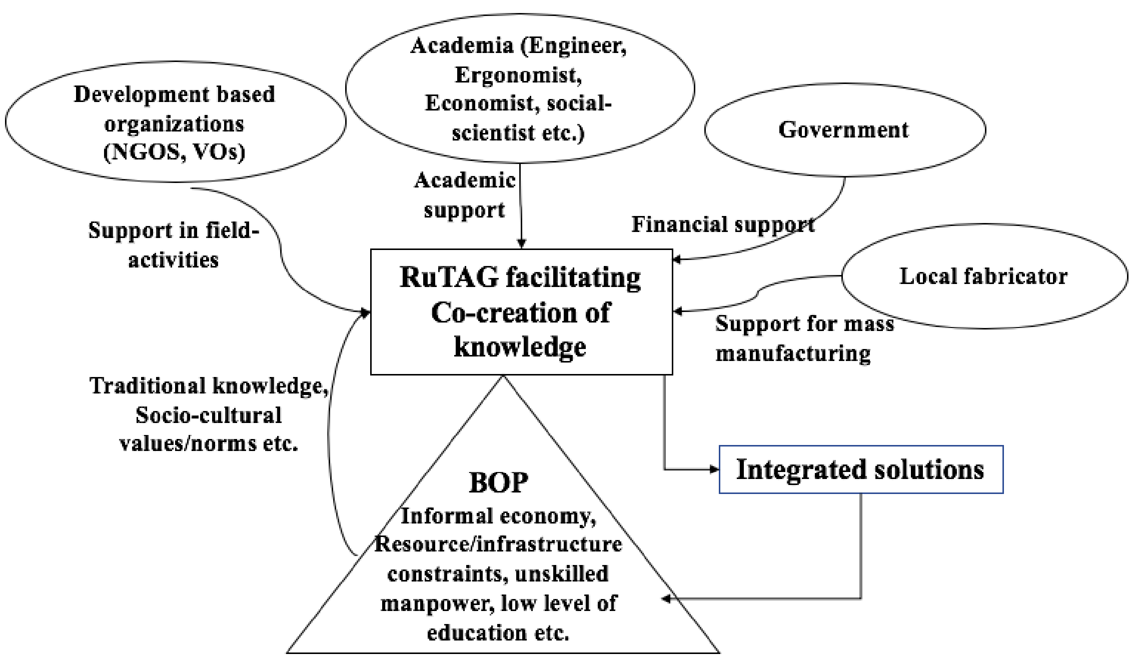


Fig. 6.3 Multi-stakeholder socio-technical engagement facilitated by RuTAG

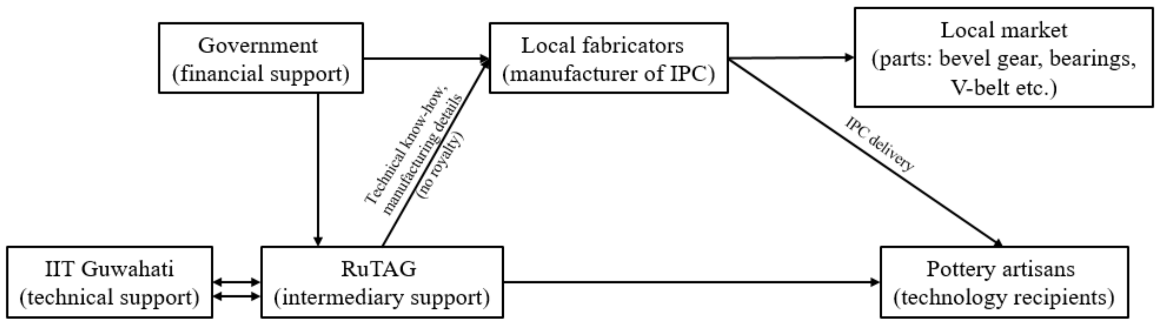


Fig. 6.4 *Technology transfer framework*

6.3 Planning the production process of IPC

Based on learnings derived from the case study on RuTGA, a localized framework for distribution and management of IPC is enunciated. As a part of decentralized technology transfer process, technical know-how and other knowledge are transferred to three local fabricators (e.g. M/S. A. P. Enterprise, M/S. Labanya Udyog, and M/S. Jalan Agro Pvt. Ltd.).

First, they were trained at the Central workshop of IIT Guwahati. Design details of all the components are illustrated to them. Only those enterprises that have the minimum facility to manufacture the technology are selected; hence, extra investment is not necessary to improve infrastructure.

The major concern is that rural micro-enterprises are working with very low skill and less infrastructure. During the design stages, necessary precautions are taken so that some of the parts *viz.* bevel gear, belt, both pulleys, nut and bolts and bearings cab be purchased from the market directly. Design specifications are fixed accordingly. Other components are fabricated locally (e.g. frame, pedal, assembly works, painting etc.). Necessary materials are purchased from the market. List of items with price details are presented in Annexure C.

In case of technology transfer to rural micro-enterprises, owner of those enterprises find it difficult to follow formal norms/procedures. Thus, formal agreement mechanism viz., intellectual property rights are avoided. A simple agreement is signed between RuTAG and micro-enterprises. As per the agreement RuTAG will provide necessary technical help as per need. A pictorial representation of the technology transfer and distribution strategy is presented in the Fig. 6.4. The differences between the traditional technology transfer process and the technology transfer framework emerging under RuTAG project are discussed in Table 6.1.

Table 6.1
Traditional technology transfer verses the technology transfer proposed in this study

	Traditional TT process	TT discussed here
i)	Profit is the prime concern of the technolgy developers.	The prime concern is societal issue and economic empowerment of the rural micro-enterprsies.
ii)	Technology transfer is possible without governemnt support.	Poor finacial capability is the major issue, hence connecting the recipent with finance, either governemnt support or micro-finace plans, is the only answer to make it effective.
iii)	Mostly technology transferors and technology recipients are involved in traditional practices (e.g. Alessandrini, et al., 2010).	A collaborative framework is proposed with involvement of all the stakeholders including academia, governemnt, non-government, micro-enterprises and community.
iv)	Organizational, attitudinal and behavioral factors hinder the technology transfer efforts (Fitzgerald, 1992).	Brokering events helps to overcome those issues in the said case.
v)	Rigid knowledge sharing mechanism (formal contract) (Lichtenthaler and Lichtenthaler, 2010).	Informal contract mechanism is applied. Stress is given for doing business by informal actors.
vi)	Market-centric approach where transferors develop technology for passive recipients (profit-making model) (Decter et al., 2007).	The recipients were actively participating from ideation into product delivery and management (developemnt-assited model).
vii)	Demand is created through survey in different medium.	Demand is identified through consultation; community dialouge organized by RuTAG.

6.3.1 Handholding

Finally, those who are receiving the technology, i.e., the artisans, are trained to use the new machine. For training purpose, support is sought from RuTAG. RuTAG is providing two types of training: improving the skill of the artisans (i.e. the receiver of the technology) and enhancing the skill of the village-based enterprise; hence, they can manufacture the machine and provide maintenance-related service per the demand. Thus RuTAG is acting as an intermediator in the technology transfer process.

Lack of financial resource is one of the major issues in technology intervention efforts for rural cottage industry in rural developing economy. In a country like India, many time artisans believe that it is the responsibility of the government to connect them with better technology. It is also true that the government of India has been spending a big share of budgetary allocation in different welfare schemes. Hence, to facilitate successful technology transfer of IPC, stress is given for financial support from government schemes. Necessary financial support is generated from the *STINER* scheme of the Ministry of the Development of North-east, Government of India. Five different Pottery clusters from North-eastern part of India are selected under this initiative for technology transfer. Besides, RuTAG-IIT Guwahati has selected six Pottery clusters of Assam, where technology is provided under RuTAG's own fund. ICCO India, a development organization helped in generating philanthropic funds for imparting skill training to pottery artisans in Assam.

Stakeholder details and their role during the ideation to product delivery of IPC is briefly discussed in the Table 6.2. Successful TT from university-to-rural enterprises necessitates a complex network of physical resources/ infrastructures, active network of institutions, enabling role by government policy and willingness of the stakeholders associated with the effort. The problem arises due to fragile connections between stakeholders at the BoP. To bridge those voids and to facilitate the innovation process at the BoP, Mattson and Wood, 2014 posited "*nine principles of product design for developing world*". To shed light on how those principles are accommodated during design, manufacture, and delivery of IPC, a detailed discussion is presented in the Table 6.3.

Table 6.2

Stakeholders details and their role in design and delivery of IPC

Sl. No.	Organizations	About the organizations	Role in the project
1.	Rural Technology Action Group (RuTAG)	RuTAG is a socio-technical initiative, initiated by the Government of India in 2004. The mandate of this project is to make a synergy of higher learning institutes of the country with grassroots organizations to expedite demand-driven technology intervention in rural India.	RuTAG has played the role of intermediary. It acts as the mediator in keeping other stakeholders in one platform. RuTAG's role can be listed as the generation of finance, coordinating with technical team for data collection, community-dialogue, field-study, training to fabricators and artisans.
2.	Indian Institute of Entrepreneurship (IIE) Guwahati	IIE Guwahati is an autonomous government organization in India with the mandate of rejuvenation of Small and Micro-Enterprises (SME) in the country [www.iietraining.org].	The organization has coordinated in technology transfer and imparting training in Chapar pottery cluster, District Dhuburi of Assam, India.
3.	Ministry of Development of the North East Region, Government of India	It is a ministry of government of India, who has the responsibility of planning and execution of development schemes in the north-eastern region of India.	The ministry has provided financial support for technology transfer of IPC under *STINER* scheme. This scheme was initiated for *lab-to-field* technology transfer of RuTAG technologies.
4.	Indian Institute of Technology (IIT) Guwahati Indian Institute of Technology (IIT) Kharagpur	These are the premier academic and research institutions in India. IIT Guwahati host the RuTAG- North-eastern Centre, whereas, IIT Kharagpur hosts the RuTAG- East Centre.	Academic supports (research and development), Workshop facility etc. were provided for prototype development.
5.	M/S. A. P. Enterprise M/S. Jalan Agro Pvt. Ltd. M/S. Labanya Udyog Private Ltd.	These are local fabricators from Assam, India.	Their infrastructure has been used for mass manufacturing of the machine.

Table 6.2 (continued)

6.	Swabhiman North-east Pottery Research and Training Centre (NPRTC)	Both the organizations are voluntary organizations who has been tirelessly working in Assam, India for sustainable community development of rural people.	Supported RuTAG in identifying the technological need, trust-building, field activities, training, workshop etc.
7.	Innovate Change Collaborate (ICCo) India	ICCo India is an organization working in the development sector in India. They are primarily working in livelihood generation for rural people in India.	They have supported in generation of philanthropic funds for imparting skill training to pottery cluster in Majuli district of Assam, India.

Table 6.3
Guiding principles in product design and delivery effort at the BoP (the case of IPC)

Sl. No.	Principles	Steps considered
1.	***Principle 1:* "***Co-design with people from the specific developing world context encourages designer empathy, promotes user's ownership and empowers resource-poor individuals".*	• The working mechanism of the IPC is decided based on users' recommendations. Thus 'Co-design' principle is appreciated during the design and innovation process. Three different types of prototypes are tested in the field. Finally, based on users' suggestion, the treadle mechanism is adopted. The issue is consulted with local fabricators so that the final product can be manufactured locally.
2.	***Principle 2:* "***Testing the product in the actual setting is an essential part of design for the developing world, not merely a final step".*	• The prototype developed by IIT Kharagpur was field-tested in different places. Based on users' opinion, the next model is developed. This model is again redesigned to obtain the final model. Besides, regular interactions happened between the technical team and other stakeholders, starting from ideation to product delivery so that their requirements are reflected in the final product. For example, local people's anthropometric data is collected and the same is used in deciding different dimensions.
3.	***Principle 3:* "***Importing technology without adapting it to the specific developing world context is ineffective and unsustainable".*	• To cherished Principle 3, mechanized pottery wheels which are available in the market are not imported blindly.
4.	***Principle 4:* "***Both individuals in urban and rural contexts can benefit from poverty alleviation efforts".*	• During the collection of users' opinion and field-testing, necessary attention is given to include clusters from urban areas. For example, a Pottery cluster situated in Guwahati, an urban center in the capital of Assam, India is included.
5.	***Principle 5:* "***Women and children are more affected by poverty alleviation efforts than men".*	• In deciding technical features, attention is given for reflecting the needs/aspiration of both male and female artisans. For example, the height-adjustable seat is designed so that both male and female can use the machine. Besides, necessary safety measures are incorporated to avoid accidents among children due to exposure of machine parts.

Table 6.3 (continued)

6.	***Principle 6:*** ***"****Project management techniques that are adapted to the specific developing world context enable a more effective and efficient design process".*	• As shown in Fig. 2, RuTAG is facilitating a common platform for experts from multiple-domain. Technical and non-technical support from members of RuTAG's extended network is skillfully used during implementation of the project. Keeping in mind the resource-scarcity at the BoP, development-based model of technology transfer is cherished here. Development-based model of technology transfer refers here financial support from the government for incurring the necessary cost of technology transfer. Local fabricators are trained so that they can manufacture product locally and solve maintenance related issues at the artisans' doorstep.
7.	***Principle 7:*** ***"****Products for the developing world have greater impact when contextualized, developed, and implemented by Interdisciplinary teams".*	• The contextualized development process is discussed in Principle 1. The multidisciplinary nature of the project team can be understood from Table 6.2.
8.	***Principle 8:*** ***"****Cooperation with governments and local Influencers Contextualizes and enables poverty alleviation plans".*	• Collaboration with the government helped in getting the necessary support from STINER initiative.
9.	***Principle 9:*** ***"****There are existing distribution strategies that can be used to successfully introduce products into developing world markets".*	• Distribution strategy is discussed in section 6.3.

6.4 Major Learnings

Knowledge related to product design for BoP derived during the design and delivery of IPC can be discussed as follows:

6.4.1 Uniform design criteria does not work in BoP

The evidence from the design activities shows that technological needs vary based on gender, location/remoteness and age. For example, the initial model of the pottery wheel was developed based on a bicycle pedalling mechanism for the artisans in Kharagpur area, a state located in the eastern part of India. However, the female artisans situated in remote villages in Assam, a state in the north-eastern part of India, expressed their concern stating that such a mechanism will not be acceptable for them. Wearing their traditional dress and operating the *Chaak* using the concept of bicycle pedalling is not acceptable due to inappropriate exposure of a small portion of their lower leg. The survey results show that the issue is not so serious in urban locations even in Assam, but it is a significant problem in remote villages due to social norms. Thus, a technology that is good for a village near an urban area is not acceptable in a remote village.

Thus, the need varies from one context to another within the same BoP setting, based on age, gender, etc. To present how such context-specific needs/ aspiration are addressed during the design of IPC, the pictorial representation of design process is presented in Fig. 6.5.

The crucial component in TT for the BoP is gathering real-time feedback from target-users. Feedback collection from users regarding the appropriateness of technology and correction of the technology accordingly helps standardization of technology as per the embedded social needs of the community. Many a time, technology is tested centrally and transferring it to different locations with the assumption that variation in the social fabric will not hamper successful transfer. The case of IPC depicts that such an assumption is not correct.

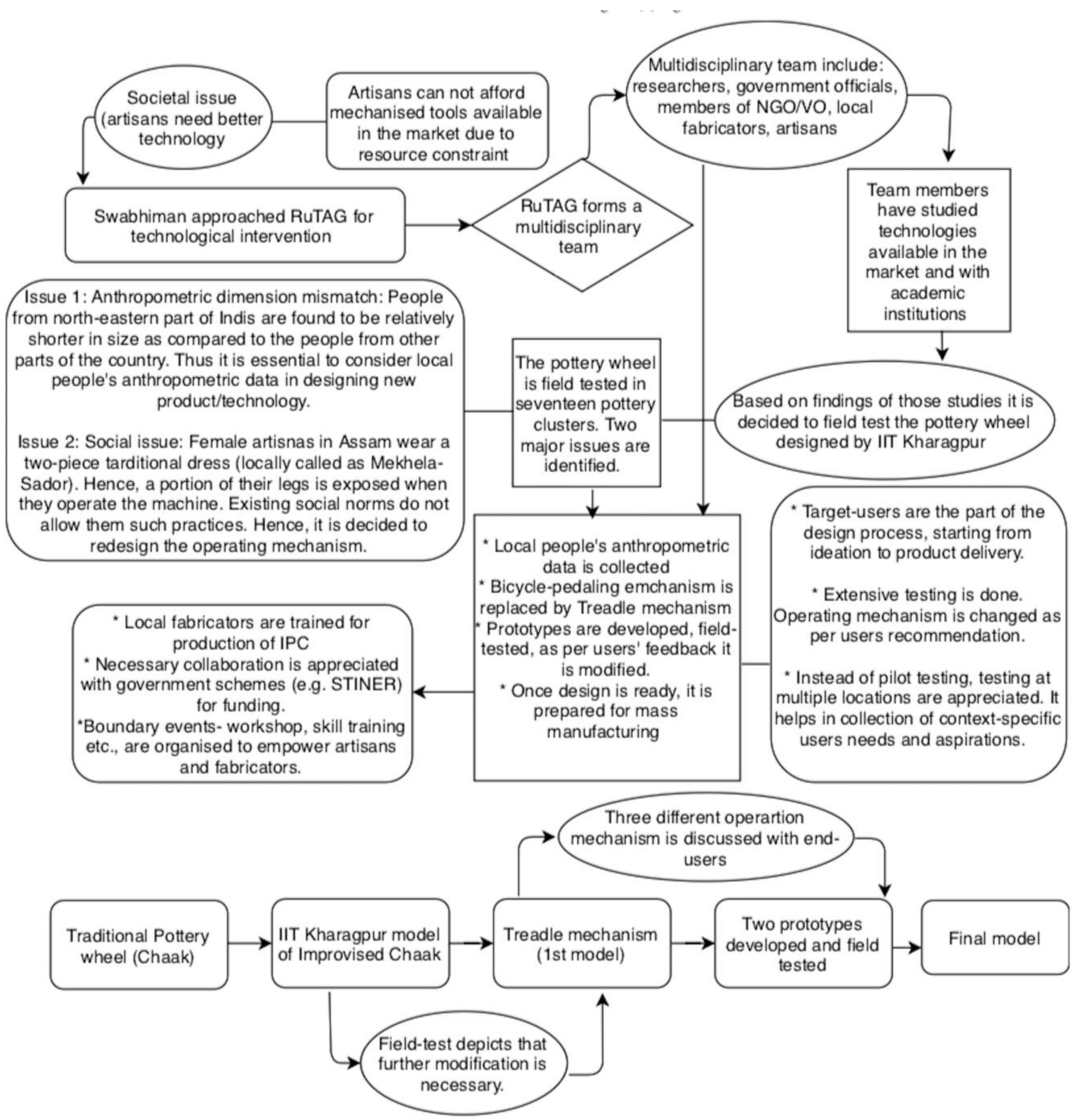


Fig. 6.5 Pictorial representation of the flow of the design process

6.4.2 Decentralized innovation planning better suits in BoP

The production of the technology in a decentralized manner has positive impacts. Manufacturing technology at the local level helps in reducing the transportation cost of the technology. Such an arrangement is useful for the artisans as they will get their maintenance service at their doorstep. Otherwise, if they would have to travel to a nearby city for maintenance-related issues, their work will be hampered, which is one of the reasons for technology failure in BoP settings.

Finally, the case depicts that in deciding the design matrices, extensive consultation with all the stakeholders is imperative that demand a decentralized decision-making system.

6.4.3 Blending the formal science with traditional knowledge inherited in the society ensures better adoption of technology in BoP

Creating synergy among multidisciplinary science and technology community, civil society groups, and targeted users are the key to technology development and dissemination in resource-constrained society. The approach is that while developing technology capability in such situations, collaborative efforts help in linking formal science of different domains into traditional knowledge. Experts who have a technical background, and who, at the same time, can can understand the social perspectives of the TT are supposed to give a better result. Existing indigenous knowledge may be taken as a starting point for technology development and looking at how formal science helps in strengthening the existing tools/methods to improve productivity and reduce drudgery and overall business development.

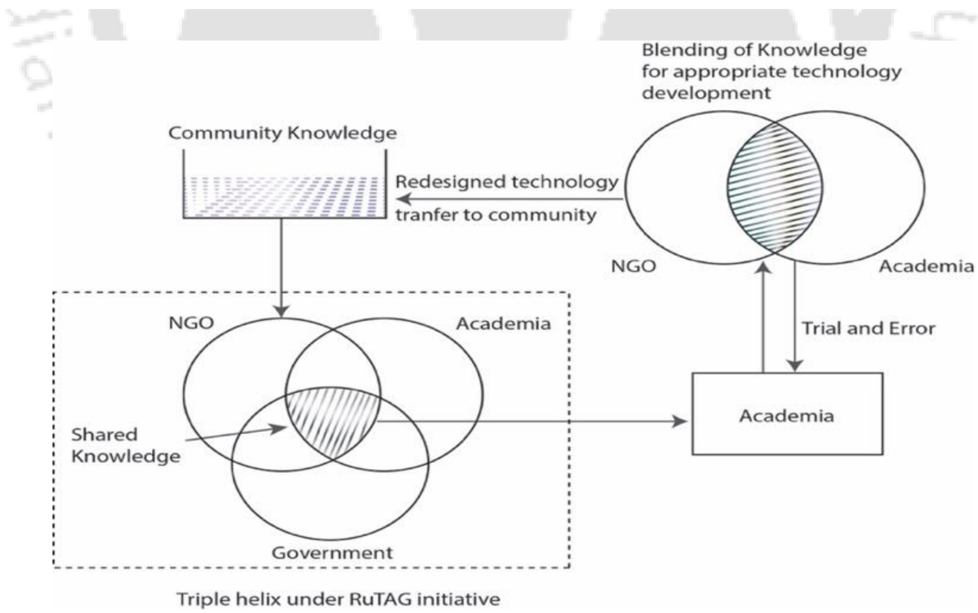


Fig. 6.6 Knowledge flow and learning mechanism created during design, development and technology transfer

In this case, pottery artisans know about pottery making. They are practicing such knowledge for ages in pottery making. However, there was a need to standardize the traditional process to make it better. The same is achieved through collaborative intervention by stakeholders. In doing so, knowledge is gathered from different domains *viz.*, mechanical engineering and ergonomic science, socio-economic constraints of the target users, availability of resource/finance etc. Knowledge flow mechanism emerging during design and dissemination effort of IPC is presented in Fig. 6.6.

6.4.4 Successful TT in BoP necessitates constant hand-holding

The primary issue to be tackled in TT for BoP is that those people, in general, do not have the necessary confidence for accepting new technology. That is why they need to be empowered by constant hand-holding. Skill training, workshop, interactions, idea sharing sessions, etc., help to improve their confidence level that gives a better result. Another important aspect is finance. They find it challenging to approach either bank or officers to avail government schemes. Thus, they need support to connect them with existing government schemes, bank loan, micro-financial organizations' help, etc.

Similarly, micro-enterprises require hand-holding for the production of new technology. They need skill training, finance for infrastructure improvement and buying raw materials, etc. In the said case, initially, no single micro-enterprise was ready to manufacture the technology. Three existing village-based fabricators (i.e., M/S. A. P. Enterprise, M/S. M. K. Engineering, and M/S. Jalan Agro Pvt. Ltd.) were trained to overcome this hurdle.

6.5 Summary

This chapter demonstrates a decentralized technology innovation and management mechanism for the IPC. Keeping in mind the challenges and existing complexities, a collaborative technology transfer approach is presented here. Based on learnings during design and delivery of IPC, a number of insights are presented in this chapter which is expected to have a significant contribution to the future technology planning and management for BoP settings. In the next chapter, the contributions and implications of this thesis are presented to draw conclusions. Besides the scope of future work is also highlighted in the chapter.

Chapter 7

Conclusion: achievement, recommendations and scope for future work

7.1 Introduction

The chapter summarizes the research work carried out during the thesis work. As a part of this research endeavour, the TPW is redesigned. Local people's anthropometric data have been incorporated in the IPC to make it ergonomically correct. An informal technology transfer framework involving three local fabricators is enunciated. Besides, based on the experiences obtained during the design, development and delivery of IPC, an attempt is made to discuss how the technical team should interact with social actors in shaping the technical features of a product/technology. Findings of this study are discussed here.

7.2 The key contribution of present research work

7.2.1 Development of an anthropometric database of Assamese population

Before this study, the lack of anthropometric data of the Assamese population was a significant issue for design and development of new product/technology. Hence, as a part of this research, an effort is made for the collection and documentation of anthropometric data of five communities of Assam. As per the guidelines provided by the "*All India Coordinated Research Project (AICRP) on Human Engineering and Safety in Agriculture (HESA), India,*" this study included 72 anthropometric dimensions. Considering the objective of this study, people from the nonfarm sector is considered for this research.

The sample included 265 male and 188 female participants in the age group of 18 to 60 years. Five different ethnic groups of the state, Boro, Garo, Hira, Karbi, and Rabha, were considered in the study. Stature is found to be highly correlated ($r > 0.8$; $p < 0.01$) with a number of anthropometric dimensions. The variation in anthropometric data considering gender and ethnic diversity has also been examined, and significant differences are observed concerning gender and ethnicity. The most notable variation is observed in the anthropometric dimensions of Hira population when compared to the other four ethnic groups of the same gender. Factor analysis and regression modelling are also performed as part of the study. The study shows that height-related variables could be predicted mostly in factor 1. Further, the collected data are used to redesign the traditional pottery wheel and cater to artisans' comfort with added safety.

7.2.2 Ergonomic design modification of the TPW

The TPW has some shortcomings in terms of health drudgery of users. A new design is conceptualized, designed, developed and prototyped.

Essential features of IPC:

- Treadle mechanism which is used in *manual sewing machine operation* is skillfully adopted, thus reducing the manual effort required to rotate the TPW for moulding pottery items.
- Correct sitting posture is the essential requirement for productivity and comfort. Hence, a new seating arrangement is designed with height adjustment features to make it appropriate for maximum users. It will facilitate better ergonomic in traditional pottery making, thus reducing health drudgery among artisans.
- Serious attention is given for accommodating the "Designing for adjustable range" principle (Taifa and Desai, 2017) during the design of the machine. Thus, the same device will be valid for both female and male artisans.
- Considering the inadequate supply of electricity in remote villages, manually powered mechanism is incorporated.
- Nut and bolt joining are preferred to facilitate easy assemble/disassemble of a significant number of components. It will facilitate easy transportation into remote villages.

- The new intervention will improve the productivity of artisans as compared to that obtained by the existing pottery wheel that is being used by the artisans. The field-testing results also reveal that the use of this machine will provide more comfort as compared to the traditional tool.

7.2.2.1 Performance evaluation of IPC

To evaluate the performance details of the IPC, a number of experimental investigations were carried out. Following observations are reported from experimental investigation:

- The actuating force (kg, mean ± standard deviation) is found to be 3.5 ± 0.7 kg. Similarly, the working force was measured as 1.1±0.2 kg. During the experimental investigation, the artisans expressed that they can easily exert this amount of force without any discomfort. The actuating force and working force required to operate IPC are much less than the isometric muscular strength of the Assamese people as reported by Patel et al., 2015. Therefore, this design of the machine is considered to be comfortable for the artisans.

- Male artisans' average productivity is found to be almost 1.7 times higher in the case of IPC than that of the TPW. Similarly, female artisans' average productivity is found to be almost 1.8 times higher in the case of IPC than that of the TPW. Due to the use of IPC, the average production of small-sized items per hour for female artisans is found to be enhanced from 62.3 to 110.1 number and for male, from 98.6 to 168.4 number. The result depicts that differences in productivity in case of TPW *vs*. IPC is statistically significant ($p < 0.01$) for both male and female.

- The discomfort rating score is lower in case of IPC if it is compared with the discomfort rating score of TPW. Bending and wrong sitting postures are the major issues in the traditional process. The results depict that introduction of new sitting arrangement is successful in reducing discomfort in majority of the body parts viz., neck, upper back, lower back, knees, thigh buttock. Similarly, the new arrangement of rotating the wheel by leg power instead of hand power, discomfort is reduced in body parts, viz., shoulders, elbow, hand wrists, claves.

- Before the start of the work, for male, the mean value of handgrip strength is found to be 32.5 ± 2.1 kg and 28.2 ± 2.3 kg for dominant and opposite hands, respectively. After two hours of working in the TPW, the mean value of the handgrip strength is found to be 29.9 ± 2.1 kg and 25.8 ± 2.2 kg for dominant and opposite hands, respectively. Similarly, after two hours of working in the IPC, average handgrip strength is measured as 31.0 ± 2.2 kg and 26.5 ± 2.1 kg for dominant and opposite hands, respectively. For female, the mean value of handgrip strength before working is found to be 23.1 ± 2.1 kg and 18.2 ± 2.0 kg for dominant and opposite hands, respectively. After two hours of working in the TPW, the mean value of handgrip strength is found to be 20.2 ± 2.3 kg and 14.8 ± 2.0 kg for dominant and opposite hands, respectively. Similarly, after two hours of working in the IPC, the average handgrip strength is measured as 21.9 ± 2.4 kg and 16.7± 1.8 kg for dominant and opposite hands, respectively. The results establish the fact that the design intervention is successful in reducing with time the decrease in muscular strength. The change is statistically significant ($p<0.01$) for both right and left hands of the female artisans. For male, the change in the right hand is statistically significant ($p<0.01$).
- The results depict that the AWHR increased 47.2% above the resting heart rate for the TPW compared to 38.8% increase for the IPC. Similarly, the average oxygen consumption rates are 1.36 liter/minute and 0.85 liter/min for TPW and IPC, respectively. The average energy expenditure rates are found to be 28.62 kJ/minute and 17.68 kJ/minute for TPW and IPC, respectively. For female, the average working heart rates during work with TPW and IPC are found to be 102.7 beats/minute and 99.8 beats per minute with the corresponding work pulse (ΔHR) is 59.5 beats/min and 53.8 beats/minute. The results depict that the AWHR increased 40.7% above the resting heart rate for the TPW compared to 36.9% increase for the IPC. The average oxygen consumption rate is calculated as 1.17 liter/minute and 0.77 liter/min for TPW and IPC, respectively. The energy expenditure rates are found to be 24.57 kJ/minute and 16.01 kJ/minute for TPW and IPC, respectively.

7.2.3 Technology transfer of IPC

As part of the technology transfer initiative, three local fabricators are trained to empower them for manufacturing the IPC. They are enabled through training and handholding, so that IPC can be produced at the village level and delivered as per the demands. The necessary effort is given during conceptualization of the design, so that a complex manufacturing process can be avoided. Necessary finance is generated from the existing government schemes (e.g. STINER, RuTAG, etc.) for successful technology transfer.

7.3 Perspectives of SoD in product design for BoP

SoD is a holistic approach with multidimensional features of sustainable development goals coined by UNO. The major challenge in such an approach is the integration of multiple actors/stakeholders in the process. However, in this research endeavour, an attempt has been made to present the realistic view of SoD in product design while solving a societal issue at the BoP. Multi-stakeholder engagement is appreciated starting from ideation to product delivery. Participation of local-level actors (e.g. civil society, local fabricator, etc.) and support from government facilitates a common platform for co-creation of knowledge, which is essential to reflect marginalized people needs and aspirations in the features of IPC. It also helps in the generation of resource that is a critical component in any technology transfer program for marginalized people living in BoP. How participation of multiple stakeholders facilitated the co-creation of knowledge and accumulation of resource during design and delivery of IPC is already discussed in the previous chapter. This study demonstrates that non-business actors can constructively participate in the product design and delivery for sustainable community development at the BoP.

7.4 Limitations of this study and future scope of research

Serious efforts are being made in this study to achieve the best result. However, some unavoidable concerns are always beyond the reach of the experimenter, which could be considered as the future scope of research.

- To achieve the aim of this research, the TPW is redesigned and evaluated through users' perception. It could be tested, considering users from other parts of the country. The long-term impact of the machine in terms of health hazards, cost–benefit analysis, artisans' business opportunities, etc. could be part of the future investigation.
- Due to time and logistic constraints, performance evaluation of the IPC was carried out in a limited numbers of clusters, which may be extended to different parts of Assam in the future.
- Conversion of a manually powered system of the IPC into a solar-powered system is another possibility for the future investigation.
- The technology transfer and management framework developed for IPC can be extended to other technologies or other R&D ecosystems.
- Considering all the communities/tribes would have given better result to represent the anthropometric database of Assam. The primary concern is that collection of anthropometry data of all the ethnic groups in one phase is not possible due to logistical constraints. Keeping in mind the above-mentioned concerns, only five ethnic groups of the state are considered. Other communities can be considered in the future research efforts.

7.5 Concluding remarks

The village-based traditional cottage industry plays a crucial role in fostering the rural economy of India. But, as the profit margins of these industries are low, and most of the artisans are unskilled, research and development (R&D) intervention in this sector is very limited. Globalization of the economy, rapid changes in the role of new technologies, and intense competitive pressure have brought many challenges to the rural craft and cottage industries. They contribute to factors influencing the migration of rural youth from their native land to urban areas in search of better economic avenues. To combat such forced migration, acquisition and adaptation of technology in traditional village-based craft and cottage enterprises is an essential prerequisite. This will enhance the quality of the product, improve productivity, minimize the cost of production, and optimize the energy needs for improving competitiveness both at the local level and in the international market.

Realizing the problems of those marginalized people, this research endeavour made an effort so that pottery artisans get benefit from this work. The TPW is successfully redesigned, manufactured and distributed among the artisans. The participatory innovation approach followed during design and development of the IPC is expected to be useful in similar future efforts for need-based products/ technology in other household cottage industries.

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Appendix A

Calculation of Bending Moment on the shaft connecting the smaller pulley and bevel gear. The force system is shown in Fig. A.1 (a).

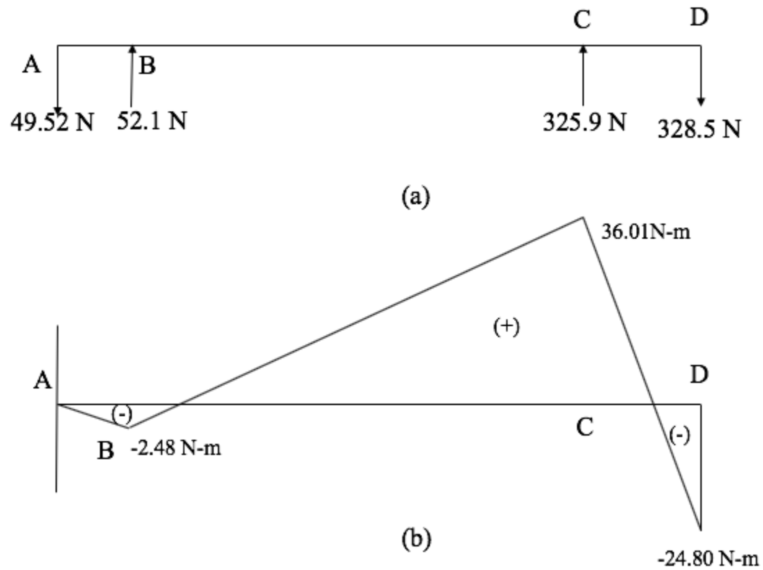
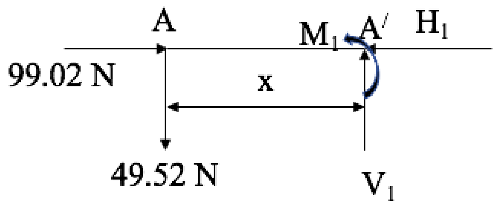


Fig. A.1 (a) *Vertical force system acting on the shaft connecting the smaller pulley and bevel gear; (b) bending moment diagram*

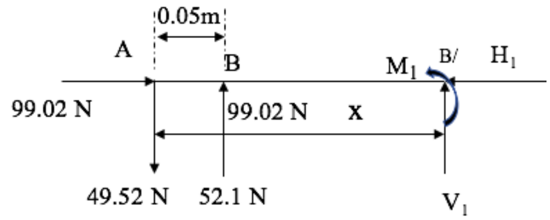
Taking a section to the left of B, at a distance of x from A, bending moment equation can be presented as shown in Eqn. (A.1).

$$M_1 + 49.52\, x = 0;\ 0 \leq x \leq 0.05 \quad [A.1]$$

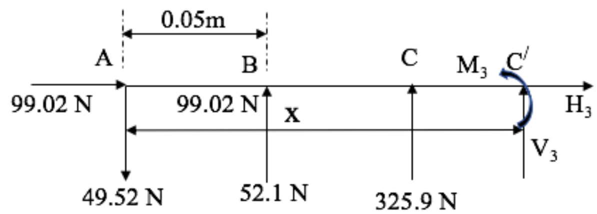
From Fig. A.2 (a), at x = 0 (at A), $M_A = 0$ and at x = 0.05 (at B), from eqn. A.1, MB = -2.48 N-m.



(a)



(b)



(c)

Fig. A.2 Diagram showing force and moment in different sectios of the beam

Considering a section to the left of C, and at a distance of x from A, ($0.05 \leq x \leq 0.380$) [shown in Fig. A.2 (b)], bending moment equation for $0 \leq x \leq 0.38$ is shown in Eqn. (A.2).

$$M_2 + 52.1\,(x-0.05) + 49.52\,x = 0 \qquad [A.2]$$

From Eqn. (A.2), at B, x = 0.05 m; M_B = 2.48 Nm; at C, x = 0.380 m; M_C = 36.01N-m

Now, considering a section to the left of D and at a distance x from A (shown in Fig. A.2 (c)), Bending Moment for ($0 \leq x \leq 0.430$) is presented in Eqn. (A.3).

$$M_3 - 325.9\,(x - 0.380) + 52.1\,(x-0.05) + 49.52x = 0 \qquad [A.3]$$

From Eqn. (A.3), at C, x = 0.380; M_C = 36.01 N- m and at D, x = 0.430; M_D = -24.8 Nm. Bending moment diagram is shown in Fig. A.1 (b)

Appendix B

Determination of different technical specifications of the Bevel gear

Sr. No.	Particulars	Specifications

Material: Steel EN8, 080M48

σ_y = *Yield strength = 245 MPa*

σ_u : *Ultimate tensile strength = 510 MPa*

K_{b1}: *life factor for bending =1*

K_σ : *fillet stress concentration factor = 1.2*

σ_0: $1.4\sigma_{-1}$

σ_0: *Endurance limit stress in bending repeated stress, kgf/cm*^{2}

σ_{-1}: *Endurance limit stress in bending for, complete reversal of stress, kgf/cm*^{2}

$\sigma_{-1} = 0.22(\sigma_u + \sigma_y) + 500$ = *50.69 MPa*

n: factor of safety = 2

K: concentration factor

K_d: *dynamic load factor*

$K_d . K = 1.3$

Twisting moment: $[M_t] = M_t . K_d . K$

$M_t = \frac{P \, x \, 60}{2\pi N}$

Thus twisting moment is equal to 14.23 x 10^3 *N-mm.*

Transverse module: $m_f = \dfrac{R}{0.5\sqrt{z_1^2 + z_2^2}}$ *= 2.67; Standard module: 3 mm*

Face width, $b = \dfrac{R}{\psi_y}$ *= 15.7 mm*

Average module, $m_{av} = m_t - \dfrac{b \sin d_1}{z_1}$ *= 1.01 mm*

Average pcd of pinion $(d_{1av}) = m_{av} \times n_2 = 16.2$ *mm.*

Pitch line velocity: $v = \dfrac{p d n_1}{60}$ *= 0.9 m/s.*

Pitch angle: $\tan d_2 = i = 2$

Or $d_2 = 63.43^0$ *and* $\tan d_1 = 90^0 - d_2 = 26.57^0$

Pinion

1.	*Pitch*	*3 MOD*
2.	*Pressure angle*	*20^0*
3.	*Bore diameter*	*14 mm*
4.	*Distance to apex*	*65mm*
5.	*Face width*	*18mm*
6.	*Hub diameter*	*36 mm*
7.	*Hub length*	*14 mm*
8.	*Outside diameter*	*55 mm*
9.	*Overall length*	*34.34 mm*
10.	*Pitch circle diameter*	*48 mm*
11.	*Recess depth*	*3 mm*

Gear

12.	*Bore diameter*	*14 mm*
13.	*Distance to apex*	*55mm*
14.	*Face width*	*18 mm*
15.	*Hub diameter*	*60 mm*
16.	*Hub length*	*20 mm*
17.	*Outside diameter*	*97.88 mm*
18.	*Overall length*	*40.12 mm*
19.	*Pitch circle diameter*	*96 mm*

Appendix C

Parts details and cost of production

Sl. No.	Items	Dimensions	Material	Price at the local market	
				Per kg	Total
	A. Items for which material is purchased from market				
1.	Frame of the machine	Rectangular hollow section: 40 x 40 x 2mm of length 760mm- 4 numbers 40 x 40 x 2mm of length 800mm- 10 numbers 40 x 40 x 2mm of length 800mm- 2 numbers	AISI hot rolled steel	68/-	700
2.	Housing for pedal	Angle (L) section: 25 x 25 x 5 mm of length 400 mm – 4 numbers		66/-	75
3.	Pedal	Shaft diameter: 20 mm; 4 rods of 10 mm diameter.		66/-	100
4.	4-bar mechanism	Shaft (diameter 10 mm): crank:73 mm; connecting rod: 303 mm		66/-	50
5.	Bearing housings	80 x 80 mm plate, width: 14 mm; 2 numbers		66/-	70
6.	Shaft connecting the smaller pulley with bevel gear	Length-360 mm, diameter- 20 mm		68/-	60
7.	Support plate for the shaft connecting smaller pulley and bevel gear	Rectangular plate: 60 x 110 x 20 mm		66/-	30
8.	Housings for the bevel gear system				50
9.	Pottery plate	Diameter: 400 mm, thickness: 20 mm		68/-	130

Appendix C (continued)

10.	Sheet for the cover				120
11.	Paint				300
	Subtotal (A)			**1785**	

B. Items directly purchased from market

1.	Nut and Bolts	M8 & M6	Aluminum	8/-	280
2.	Pulleys	Outer diameter: 545 mm- 1 number Outer diameter: 120 mm- 1 number	Cast iron	785/- and 120/-	905
3.	Bevel gear	Pinion: Pitch: 3MOD; Pressure angle:20^0; Bore diameter: 14mm; Distance to apex: 65 mm; Face width: 18mm; Hub diameter: 36mm; Hub length: 14mm; Outside diameter: 55mm; Overall length: 34.34mm; Pitch circle diameter: 48mm; Recess depth: 3mm. Gear: Bore diameter: 14mm; Distance to apex: 55mm; Face width: 18 mm; Hub diameter: 20mm; Outside diameter: 97.88mm; Overall length:40.12mm; Pitch circle diameter: 96mm.	Steel EN8, 080M48	8025/-	8025
4.	V belt	A-78	Rubber	385/-	385
5.	Roller type bearing	SKF6404	Chrome steel	47/-	376
6.	Height adjustment chair	Minimum height: 35cm; Maximum height 55cm; Seat pan width: 45cm; Seat Depth: 45cm; Backrest height: 35 cm; Lumbar support: 10mm	----	1345	1345

C. Cost of manufacturing

Sl. No	Description	Rate (per day)	Amount (Rs.)
1.	Cutting and grinding	350	350
2.	Welding and grinding	350	175
3.	Fitting	350	175

Appendix C (continued)

4.	Lath works	350	350
5.	Painting	350	500
	Subtotal (C)	**1550**	
	Subtotal (D = A+ B+ C)		13306
	Profit (E = 20% of D)	20% of the	2661.2
	Total (Rs.)		**15967.2**

Publications

Book Chapters

1. **B.R. Bhattacharjya**, S.K. Kakoty. 2019. *A Study on the Anthropometry of the Hira Community of Assam: Its Use in Redesigning a Pottery Wheel*. In: Chakrabarti A. (eds.) Research into Design for a Connected World. **Smart Innovation, Systems and Technologies**, 135, 417-426. (https://doi.org/10.1007/978-981-13-5977-4_35, Springer, Singapore)

2. **B.R. Bhattacharjya**, S. Sarmah, S.K. Kakoty. 2019. *Design and Development of Technology Appropriate for Rural Community to Address Sustainability*. In: Saha S., Ravi M. (eds.) Rural Technology Development and Delivery. **Design Science and Innovation,** 95-112. (https://doi.org/10.1007/978-981-13-6435-8_6, Springer, Singapore)

Journals

1. **B. R. Bhattacharjya,** S. K. Kakoty, S. Singha. 2019. *A feedback mechanism for appropriate technology development and dissemination: Case study approach*, **Technology in Society 57**, 104-114. (DOI: 10.1016/j.techsoc.2018.12.008; Elsevier)

2. **B. R. Bhattacharjya,** S. K. Kakoty. 2020. *A survey on the anthropometric data of five ethnic groups of Assam with gender and ethnic diversity: Application of the data in redesigning a manual pottery wheel*, **International Journal of Industrial Ergonomics**, **76**, 102927 (DOI: 10.1016/j.ergon.2020.102927, Elsevier)

3. **B. R. Bhattacharjya,** S. K. Kakoty. 2020. *An exploration of Intermediary's role in participatory product design at the bottom of the pyramid: The case of Improvised Pedal-operated Chaak*, **Journal of Mechanical Design, 142 (12), 124501-7** (DOI: 10.1115/1.4047897, ASME).

Journals (under review/ in preparation)

1. **B. R. Bhattacharjya,** S. K. Kakoty. *Antecedents of sustainability-orienting design approach for design and delivery of new product at the bottom of the pyramid*, **Journal of Cleaner Production** (1st review submitted).
2. **B. R. Bhattacharjya,** S. K. Kakoty. *Design, development and testing of Improvised Pedal-operated Chaak to replace traditional pottery wheel*, **Journal of Mechanical Design** (in preparation).

Conference Proceedings

1. **B. R. Bhattacharjya**, S.K. Kakoty. *Fostering sustainability in resource constraint society through Frugal Engineering Knowledge in the context of Pottery sector of Assam*, International Conference on Frugal Innovation for Sustainable Global Development, organized by the Centre for Frugal Innovation in Africa in Leiden, The Netherlands on November 7- 8, 2017.

2. **B. R. Bhattacharjya**, S.K. Kakoty, Design and Development of Technology Appropriate for Rural Community to Address Sustainability, 1st International Conference on Rural Technology Development and Delivery organized by Indian Institute of Technology Delhi, 9-11 March, 2018.

3. **B.R. Bhattacharjya**, S.K. Kakoty, A Study on the Anthropometry of the Hira Community of Assam: Its Use in Redesigning a Pottery Wheel, 7th International Conference on research into Design held at Indian Institute of Science Bangalore, January, 2019.

4. **B.R. Bhattacharjya**, S.K. Kakoty. *Towards an Iterative Technology Innovation and Management Framework for Resource-Constrained Society*, 28th International Conference for the International Association of Management of Technology (IAMOT 2019) on the theme –Managing Technology for Inclusive and Sustainable Growth, organized by NITIE Mumbai (India) on April 07-11, 2019.

5. **B.R. Bhattacharjya**, S. K. Kakoty. *Presenting an iterative innovation framework perceived for resource-constrained society*, IEEE TEMS International Symposium on

Innovation and Entrepreneurship (ISIE), **Hangzhou, China, October 24 – 26, 2019 (DOI:** 10.1109/TEMS-ISIE46312.2019.9074377**).**

6. **B. R. Bhattacharjya** and S. K. Kakoty, *Innovating demand-driven technology for rural mechanization, All India Seminar on Rural Industrialization through Innovative Process Mechanization*, The Institution of Engineers (India), Assam State Centre, 08-09 June 2019.

7. **B.R. Bhattacharjya**, S.K. Kakoty. Critical factors in designing frugal products: *The case of Improvised Pedal-Operated Chaak (IPC)*, FORE International Conference on Frugal approach to Innovation (FICFAI) 2019, FORE School of Management, New Delhi (India), December 13-14, 2019.

Appreciations

- Awarded **distinguished paper award** at the *7th International Conference on research into Design* held at Indian Institute of Science Bangalore, 9-11 January, 2019.
- Awarded **best paper award** at the *Fore International Conference on Frugal* Approach to Innovation, organized by Fore School of Management, New Delhi, 13-14 December, 2019.

Functional model of the Improvised Pedal-operated *Chaak*
