Design Interventions in Farm Equipment for Indian Small Farmers

Submitted in partial fulfillment of the requirements

of the degree of

Doctor of Philosophy

of the
Indian Institute of Technology Bombay, India
and
Monash University, Australia

by

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The course of study for this award was developed jointly by
Monash University, Australia and the Indian Institute of Technology Bombay, India
and was given academic recognition by each of them.
The programme was administrated by The IITB-Monash Research Academy

2024

Dedication

अज्ञानतिमिरान्धस्य ज्ञानाञ्जनशालाकया

चक्षुरुन्मीलितं येन तस्मै श्रीगुरवे नमः

He who removes darkness of ignorance of the blinded (un-enlightened) by applying the collyrium of knowledge. He who opens the eyes, salutations unto that respected guru.

To all my gurus (teachers), thank you.

Approval Sheet

The thesis entitled "Design Interventions in Farm Equipment for Indian Small Farmers." by Pai Sanket Satish is approved for the degree of **Doctor of Philosophy.**

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Abstract

Indian agriculture sector is an essential part of the country's economy and employs a significant portion of its population. Farmers with landholdings of less than one hectare and between one to two hectares are classified by the Indian government as marginal and small-scale. Due to the fragmentation of landholdings and land division among children with each new generation, the number of small farms and farmers is steadily increasing. This land size reduction can impact the farmers' yield and ability to afford farm inputs making small farm cultivation a challenging process. Despite a thrust towards farm mechanisation, most small farmers still rely primarily on traditional tools and methods. Though farm implements reduce drudgery and enhance efficiency, small farmers struggle to balance investment in expensive farm equipment and crop yield. A gap exists between simple, cheap hand tools and costly, large-scale powered tools like tractors.

This exegesis documents studio-based research through design approach. The researcher has used principles of industrial design, appropriate technology, and a human-centred design process to investigate, design, and develop interventions that could ameliorate small farmers' issues. The data collection methods of literature study, observations, analysis of artefacts and semi-structured interviews were used to understand Indian agriculture and the challenges faced by small and marginal farmers. These were used to generate morphological visualisations of small farmers' activities, tools, and needs for rice farming. The outcomes of this research activity were then analysed, and twenty-six factors were defined for consideration while developing the design intervention. A theoretical framework was then developed to inform and drive ideations, design choices, and design decisions during concept generation and evaluations. Based on the analysis of collected data, threshing activity was selected as the focus of the studio research project. The factors and drivers from the framework were used to develop ideas in multiple directions and to make design choices while evaluating and selecting concepts for thresher development. Mind maps, morphological charts, sketching, CAD, and quick prototyping have been used to develop, test, and refine concepts. An iterative design process was followed to create multiple concepts and four prototypes which helped inform and refine the final concept solution of novel rice threshing equipment.

The research has led to the generation of a design framework that allows for designing context-specific, human-centred interventions in farm equipment for small and marginal Indian farmers. The design framework has been verified during the steps of the project-based iterative design approach. This has led to the design of a low-cost, portable, human-powered rice thresher which considers the locally available materials as well as skill sets of fabrication and repair while allowing ease to learning and operating. The framework developed to design these type of interventions would help other researchers, designers and engineers to work more effectively in the farming domain. In the long run, the research aims to improve small farmers' livelihoods while improving food security.

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Abbreviation, Notation, and Nomenclature

BAIF: Bharatiya Agro Industries Foundation
BoP: Bottom of the pyramid
CAD: computer-aided design
CHC: custom hiring centre
COVID: Coronavirus disease
DBR: Design-Based Research
DeF: Design Futures
FAO: Food and Agricultural Association
FBS: function-behaviour-structure
GDP: Gross Domestic Product
GI: Galvanised Iron
GOI: Government Of India
ICSID: International Council of Society of Industrial Designers
IDFC: Infrastructure Development Finance Company
IDSA: Industrial Designers Society of America
IITB: Indian Institute of Technology Bombay (IITB)
IRRI: International Rice Research Institute
MS: Mild Steel
MSD: musculoskeletal disorder
MSP: muscular-skeletal pain
NGO: Non-governmental organisation
NMAET: The National Mission on Agriculture Extension and Technology
PET: Polyethylene terephthalate
RtD: Research through Design
SMAE: Sub-Mission on Agriculture Extension
SMAM: Sub-Mission on Agricultural Mechanisation
SMPP: Sub-Mission on Plant Protection and Plant Quarantine
SMSP: Sub-Mission on Seed and planting Material
UNIDO: United Nations Industrial Development Organisation

Declaration

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Date: 16.12.2022

1. Introduction

1.1 Research background

1.1.1 Agriculture in India

India is traditionally known to be a diverse, multicultural, multi-linguistic country that is agrarian at heart. It is estimated that almost half of the population of this country directly as well as indirectly depends on agriculture and allied activities for their livelihood. The importance of agriculture as a source of livelihood becomes even more apparent in rural India, with fifty-seven per cent of the population employed in the sector (Grant Thornton India Ltd., 2015). Yet, agriculture as a sector contributes only twelve per cent to the gross domestic product (GDP) of India (Ministry of Agriculture and Farmers Welfare, 2016). The steady decline of the sector's share in GDP, along with factors like an increase in the number of small and marginal landholdings as well as the casualisation of agricultural labour could be considered significant indicators of agrarian distress (Mishra, 2010; Rao, 2010).

1.1.2 Agrarian distress

Agrarian distress in India can be broadly ascribed to a few significant factors including but not limited to complex relations between fragmented landholdings (i.e. a piece of land that is owned or rented), climatic variations, lack of credit, and post-harvest losses (Pai et al., 2021). These factors, along with the diversification of agriculture and a lack of alternative off-farm employment (Ministry of Agriculture and Farmers Welfare, 2016), contribute to the distress. In addition, inefficient supply chains, volatile markets, deterioration of land and water resources, lack of appropriate technology, and low income are also contributing factors (Dev, 2011; Ministry of Agriculture and Farmers Welfare, 2016). These issues collectively create much stress on the livelihood of farmers, especially farmers with small and marginal landholding.

1.1.3 Challenges faced by small farmers

Farmers who own landholdings of less than one hectare and between one to two hectares are classified by the Indian government as marginal and small. These farmers collectively represent 86.21 per cent of all Indian farmers, with a 47.34 per cent share of the total area (Ministry of Agriculture and Farmers Welfare, 2016). The number of small farms and farmers is steadily increasing due to the fragmentation of landholdings and land division among children with each new generation, (Pai et al., 2021). Along with the rise of small farms, the average size of the farm has reduced from 1.15 ha in 2010-11 to 1.08 ha in 2015-16 (Ministry of Agriculture and Farmers Welfare, 2016), which can impact no just the yield but also the farmer's ability to afford farm inputs.

Small farm cultivation can be a challenging process. Some of the major challenges are low yield with high input cost, unavailability of appropriate technology, lack of capital to afford machinery and its maintenance, climate change, and a lack of water resources (Dev, 2011; Ministry of Agriculture and Farmers Welfare, 2016; Grant Thornton India Ltd., 2015; Singh et al., 2002). These challenges are further exacerbated by issues like low literacy rates as well as a lack of awareness about government policies, schemes and available modern technology. In rural areas, the low literacy rate and low level of education also become a hurdle to the effective dissemination of technology and knowledge.

1.1.4 Cropping patterns

Farmers usually tend to shift from purely subsistence farming to a combination of subsistence and commercial farming to increase their income (IDFC Rural Development Network, 2013). This shift of cropping to meet market demands leads to increased production of non-food and cash crops while reducing the cropping area for food crops. This shift to commercial farming also tends to carry a much higher risk of losses due to the failure of crops and market volatility due to global and local factors.

Small and marginal farmers usually opt for a safer route of increasing income by growing vegetables as commercial crops apart from the usual farming of rice and wheat. The intercropping of vegetables with grains is labour-intensive but provides quicker and more regular returns (IDFC Rural Development Network, 2013). Irrespective of the cropping pattern, by and large, rice tends to be the most ubiquitous crop and essential crop for small farmers across the country, with almost four hundred and thirty varieties and hybrids. Rice is also a favoured crop as by-products of rice cultivation have multiple uses apart from the grain. For example, the rice straw that's obtained after threshing the grain can be used as feed for cattle, as a fuel source, as a bio fertiliser and for thatching roofs. The grain straw, when chopped, can also be used for mushroom cultivation and in the paper industry, which becomes a secondary source of income.

However, rice is a labour-intensive crop, especially since small farmers still tend to use traditional methods for activities like transplanting, weeding, harvesting and threshing. Threshing, in particular, is an activity with a higher amount of grain losses and a higher rate of injury due to existing machinery or lack of appropriate machinery. There is an urgent need for appropriate technology, better institutional support, new robust farming strategies to support small and marginal farmers and in turn prevent a food security crisis in the future (Pai et al., 2021).

1.1.5 Small farm mechanisation

Small farmers tend to rely on locally manufactured hand tools and traditional farm implements like the wooden plough (Pai et al.,2021). In rural India, most local artisans lack modern technical capabilities of design as well as manufacture of farm implements. Therefore, these artisans might not be able to adhere to safety and design standards. These deficiencies in farm tools, along with high rate of work and an awkward posture lead to most of the injuries and musculoskeletal disorders (Nag and Nag, 2004).

Most small and marginal farmers lack financial stability and make do with a limited capital (Pai et al. 2021). Hence, they are not able to afford cost of purchasing farm equipment or running costs of fuel and electricity (Ministry of Agriculture and Farmers Welfare, 2016). Modern large farm equipment like tractors and combine harvesters cannot access some small farms due to the lack of approach roads. Though farm implements tend to reduce drudgery while enhancing efficiency, small farmers struggle to balance crop yield with investment in farm equipment (Pai et al., 2021). Many farms are too small to amortise large equipment because the efficiencies the equipment offer cannot be realised over a single hectare. A gap exists in the market between simple, cheap hand tools and costly, large-scale powered tools like tractors.

1.2 Research Challenges and need

Due to the lack of appropriate technology that can bridge the gap between equipment utility and cost on one hand and income from farms for small farmers on the other, there is a need to develop low-cost, context-specific tools which can be disseminated easily among small and marginal farmers.

Since India is a culturally diverse country, this diversity is also reflected in the way agricultural methods, traditions, techniques and tools vary from region to region, especially amongst small and marginal farmers. Hence, there is a need first to understand the environment and requirements of farmers of each region to generate a user-centric, context-specific solution.

In order to generate such solutions in the farm equipment domain for small farmers, it is crucial first to capture and understand the needs, wants and aspirations of small and marginal farmers. Industrial Design is defined by the Industrial Designers Society Of America (2022) as a professional practice where the aim is to improve life through providing lasting value and experience using the design of objects and services. Since Industrial Designers try to create value in artefacts considering the needs and wants of both the user and the manufacturer, it is a suitable approach to understanding values to create effective interventions in farm equipment for small farmers.

1.3 Scope of the research

The scope of this research is limited to using a research through design approach to generate a framework for design intervention in the broader area of farming. This research then led to a studio project approach where the researcher has used industrial design, and design engineering methods as well as processes in the post-harvest operation of rice threshing to generate a threshing solution. The research, in terms of geographical area, is also restricted to the west Indian zone of Coastal Maharashtra and Goa due to proximity to the location and language compatibility of the researcher. However, the research output is designed to be scalable and adaptable to fit agricultural trends and techniques used by small and marginal farmers of India and in comparable scenarios worldwide.

1.4 Research Aim and objectives

The research aims at developing interventions that can ameliorate small-scale farmers' needs and wants concerning farm implements. Two primary objectives define the research:

1. To develop a design framework which could help other researchers, designers and engineers to work more effectively in the design and realisation of farm equipment.
2. To design and develop appropriate, affordable, and context-specific rice threshing solutions for small Indian farmers.

1.4.1 Research hypothesis

This research posits that a design intervention for low-income economies in the farming domain would be easier to disseminate and succeed if it is driven by context-specific design values derived from understanding the needs, wants and aspirations of users at a local level which are then used for enhancing the productivity using a designed response to an identified problem.

1.5 Research design and methodology

This study uses design methods to understand the domain of small farming and the needs of small farmers. This was used to generate and refine a list of design drivers and frameworks that could help generate farm equipment solutions. The framework was tested using a studio project method where a low-cost threshing solution using the design drivers and framework was generated.

A methodology of research through design was followed. The insights and decisions taken during the studio research process of developing the thresher were also simultaneously used to validate and refine the design drivers and framework for design intervention.

1.6 Thesis structure

This exegesis is composed of seven chapters (Fig 1.1).

Chapter One introduces the state of Indian agriculture, the challenges faced by small and marginal farmers and the need for small farm mechanisation. It also introduces the research's need, aims, and methodology used for the study.

Chapter two is a literature and artefact review. It provides an overview of existing small farming trends, especially regarding the use of farm tools, and provides an overview of the feminisation of agriculture. It then details some of the existing design approaches that could be pertinent for the design of farm tools for small farmers. It covers approaches to engineering design, Industrial design, appropriate technology and grassroots innovation. This is followed by a study of traditional tools as well as threshing tools used by farmers and the use of pedal power for threshing. The chapter ends with the identification of gaps and needs for human-powered, gender-friendly equipment for small farmers.

Chapter three presents an overview of the research design, methodology and design processes followed during the course of the study. It provides a summary of the methods used for both the theoretical research and the practice-based studio research project, along with the selection and justification of the approach chosen for design intervention.

Chapter four explores avenues of design intervention in farming. The chapter details how data obtained through the study of literature and artefacts, field visits, and observations were used to generate a morphological map and overlays to visually represent stages of farming, activities and tools used by small farmers. It uses the findings and insights gained through the research and the visualisation to identify, define and categorise 26 factors that need to be considered while designing and developing farm equipment for small farmers. The chapter concludes with the identification of the threshing process and the justification of designing a rice threshing solution as part of the studio research process. The chapter also provides a product design specification that was used as a guide for subsequent steps in the design process.

Chapter five details the stages of development for generating a low-cost, bicycle-powered thresher. The chapter explains how alternative solutions were generated for each module of the thresher, and concepts were created and evaluated. Then the design work and further fieldwork, interviews, and study of artefacts were used to further refine and categorise the 26 factors into six design drivers and generate framework structures that could aid the design process.

Chapter six details the process of fabricating the prototype and subsequent field testing to validate the design against the product specification generated in chapter six. The chapter also details the outcomes of the field testing and the incorporations of lessons learnt to generate a refined modular thresher design with add-ons to aid in power transmission depending on the need of the user.

Chapter seven discusses the outcomes of research and design work conducted during the study. It describes the usefulness and effectiveness of the framework for design intervention in farm equipment. It also uses the design outcome of a low-cost human-powered thresher and its possible use and benefit of informing design decisions for making similar interventions for other farm activities. It summarises the findings and justifies the need for developing low-cost, context-specific, gender-friendly solutions for low-income farm economies of India and places the outcome with respect to the gaps identified during the study of literature and artefacts. The chapter concludes the research and answers the overarching research question. It also reflects upon the contribution to knowledge and the limitations of this research while providing possible scope for future work.

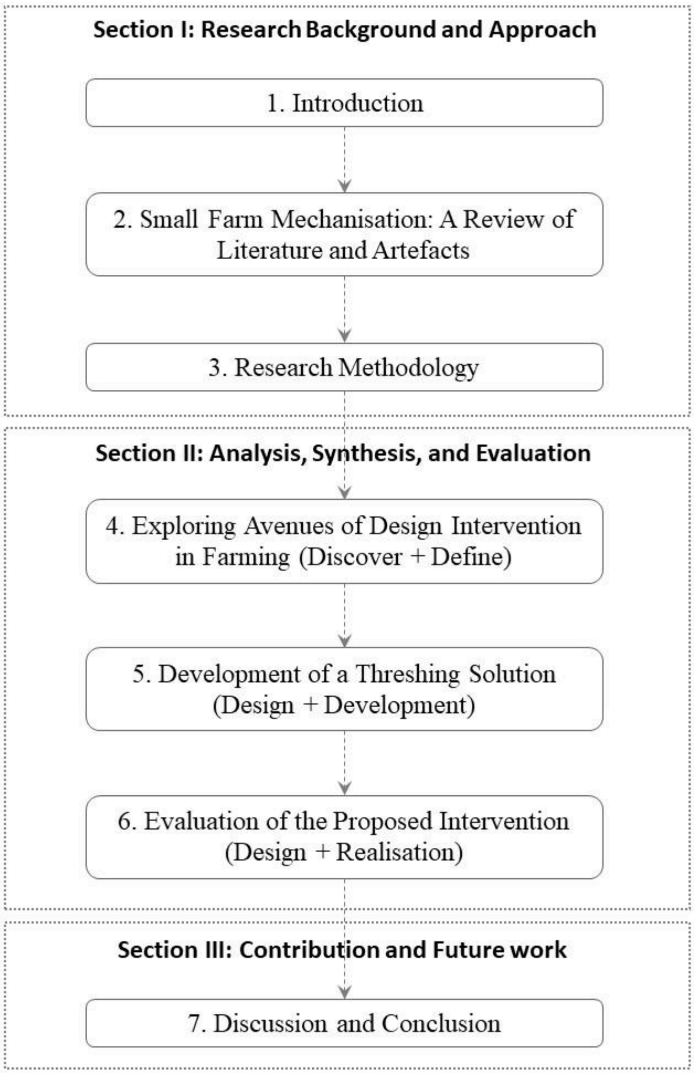


Figure 1.1: Overview of the exegesis

2. Small farm mechanisation: a review of literature and artefacts

2.1 Chapter objective and structure

The previous chapter provided a background and an introduction to the research topic along with an overview of research aims and exegesis structure. This chapter (Fig. 2.1) reviews and studies the existing literature and artefacts which form the bases of subsequent research inquiry. The chapter highlights topics around small farmers and mechanisation, followed by approaches to the design of farm tools and human-powered farm solutions to find gaps, opportunities and possible design directions. The chapter concludes with knowledge gaps and research questions.

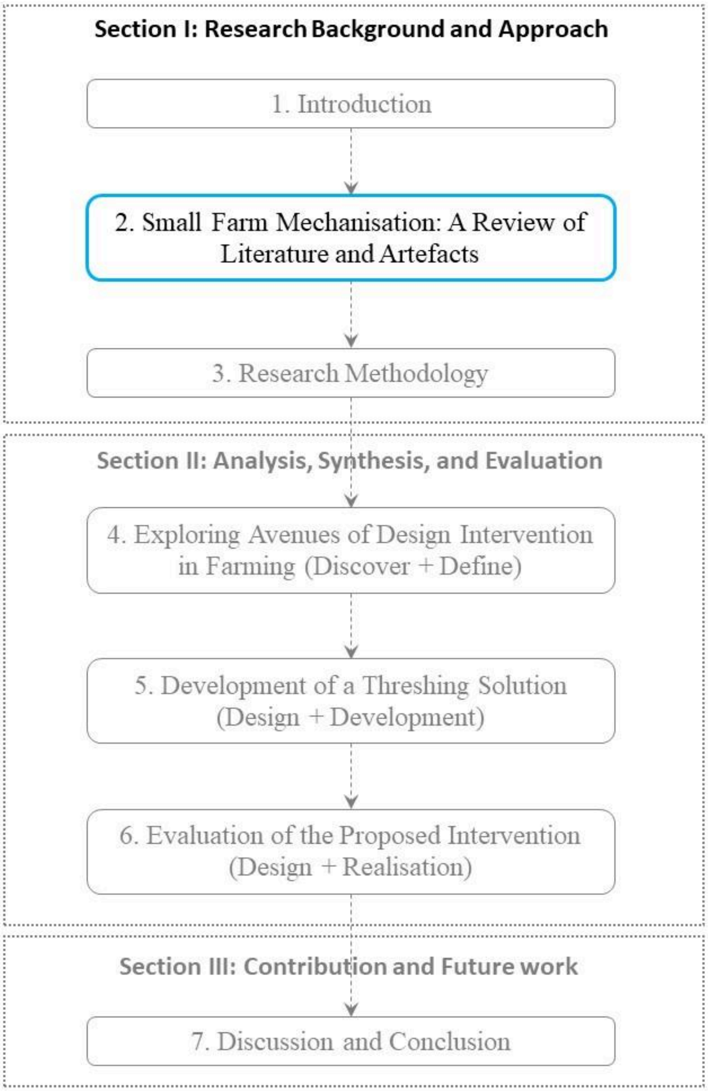


Figure 2.1: Overview of the exegesis - Small Farm Mechanisation: a Review of Literature and Artefacts

2.2 Small Indian farmers and mechanisation

Indian small farmers depend on their land for livelihood and sustenance. The cropping patterns on small farms are determined primarily based on household food needs. Small farmers significantly contribute to the crop diversification as almost four-fifths of their farm area tends to be used for food crop cultivation (Dev, 2011). An average household size of small farms tend to be four to five people. Since these farmers find it difficult to afford outside labour, they tend to rely predominantly on the household for farm-labour requirements (Pai et al., 2021). Small and marginal farms tend to be more efficient in terms of yield value per input costs than commercial farms at cultivating crops and management of livestock as they depend on the land for sustenance. This is due to the reliance of commercial farming systems on inputs like purchased seeds and chemical fertilisers, which in turn increases the cost incurred. However, due to the small land size, the income generated is insufficient for the family (IDFC Rural Development Network, 2013). Some of the small farmers work larger farms as agricultural labourers as only 47% of rural households own land (Government of India, 2011).

According to India rural development report 2012-13, Indian farms used to follow a zamindari system (wealthy landowning aristocrats overseeing a large group of peasants), till it was abolished during land reforms in 1951 (IDFC Rural Development Network, 2013). The land reforms and then the green revolution brought about profound changes in the agricultural economy. Land reforms during 1950-70 protected land rights and provided access to information and policies, whereas the green revolution increased farm yield, food security and economy through an influx of agricultural technology. However, due to increasing land fragmentation, the increase in yield due to the influx of technology was offset by small farmers losing purchasing power. The over-dependence on hybrid seeds, fertilisers, and pesticides introduced during the green revolution increased the input costs while deteriorating soil and the effects are more prominent as the farm scale reduces.

To deal with increased input costs, medical needs and massive expenditure on ceremonies and marriage due to cultural and social pressures, a small farmer ends up borrowing money. However, due to a lack of awareness as well as access to formal micro-credit systems, most small farmers take credit from money lenders instead of formal institutional sources (Dev, 2011). Since these farmers often do not have assets for collateral and clear land titles, they end up paying higher interest rates and are subject to forced loan recovery measures.

Crippling debt and confiscation of land during loan recovery are considered leading causes of farmer suicides. Approximately 198,000 (one hundred ninety-eight thousand) farmers committed suicide during the period from 2001 to 2012 (IDFC Rural Development Network, 2013). The number goes even higher if the suicides of family members, farm labourers and artisans like weavers and carpenters are considered as they depend on farmers for livelihood in rural India.

Apart from debt, small farmers are also more susceptible to the deterioration of natural resources and problems arising out of climate change. Since only 9% of rural households own any irrigation equipment, small farms are dependent on rain and groundwater for irrigation (Government of India, 2011). Rising temperatures and overdependence on groundwater have led to the depletion of natural water resources. Also, the soil is constantly degraded over time due to overreliance and overuse of certain fertilisers (Reji et al., 2019). This degradation has led to a drought-like situation during summers in the country and has contributed to reduced yield. Also, there is a rising conflict for natural resources as a requirement by other sectors of the economy increases. The lack of access to resources in some cases is also due to a village's cultural and traditional power dynamics.

Farming in rural areas remains deep-rooted in traditions which results in social exclusion of castes and gender. The discrimination of women and lower castes by upper-caste males in villages has led to a large section of the rural population living in poverty with a lack of access to education, healthcare and social services, which limits their influence in social, political and economic spheres (IDFC Rural Development Network, 2013). This discrimination leads to lower caste farmers having the most infertile and difficult soil along with a lack of access to resources, further compounding the challenges. Also, most of the tribal farmers face exclusion from development and education as they live in remote locations with very limited access to any institutional infrastructure.

Small farmers also face issues of volatile prices and lack of market access. There is very little value addition during post-harvesting operations and logistics. A large number of intermediaries also dominate the current supply chain system, which increases inefficiency and leads to a high cost for the end customer and low prices for farmers (Reji et al., 2019). The middlemen end up disproportionately benefitting from most legislative measures compared to small farmers due to illiteracy and lack of awareness.

Apart from awareness of new, effective farming techniques, an assimilation of appropriate technology and the adoption of robust farming practices to support small and marginal-scale farmers would help in improving their livelihood. These interventions also need to be context-specific and should take into account the existing cropping patterns, farm tools, and trends.

2.2.1 Cropping patterns of Small and marginal scale farmers

Small and marginal farmers, especially in the western zone of India, tend to use a cropping pattern of food grain, pulses and vegetables. These farmers tend to rely predominantly on rice for sustenance. *Oryza sativa*, the rice plant, has a wide range of physical adaptability and may be grown in a variety of soil and climatic circumstances (Directorate of Rice Development, 2014). With more than 430 different rice varieties and hybrids, it is India's most widely grown and significant food crop. Rice is mostly grown under rainfed conditions from June through August and from October through December. Small and marginal-scale farmers can make good money from rice, and in addition to the grain, the numerous by-products of rice production offer a variety of uses. For instance, rice straw, after threshing the grain, can be utilised as a fuel source, for thatching roofs, as a source of food for animals in drought, and as a biofertilizer. Additionally, the paper business and the mushroom industry require chopped straws.

Small farmers tend to shift to commercial farming from subsistence farming to increase income and to meet market demands. This shift has led to an increase in the production of non-food and cash crops which in turn leads to reduction in the area under food crops. Due to crop failure and market volatility, the shift to commercial farming tends to carry a higher risk of losses. Apart from grain crops like rice and wheat, small farmers usually grow vegetables as commercial crops. The vegetable crops provide more regular and faster returns on investment although they are more labour-intensive (IDFC Rural Development Network, 2013).

2.2.2 Existing farm tools and techniques

The Indian government is consistently creating policies and schemes through the Ministry of Rural Development and the Ministry of Agriculture to strengthen the rural areas and agricultural sector, respectively. The government is aiming to promote critical inputs, improved agricultural practices and appropriate technology with a focus on farm mechanisation (Grant Thornton India Ltd., 2015). The National Mission on Agriculture Extension and Technology (NMAET) aims to improve agriculture extension and technology through four sub-missions. These are Sub-Mission on Agriculture Extension (SMAE), Sub-Mission on Seed and planting Material (SMSP), Sub-Mission on Agricultural Mechanisation (SMAM) and Sub-Mission on Plant Protection and Plant Quarantine (SMPP). SMAM is a centrally sponsored scheme for promotion of farm mechanisation, which was implemented in 2014-15. The main components of the scheme are training, testing, and demonstration of farm equipment, the establishment of custom hiring centres (CHCs), subsidy through the state department of agriculture for purchase and distribution of farm implements to farmers along with the promotion of post-harvest technologies. (Department of Agriculture, Cooperation and Farmers Welfare, 2018)

A 2018 final monitoring, evaluation and assessment report of SMAM concluded that most small farmers who utilised improved farm equipment from CHCs were able to increase productivity and reduce the cost of production. However, even though 62.7% of CHCs covered farm operations in a ten-kilometre radius, farmers from faraway places were not interested in availing of services. Field operations like seeding, weeding, fodder cutting and harvesting were still performed manually on small farms. Also, increased productivity did not necessarily lead to increased income due to the lack of technologies that prevent post-harvest losses and add value addition to produce and by-products. (Department of Agriculture, Cooperation and Farmers Welfare, 2018)

Most small farmers rely primarily on traditional tools and methods despite a thrust towards farm mechanisation like sickle and manual weeders (Fig. 2.2). The reluctance to shift to modern machinery and tools stems from their inability to afford new equipment. The traditional tools are typically manufactured and maintained by village artisans. Since these artisans capability of modern methods of design and manufacture and hence rely on traditional methods to make these old farm tool designs, the deficiencies and lack of consideration to safety and ergonomics leads to injuries on farms (Pai et al., 2021). The lack of appropriate tools and ergonomic considerations leading to injuries becomes even more conspicuous as the involvement of women in agriculture is increasing.

Figure 2.2: Tools used by tribal farmers from Jawahar village, Maharashtra, India (Own photo)

2.2.3 Feminisation of agriculture

Rural India is traditional and highly patriarchal. Over the years, this has led to the exclusion of women from decision-making and owning farms. Rural women are expected to handle household duties, livestock management and farm activities. Women farmers are mostly considered as workers and not farmers despite handling most critical farm activities like sowing, weeding, harvesting, and cleaning of crop output (Chayal et al., 2017; Rao, 2011; Dev, 2011). These tasks do not require a lot of physical strength. However, they involve a lot of drudgery, long hours of work, and require hand skills (Pai et al., 2021). In peak as well as lean agricultural seasons, women spend approximately seven to eight hours and four to five hours a day respectively out of fourteen hours working on agriculture while doing all three activities of farm household and livestock management, with one hour of break (Suthar et al., 2017).

Farm women have very little influence on the decision-making process in agriculture and remained invisible farmers until the last few years. Due to the Agrarian crisis, most men tend to migrate to opportunities in either urban areas or non-farm rural employment. The migration has led to a rural labour force where women are more likely than men to be working in agriculture along with an increase over time in the proportion of agricultural work done by them (Pattnaik et al., 2017; Dev, 2011; Ministry of Rural Development, 2019; Ministry of Agriculture and Farmers Welfare, 2016). Indian Agriculture is thus becoming increasingly feminised. The majority of the rural women are illiterate, lack knowledge of modern farm techniques, face dominance by males and have restricted mobility due to several cultural taboos (Chayal et al., 2017; Majumder et al., 2017). There is a need for policy changes leading to social inclusion, recognition of their land rights and education of rural women in order to improve the state of Indian agriculture.

Most of the old as well as new agricultural equipment is primarily designed for men (Criado-Perez, 2019). However, the majority of women farmers still use traditional tools and techniques which leads to health risks due to increased drudgery, low efficiency, and less income. The lack of attention to ergonomic design while designing these tools also leads to a higher risk of farm injuries for women (Pai et al., 2021). There is an urgent need for women-friendly tools and equipment which will reduce drudgery while increasing efficiency, and productivity and minimise musculo-skeletal disorders (MSDs) and muscular-skeletal pain (MSP) (Singh et al., 2017; Suthar et al., 2017; Ministry of Agriculture and Farmers Welfare, 2016; Nag et al., 2004; Majumder et al., 2017).

2.3 Approaches to design of farm tools

Design as a noun is a broad and often difficult-to-define term due to its multiple connotations depending on the context of use. Heskett (2002) playfully describes this issue by stating, *"Design is to design a design to produce a design"*. Where the first instance is a noun for the general domain, the second is a verb for action, third and fourth are again nouns for an idea/concept and a finished artefact respectively. Design also can be broadly categorised into two parallel tracks, one which uses training and draws from technical disciplines to facilitate the manufacturing of user-centric artefacts, using an understanding of engineering, ergonomics and product design principles. The other is more inward-looking and draws from the practice of creative arts to generate a visual form that elicits some form of visceral response from the audience of the work.

In this research principles of industrial design were followed and values of grassroots innovation were used to generate ideas; these ideas were then realised and evaluated using the process of design engineering and appropriate technology.

2.3.1 Engineering design

Engineering design is typically defined and framed in the context of 'problem-solving' and is defined by the Collins English Dictionary (2022) as:

"the art or science of making practical application of the knowledge of pure sciences".

Going further Blumrich (1970) describes engineering design as "A process that establishes and defines solutions to pertinent structure for problems not solved before, or new solutions to problems which have previously been solved in a different way".

An engineering designer usually using the processes of testing, evaluation, and analysis will try to balance product function and production (Kimura, 1977) to achieve the required outcome. The engineering designer will focus primarily on innovation, technology and function (Eekels, 1994) unlike an industrial designer who tends to be concerned with holistically working on aspects of a product that enhance user experience (Ulrich et al., 2011).

Most existing farm equipment currently available to small and marginal farmers has been a result of an approach that is focused on engineering design. However, traditional farm tools were an outcome of work of village artisans which will be explored in the later sections. Though this approach can produce effective and efficient technology capable of achieving the intended outcome, the lack of sufficient sensitivity to human factors and socio-cultural realities can act as major hurdles toward technology dissemination. Having said this, an engineering approach of converging to an optimised, effective and efficient solution does lend itself well when one needs to realise the concepts and ideas generated in the process of problem-solving. It ensures that the generated concepts are not only manufacturable, but are also robust, and functional.

2.3.2 Industrial Design

Like engineering designers, industrial designers also focus on functionality and manufacturability of the product, however they follow a human-centred approach to create lasting value and experience that a product or a service for the end-users (IDSA, 2022). Industrial design during the days of its conception in the early 19th century was considered to be a professional practice balancing between the fields of art and engineering. Industrial designers would typically make choices and take decisions with a focus on aesthetics and styling in a product development process. Industrial design practice, however, has now shifted to creating value through integrating, and encapsulating functional, emotional and social utilities into new products to improve impact of design output (Heskett, 2017).

In modern times, the process of industrial design typically involves understanding the context and user through observations and analysis of tasks in order to define the problem. The next step usually is ideation and concept development, which are diverse ways of solving the defined problem. The next step is considered to be one of the most critical steps in the process by Archer (1964) and French et al. (1985), this involves generating a feasible solution through evaluation, reduction and refinement of the concepts generated in the previous step. Jones (1992) also highlights the need to then evaluate these probable feasible solutions further to refine and realise the design as an usable artefact.

Industrial designers unlike engineering designers thus start with a divergent approach (Design Council, 2019) to problem solving. The purpose of the approach is to foster creativity and innovation in order to conceive unique propositions for artefact generation. In order to however, then converge to an optimal solution, the designer takes help of a user-centred approach that involves understanding of the behaviour and habits of the user (Bhamra et al., 2016). These lead to generation of design values and drivers which also are derived partially from existing research involving users and the context. This approach helps create a context-specific design that is sensitive to users needs, wants and limitations (Abras et al., 2004). Industrial design is thus well suited to re-frame and re-imagine complex (Kandachar, 2012) and difficult to define ‘wicked’ problems (Rittel et al.,1973) in order to generate new ideas that are optimal and innovative (Pannozzo, 2010).

However, while designing for marginalised communities, especially in low income economies like small and marginal farming, one needs to also focus on involving the users in certain stages of problem identification and solution generation. Hussain et al. (2012) and Sanders (2002), both stress on the need for blurring the lines between designers and researchers along with involving the user in the design and development process to co-create an optimal solution. Hence, while designing farm equipment, design methods and processes of workshops, focus groups, observations and interviews lend themselves well to understanding and defining the problems of farmers whereas, prototyping and field testing becomes paramount while evaluating the efficacy of the generated solutions.

2.3.3 Appropriate technology and Design for Development

According to Date (1984), development for a society or a community should not be just industrial growth or technological improvements but should involve a change in the right direction at the desirable pace. For this to happen, the socio-economics and cultural contexts need to be taken into consideration along with holistic design and production processes which are sustainable. Society ideally should try for sustenance by finely balancing the four aspects of resources, production, consumption and waste (Date, 1984).

Papanek et al. (1972) implored designers and engineers to keep users' needs at the forefront in order to generate technology that was appropriate. Schumacher (1973), further expanded on this thought by suggesting that one needs to create solutions as if people matter and suggested generating ‘intermediate technology’ to bridge the gap between existing techno-centric solutions and traditional solutions used by users on the ground. In 1979, the International Council of Society of Industrial Designers (ICSID) and United Nations Industrial Development Organisation (UNIDO), declared that design could be used effectively to improve quality of life in the developing world.

Papanek (1985), posited that design should work towards needs instead of (often artificially generated) wants. Though this statement is motivational, it failed to account for the needs of manufacturers in capitalist, commercial systems (Er, 1997). In order to bridge this gap, Er (1997) suggested shifting from Papanek’s Socio-cultural dimension to a socio-economic model of approaching design for marginalised and the underserved communities. Appropriate technology typically, is one which is appropriate for a given situation (Smillie et al., 2000).

Schumacher (1973) had suggested generating ‘intermediate technology’, which would not only be a lot cheaper than sophisticated, capital-intensive modern solutions but would also be more productive than a traditional, indigenous solution. Since ‘intermediate technology’ was considered to have connotations of inferior technology that did not consider social and political factors (Kaplinsky, 1990; Willoughby, 1990; Hollick, 1982), appropriate technology was considered to be a more suitable term. Jequier (1979) aptly suggested that appropriate technology should not be considered as contradictory to modern technology. Especially when this technology supports local development while complementing existing modern solutions (Akubue, 2000). However, the lack of an effective user feedback loop was identified as a major hurdle by Donaldson (2006) in existing approaches to solving problems in such communities.

The lack of feedback loop for the designer and thus the problems arising from it were made evident through case study of agricultural products donated by Non-governmental organisations (NGOs) to farmers along with setting up of manufacturing and distribution units. (Donaldson, 2006). According to Donaldson (2006) difficulty in getting accurate feedback not just due to complexity of development of product, but also because of the pressure of publishing positive results on the NGO. Prahalad (2008), suggested a Bottom of the pyramid (BoP) approach to resolve such problems. The BoP approach involved empowering local businesses and markets to generate affordable solutions to foster entrepreneurship and growth.

In order to provide such appropriate solutions and to understand the factors affecting a community, a researcher and innovator should then ensure that all the insights and the needs are correctly identified. This is only possible by observing and articulating the changes in a community and how they affect a user's needs and wants. This firm understanding of ground reality using methods like ethnography, semi-structured interviews, contextual inquiry, grounded theory etc. would enable a firm understanding of concepts and would ensure that solutions developed are truly user-centric and not just business or industry-centric. One also needs to take into account affordability and local skill sets to ensure technology dissemination by empowering local communities to manufacture and distribute the artefacts. There are multiple design approaches that one can take to address this, namely social design, co-design, and participatory design among others.

Social design could be considered an approach where design methodologies address and ameliorate issues to bring about social change. Hence, social design usually employs Human human-centred design (HCD), collaborative, and participatory design methodologies at various stages. The critical aspect of social design is creating social change, not primarily through solving social problems but by creating opportunities to generate services, networks, and systems that aid positive chang. Similarly, co-design or co-operative design is a methodology considered a “collective creativity as it is applied across the whole span of a design process” (Sanders & Stappers 2008, p. 6).

Existing design methodologies are generally criticised due to inequalities arising from unequal technological, social and cultural capital and power dynamics between the designer and the people for whom an artefact is designed (Papanek et al., 1972). The social design approach provides a holistic lens to look at wicked or ill-structured problems in the community. Communities and societies with multiple cultures, languages and traditions require a cautious approach. One needs to ensure that existing inequalities of gender, colour, race, caste, and religion, which exist in any social setting, do not also transfer to the design process while co-creating. The success of co-creation also depends on the different values and perspectives stakeholders bring. This is very useful during the process of understanding and defining aspects of the problems along with users' needs, wants, and aspirations. Co-design also aids during the evaluation of existing and new solutions.

Participatory design is similar to co-design, an approach that tries to involve all stakeholders at the required stages of a design process to ensure that their needs are met. In this approach based on the context of the design problem, various stakeholders are identified by the designer and then involved at stages of user study to understand needs and wants, at the ideation and concept development stage to identify and evaluate emerging solutions and at the testing phase for usability analysis and validation. This enables the design solutions to meet the needs effectively and ensures or at least encourages easier adoption of solutions by stakeholders as they feel empowered and involved in the creation process.

However, unlike co-design, participatory design also tries to balance the opportunity provided for stakeholders to be a part of the process and constraining the stages of the process where they need to be involved. A lack of awareness and technical knowledge might affect the quality of ideation or concept development. Hence, the need to identify the right stakeholders and the right amount of their involvement in a design process needs to be decided based on the context of the problem being solved. The designer is then needed in a role where this active feedback and stakeholders' inputs are analysed and adopted

2.3.4 Grassroot innovation

Grassroot innovation is a phenomenon where sustainable solutions are generated through a bottom- up approach. Hess (2007) and Tang et al. (2011) argue that grassroot innovation typically is driven by civil society driving a social change through technological advancement instead of large organisations and government. However, despite being a bottom-up approach, it need not stem only at the community level. The most widely referred definition by Seyfang et al. (2007), defines grassroot innovation as:

> "*...a novel bottom-up solutions that are developed for sustainable consumption and development while responding to values, interests and situation of local communities by a network of activists and organisations."*

Grassroot innovations, thus can emerge at individual, group or societal level. However, all grassroot innovations are usually firmly rooted in a bottom-up, context-specific approach with an overarching goal of sustainability at its core.

Grassroot innovations have not been historically considered to be a source of innovation according to Grabs et al. (2016). However in India, movements like the honey bee network (Gupta et al., 2003) and the people's science movement (Kannan, 1990) have been a good source of documentation and inspiration of local sustainable innovation. These innovation systems differ from mainstream innovation as they stem from social enterprise, cooperatives and informal, often voluntary community groups (Martin et al., 2015) and usually operate without commercial or state interests. (Yalçın-Riollet et al., 2014). However, mainstream and grassroot innovations can be complementary in nature (Ornetzeder et al., 2013). Further, Jain et al. (2012) feel that both the grassroot and mainstream approach to innovations tend to have the same basic requirements of an entrepreneurial climate along with ease of access to risk capital and essential know-how, and hence, the foundations to innovation can be eliminated or integrated.

India has a history and tradition of frugal innovation, at grassroot level, individuals and communities use makeshift work-arounds and hacks using limited locally available resources. This approach is colloquially referred to in Hindi-Urdu language as 'Jugaad'. In recent years, this approach has also been appreciated for the improvisational approach which uses alternative ways to accomplish objectives with frugal use of resources at hand (Young et al., 2012). The flexible mindset needed for this approach helps Jugaad innovators adapt strategies to contingencies in a diversity, and volatility inherent in existing economies as well as emerging markets of India (Radjou et al., 2012).

Small and marginal farmers in India also tend to use a Jugaad or a frugal innovative approach to develop solutions for their farm equipment needs. They tend to use locally available materials like metal channels, pipes, and rods along with bottles and bamboo to create basic tools like sickles, pluckers, and weeders, this aspect is further explored in the following sections of artefact review.

The National Innovation Foundation and the Honeybee Network has also identified and documented a lot of these frugal innovations across India. A common trait that these innovations have is that they are usually made using locally available materials, and fabricated using available skillset and manufacturing setups in the region. The innovations also stem from repurposing or using parts of existing machinery.

A product does not exist in isolation. The interaction between a user and a product also exists within an environment of context (Fig. 2.3). One needs to ideally consider the user, product and the context in order to design an intervention holistically. However since the jugaad approach is aimed at primarily low-cost, makeshift solutions, there are cases where one of the three aspects might not be considered. For example, if the handle of sickle or knife is made from old Galvanised Iron (GI) or Mild Steel (MS) pipe, it is difficult for farmers to use in regions with higher temperatures or humidity. A better approach will be to use a thermally comfortable material like wood. In this example considerations about both user and the environment are not implemented during the act of creating the product. However, the product does hold value as a solution during other circumstances or in other regions, and also holds value for all in terms of its affordability and ease of manufacture.

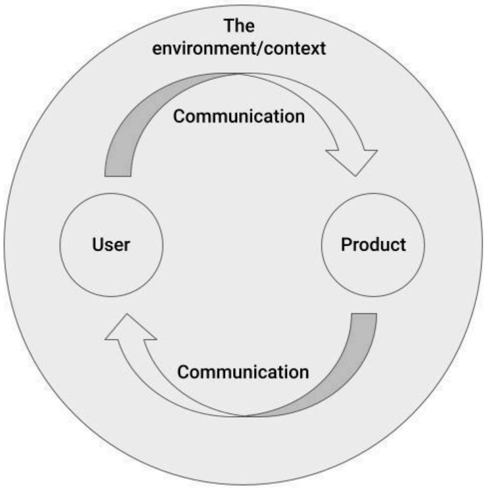


Figure 2.3: Relationship between product, user and environment. Adapted from Murdoch (1983).

2.4 Human powered solutions in small and marginal Indian farms: a review of artefacts

The Food and Agriculture Organisation of the United Nations (FAO) classifies farm mechanisation into three broad categories based on human, animal, and mechanical power sources. These categories are a) hand-tool technology, b) animal - draught technology, and c) mechanical power technology (Gifford 1981). Despite constant efforts for modern farm mechanisation, small and marginal farmers still tend to rely on mostly human powered manual traditional tools, with animal and mechanised power used for very few activities which require a lot of strength. Hence, this review of artefacts primarily focus on hand-tool technology, which are tools and implements which primarily use human muscle as a source of power.

2.4.1 Traditional tools used by farmers

Most traditional farm tools are made from locally available material like different types of wood, metal and strings and are produced by the traditional artisans who have generational tacit knowledge of finding the right type of material and making it for years. These artisans primarily use wood available around the village and use metal like mild steel and upcycled scrap like leaf spring and coils from old automobiles which is then tempered and quenched before use. The cost effectiveness of the tool usually takes precedence over quality and long life. One of the reasons behind this way of working and use of tools is also due to Indian culture and philosophy towards self and objects.

In India, people have a tradition of reusing and repurposing artefacts and tools once their initial purpose is no longer feasible. For example, a garment like a saree or a dhoti, which is essentially a long piece of clothing that is wrapped around, is repurposed into a towel or a bed sheet quilt. Once that purpose is served, it can then be refashioned or modified to work as curtains or a floor wipe, And the saga continues till the cloth can no longer be used. This same philosophy is also apparent in terms of farm tools where parts of tools will be repurposed or upcycled to perform a different activity. For example, the long bamboo poles which are used as a pillar for shades and threshing, can then be cut and repurposed as handles for pluckers or sickles.

In rural Indian villages, the farmers and artisans also use the locally available material and resources very creatively and effectively. For example, the wooden plough utilises quality and properties of different types of wood to make the handle, pole shaft and the main body that holds the mouldboard and the share. The metal component, also called a 'share' is traditionally forged by village blacksmiths and the wood is cost effective enough that it can be easily repaired, replaced over the years.

Along with wood and metal, artisans traditionally have also used material like bone, stone, bamboo, plant fibre and animal skin. This use of readily available local material allows farmers to quickly repair or adapt the tool for a different purpose (Karthikeyan et.al 2009). In most parts of rural India, artisans are still the primary source for production, repair and maintenance of these traditional tools. Hence it becomes important to document, preserve and protect this source of knowledge (Das et al., 2006).

India is a diverse country, with climatic and agro-economic zones changing across the landmass along with language, culture and farm techniques and traditions. However, most small and marginal farmers, by and large, use common agricultural implements like plough, spade, weeder, winnower, bamboo sieve, stone mill, and sickle (Das et al., 2006). The design of these tools has evolved over generations by experience and experiments of farmers, village artisans and small, tiny industrial units. Most of these tools are produced and maintained by cottage level and tiny industrial units made of blacksmiths, cobblers, potters, weavers, and carpenters. The skillset and tacit knowledge in these industries are usually passed in the community over generations which allows a slow iterative evolution of the artefact over a long period of time.

The description and analysis of following traditional tools is based on field observations as well as prior research conducted on review of traditional tools by Das et al. (2006), Karthikeyan et.al (2009), and Verma (1998).

Plough:

Tilling is one of the primary land preparation activities in farming where the land is ploughed and levelled to create favourable conditions for seed planting and plant growth. A plough is a wood and iron/steel implement used for breaking clods, and initial levelling of the field. These are mostly ox-driven. It typically consists of a single blade or a shoe made of metal that is connected to a wooden body. The plough also has a shaft for hitching it to oxen and a handle. The operation of traditional plough requires significant upper body strength as the manual force on the handle determines the depth of tilling.

Spade:

Along with tilling of land, farmers also have to create bunds, irrigation channels, ridges, shallow trenches and furrows. The spade is a multipurpose farm tool that is used for digging and moving soil for all of these activities. It has two primary parts, a wooden/bamboo handle and a rectangular working iron area. Farmers also use this tool to chop weeds and for moving plants and other material.

Weeder:

Weeding is one of the most labour intensive activities in farming. Small and marginal farmers either weed by hand or use a comb like metal piece connected to a wooden handle for deeper rooted weeds. However these weeders are only effective on dry land conditions. Since crops like rice are semi-aquatic, they grow best in wet land conditions where soil is submerged under a shallow pool of water. Therefore in rice farming, hand weeding is still the most commonly used technique.

Winnower:

Winnowing is the activity of separating impurities from grains and seeds. Small and marginal farmers tend to drop the grains or oilseeds from a height in the wind where lighter impurities get blown further away and the grains or seeds get collected at a different spot. A winnower is a tool that is made by weaving bamboo strips into a round or a U shaped structure. Before using it for the first time, it is also covered with a thin layer of cow dung paste that's allowed to dry completely to fill in the gaps.

Bamboo sieve and baskets:

Another method that is used to clean the grains and seeds is by passing them though a sieve to separate the harvested grains from impurities like dust and stones. This is also done using a tool made by weaving bamboo strips. Farmers also tend to primarily use baskets made of woven bamboo to carry harvested crops and grains.

Stone mill:

Milling is an activity of grinding grains and pulses to convert it to flour and crushing leaves to get an extract. Most small and marginal farmers tend to still prefer using a hand operated stone mill that is made using two circular disks of stone and a wooden handle. In some areas of India, this is permanently fixed in ground and also serves as a centre of socialising for village women. The top disc has a hole in the centre from which grain is poured while the top disc is also simultaneously rotated along the central pivot using a wooden handle. The grinding of two discs helps in removing husk and crushing the grain/leaves.

Sickle:

The sickle is the most common multipurpose cutting implement that is commonly used for harvesting and cutting of plants. It comprises a curved, C-shaped iron/steel blade connected to a wooden handle. The C-shape of the blade allows the farmer to harvest grains easily and precisely. Along with harvesting of cereals and pulses, it is also used for cutting hay for animal feed, and removing unwanted plants and bushes.

Although the traditional agricultural tools are sustainable and economical, they tend to have a shorter life and are also labour intensive. Most modern agricultural industries have tried to modify these tools to make them more affordable and longer lasting using modern manufacturing techniques and mass production. However, small and marginal farmers in most remote parts of India still tend to prefer locally manufactured goods due to lack of access and awareness.

2.4.2 Manual tools and techniques in rice threshing

Farm activities can be broadly divided into pre-production, growth, and post-harvest activities. During the literature and artefact review, the scope of the research was narrowed down to post-harvest activities, with a focus on threshing activity. Threshing is the process of separation of grain from the plant using an external combing, cutting, impact, and rubbing action or a combination of these. Threshing was selected as a focus activity since it is labour-intensive, contributes to grain losses, and has a high percentage of injury cases (Nag et al., 2004; Mohan et al., 1992). Most varieties of rice grains tend to easily detach from the panicle at a moisture content of eighteen to twenty percent. (IRRI knowledge bank, N.D.) and hence require less mechanical force compared to grains like wheat and millets. Rice threshing techniques can be broadly classified into manual, and mechanised threshing.

2.4.2.1 Traditional rice threshing methods. In India, most small and marginal farmers still tend to use traditional manual threshing methods like beating bundles of panicles on an object by hand, trampling under feet of humans or hooves of animals, using a stone roller or beating the harvested crop with a flail. However the grain collected using these techniques tends to be mixed with dirt and requires further cleaning. Grain loss also tends to be higher due to breaking, scattering or feeding by draught animals.

Traditionally in states of Maharashtra and Goa in the western region of India, small farmers tend to either beat the bundles on a wooden board or a metal drum or trample it under feet. Both these processes are extremely labour intensive, time consuming and can cause loss of grain. However, these techniques are also still preferred as the plant straw remains intact and can be then used for other purposes like thatching roofs, animal feed and use in mulch. The hay can also usually act as an additional source of income as it is used as a raw material for other industries like mushroom cultivation.

2.4.2.2 Modern manual rice threshing methods. Apart from traditional threshing techniques, rice farmers also tend to use pedal operated manual threshers and bicycle driven threshers where the panicles are held over a rotating drum with rasps, pegs or loops, while using human power to rotate the drum. By and large, modern solutions in threshing can be broadly classified into two categories, a hold-on type where the plants are held by the operator over the working area, and the feed-in type where the entire plant is fed into the machine (IRRI knowledge bank). The hold-on threshers tend to usually have a slower speed and lesser output compared to the feed-in threshers. However, small and marginal farmers tend to usually prefer hold-on threshers. The primary reasons for this preference are low cost, ease of learning and ease of operation using agricultural labourers instead of a skilled, trained operator. The secondary reason is that with hold-on threshers, the hay remains intact and is not crushed or chopped into tiny pieces. This allows the farmers to use the hay for other purposes as well as a source of additional income. The common types of mechanised rice threshers used in western india are a) motor driven hold-on threshing drum, b) use of two wheeled tractor to drive a stone roller, c) using tractor or motors to run large feed-in threshing machine, and d) combine harvesters. The commonly used manual modern rice threshing devices are as follows:

2.4.2.2.1 Manual pedal operated thresher. Manual pedal operated thresher (Fig. 2.4) consists of a drum fitted with flat bars which are in turn fitted with a V or U-shaped wire loops or pegs, a chassis, a transmission module made of gears and cranks and a foot operated crank pedal. A farmer or an operator holds a bundle of cut rice panicles over the drum while simultaneously rotating the drum using the pedal. Once the drum reaches an operational speed of three hundred to four hundred revolutions per minute, the farmer tries to bring the panicles in contact with the drum using both up-down and rotational motion with their hands. The loops on the rasp bars on the drum hit the panicles and separate the grain which gets collected in front of the drum. Most manually operated pedal threshers have an output of around 150 kg of grain per hour. These machines are also favoured as they are affordable compared to other modern threshing solutions and can be carried by two to four people as they weigh between 35 to 70 kg. However, K.S. Zakiuddin et al. posit that this type of pedal threshing while holding the plant bundle on drum is a strenuous activity due to constant leg movement needed for rotating the drum at high speed along with high grip strength required to hold the plants firmly.

Figure 2.4: Manual pedal operated thresher. Reference: Khadatkar et al. (2008)

2.4.2.2.2 bicycle powered threshing solutions. There have been attempts to create a more efficient human powered threshing solution using bicycle as a power source. In 1979, Dr. Job. S. Ebnexer proposed a concept of a dual purpose bicycle (fig 2.5). A flywheel attachment was designed that could be mounted on a bicycle. The bicycle could then work in two modes, one as a transport and also in a power take off mode.

Figure 2.5: Dual Purpose Bicycle.

Reference: *Dual purpose bicycle - appropriate technology*. Appropriate Technology - Sustainability for All. (2022, April 10). Retrieved June 29, 2022, from https://www.technologyforthepoor.info/dual-purpose-bicycle/

The attachment and modification was designed to ensure that only simple tools were needed to convert the bicycle from transportation mode to power production mode, The technology and the design ensured that local technicians would fabricate and repair it at low cost. This allowed the bicycle to be used for applications that used less than one horsepower like wood working , water pumping and peanut shelling along with rice threshing (Fig. 2.6).

Figure 2.6: Dual Purpose Bicycleconnected to a rice threshing device
Reference: *Dual purpose bicycle - appropriate technology*. Appropriate Technology - Sustainability for All. (2022, April 10). Retrieved June 29, 2022, from https://www.technologyforthepoor.info/dual-purpose-bicycle/

In 2008, a VL paddy thresher (Fig. 2.7) was developed by Vivekananda Parvatiya Krishi Anusandhan Sansthan (VPKAS) at Almora Uttarakhand, India. This was designed and developed for small farmers of North-western himalayan region of India. The thresher is designed to be operated by a single person and uses a combination of chain and sprocket system and bevel gears to transmit power from the pedals to the threshing drum. One of the major advantages of this system is the upright pedalling posture and light weight. The drum and wire loop size is also optimised using a response surface methodology (Khayer et al. 2019). This statistical methodology is used to optimise operational factors by exploring the relationship between multiple explanatory and fewer response variables. The machine also had a polycarbonate shield to prevent grain loss. The parameters of this device were further analysed using response surface methodology (RSM) to optimise the parameters of threshing drum like diameter, wire loop height and spacing etc., first by Singh et. al in 2008 where they also did a comparative test between VL thresher and the existing pedal thresher to show the performance benefits of VL thresher and then by Khayer et .al (2019) where the structural design was further optimised again using RSM and analysis of variance (ANOVA) and found that with minimal discomfort and optimum machine parameters, the machine could work with optimal capacity of 53 kg per hr.

Figure 2.7: VL Thresher

Reference: VL Paddy Thresher. Agrinnovate. (n.d.). Retrieved November 3, 2022, from http://agrinnovateindia.com/

2.5 Knowledge gap

The following gaps were identified for further research and design intervention

2.5.1 Need for appropriate, human- centred solutions

There is a need to develop low cost, human-centred, context-specific tools which respond to socio-cultural circumstances of small and marginal farmers (Satyavathi et al., 2010; Singh et al., 2002; Singh and Arora. 2017; Ministry of Agriculture and Farmers Welfare, 2016). The design process involves understanding context-specific needs as well as a human-centric iterative approach to developing interventions. Hence a designerly approach could lead to the development of an appropriate intervention for small farmers (Pai et al., 2021). The challenge is not just a technical one of developing a farm equipment but also an adaptive one where the farmers need to be willing to change or modify their existing methods in order to ensure technology dissemination. Hence, there is also a need to ensure that the solution is gender-friendly and can be adopted easily by all stakeholders in the given context.

2.5.2 Need for portable, human powered threshing solution

Most small and marginal farmers tend to favour either traditional methods (trampling with human/animal feet, beating crop on drum/flat surface, and using a flail) or manual pedal powered threshing machines. Both of these approaches are highly strenuous activities and lead to injuries (Nag and Nag, 2004). Satapathy and Sahay (1998) also noted that threshing utilises around 20% of total energy spent in farm work. There have been attempts to use pedalling and bicycle as a means of power generation, however these solutions either need major modification of the bicycle with a set-up time or utilise the parts of bicycle in such a way that it cannot be used for the primary activity of transport. Most small farms are scattered and do not have easy access to roads. There is a need for a portable, human powered solution that is both efficient and effective with respect to existing solutions.

2.6 Research objective

The research aims at designing and developing appropriate, affordable, context-specific and gender-friendly solutions for small farmers. This research also aims towards understanding the changing dynamics of needs and wants of small farmers in order to enable the generation of better solutions as well as technology dissemination. Ideally, the tools developed from this research would help in improving yield while reducing long term costs and drudgery of agricultural labour. The framework developed to design these tools would help other researchers, designers and engineers to develop effective solutions in the farming domain (Pai, 2019). In the long run, the research also aims at improving the livelihood of small farming households while improving food security for the country.

Two objectives define the research:

1. To develop a design framework which could help other researchers, designers and engineers to work more effectively in design and realisation of farm equipment.
2. To design and develop appropriate, affordable, context-specific and gender-friendly rice threshing solution for small Indian farmers.

2.6.1 Research questions

In order to narrow down and focus the scope of research, the researcher decided to achieve the objectives by asking the following overarching questions:

1. In what way can a design framework be identified/created to help in holistic design and realisation of farm implements for small and marginal Indian farmers?

2. How can design intervention in farm implements be used for sustainable agricultural intensification of rice farming for small and marginal farmers of the Western Ghats And Coastal Plains in India?

Here, Sustainable Agricultural Intensification is an increase in yield by increasing/improving inputs per unit of farm land without adverse environmental impact. The Indian Government categorises farmers with a total farmland area of fewer than 2 hectares as small and marginal farmers. The Western zone in India is an agro-ecological zone that primarily comprises Maharashtra, Goa and Gujarat. For the scope of this research, the researcher has decided to focus on Western Maharashtra and Goa. The region was selected due to proximity and language compatibility of the researcher. Rice was selected as it is the principal food grain crop which is grown in two different agricultural seasons.

2.7 Conclusion

The literature and the artefact review examined existing farming trends related to small and marginal farmers, especially regarding the use of farm tools. The review also outlined some of the existing design approaches that could be pertinent for the design of farm tools for small farmers. It covered approaches to engineering design, industrial design, appropriate technology and grassroots innovation. The artefact review led to a study of traditional tools as well as threshing tools used by farmers and the use of pedal power for threshing. The literature as well as artefact review led to identification of knowledge gaps and helped frame the research questions. The next chapter outlines the methodology and the studio research process that was followed during the course of this study.

3. Research methodology

3.1 Chapter objective and structure

The last chapter reviewed the literature and artefacts in order to identify knowledge gaps and research questions. This chapter (Fig. 3.1) outlines the theoretical stance of the researcher and provides a summary of the methods used for both the theoretical research and the practice-based studio research project, along with the selection and justification of the approach chosen for design intervention.

Figure 3.1: Research methodology

3.2 Research paradigm and theoretical perspective

For this research, a studio research project-based approach was used, with a theoretical perspective based on Research through Design based on the epistemological stance of pragmatism. The researcher used qualitative research methods of semi-structured interviews and observations along with design methods like artefact analysis, mind-mapping and morphological visualisations to gather and analyse data. This was then used to develop a theoretical framework and to define design drivers and values that have informed the design process of developing a new rice thresher. Figure 3.2 shows the epistemology, theoretical stance, and methodology that has been adopted.

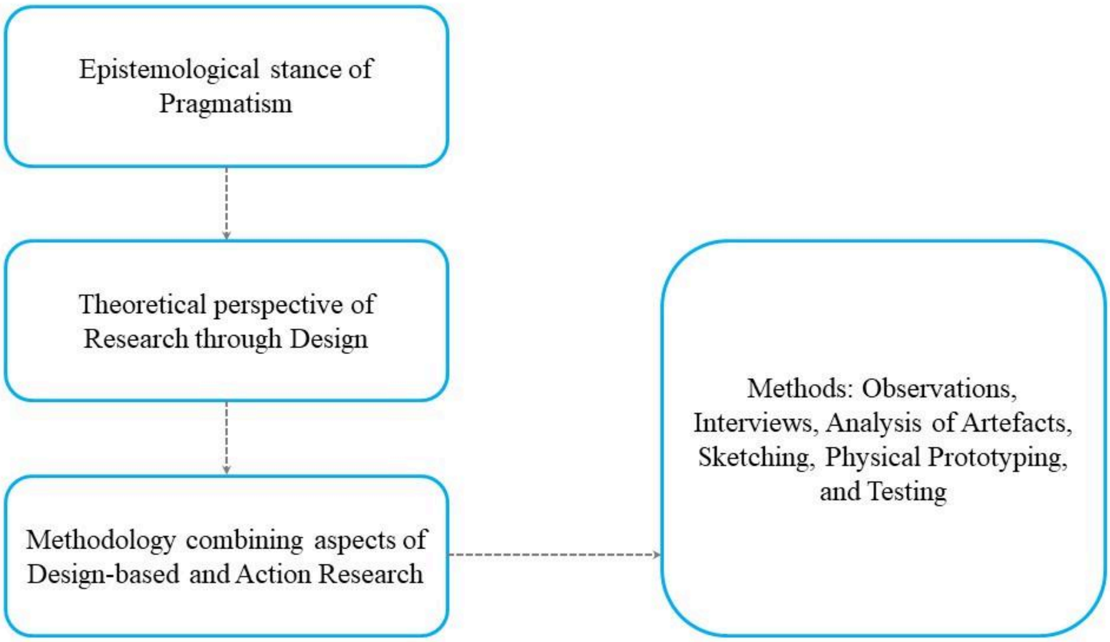


Figure 3.2: The epistemological stance and methodology

3.2.1 Pragmatism

In order to select a methodology and methods for conducting this research, it was also essential to figure out the purpose of the research and the epistemology that informs it. Crotty (1998) defines epistemology as a way of understanding what we know and how we know it. A pragmatic stance believes that reality is constantly interpreted through the lens of its apparent usefulness in a context, and the best solution is usually the one that works at a moment in this constantly changing reality (Patel, 2015). The pragmatic stance aligns with the research setting that farmers constantly interpret and renegotiate the usefulness of methods and tools in an unpredictable and changing environment, setting an epistemological precedent that the research can follow. The researcher felt that a pragmatic stance would be best suited and more aligned with the researcher's worldview to inform the research and the design methods used in this research.

3.2.2 Research through Design (RtD)

The theoretical perspective of the Research through Design approach was used to select methodology and methods. This approach is also known as project-grounded research and action research in design (Cross, 2007). Zimmerman and Folizzi (2014) define it as a way of generating new knowledge by employing methods and processes used in a design practice for the purpose of scholarly research. This research approach is inherently speculative and imagines a way of an improved world for its intended stakeholders that could be and should be by application of current and near-future research and technology. (Frayling, 1993; Zimmerman et al., 2010).

3.3 Design process

To bridge the gap between research and design practice, the researcher studied some popular design theories and processes.

In 1970, John Christopher Jones, in his book 'Design Methods' proposed that design is a continuous process of creating and making choices. He visualised it as a three-stage process (Fig. 3.3) containing divergent, transformation, and convergent parts (Jones 1970); the divergent stage involves generating many diverse ideas, the transformation phase involves refining those ideas using activities, and the convergent phase involves reducing uncertainties till only one design solution is left.

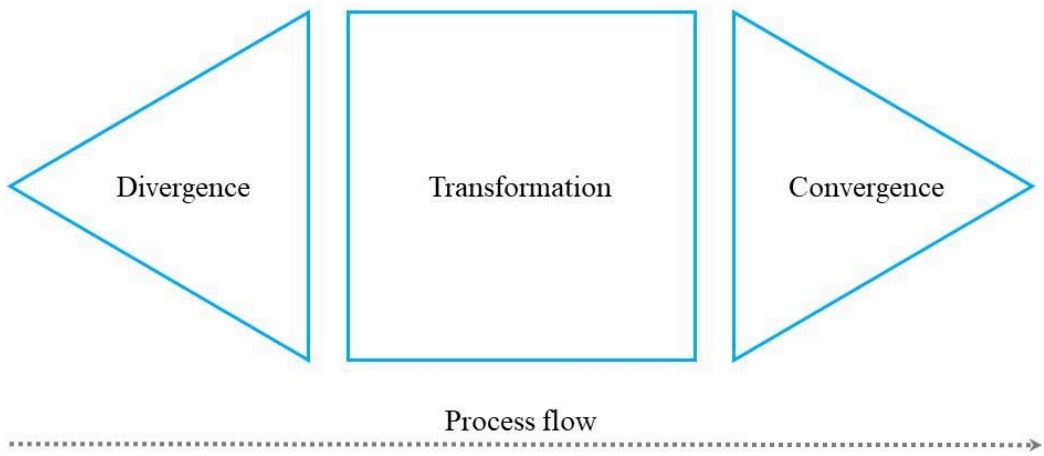


Figure 3.3: The J.C. Jones design process of divergence, transformation, and convergence Reference; Jones, 1992

In 1992, Herbert Simon proposed a decision-making theory (Fig 3.4), where problem-solving occurs by finding a solution from known concept mental space instead of studying all possible problem spaces. His model divides the problem-solving process into three components of Intelligence, Design and Choice (Simon, 1992). This method provides a way to make decisions and choices by deciding on, and applying performance criteria derived from information collected to arrive at a solution.

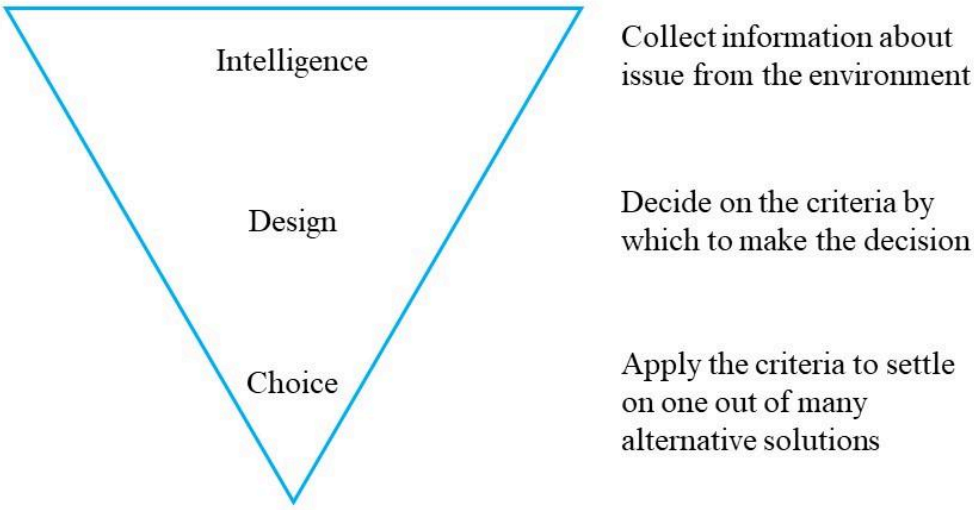


Figure 3.4: Concept model for decision making. Adapted from Sarav (2017)
Reference: Sarav et al. 2017

In 2004, the British Design Council built upon the John Chris Jones' model and proposed a framework which visualised the design process as a double diamond (Fig 3.5) containing four components of discovery, design, develop and deliver (Design Council UK, 2019).

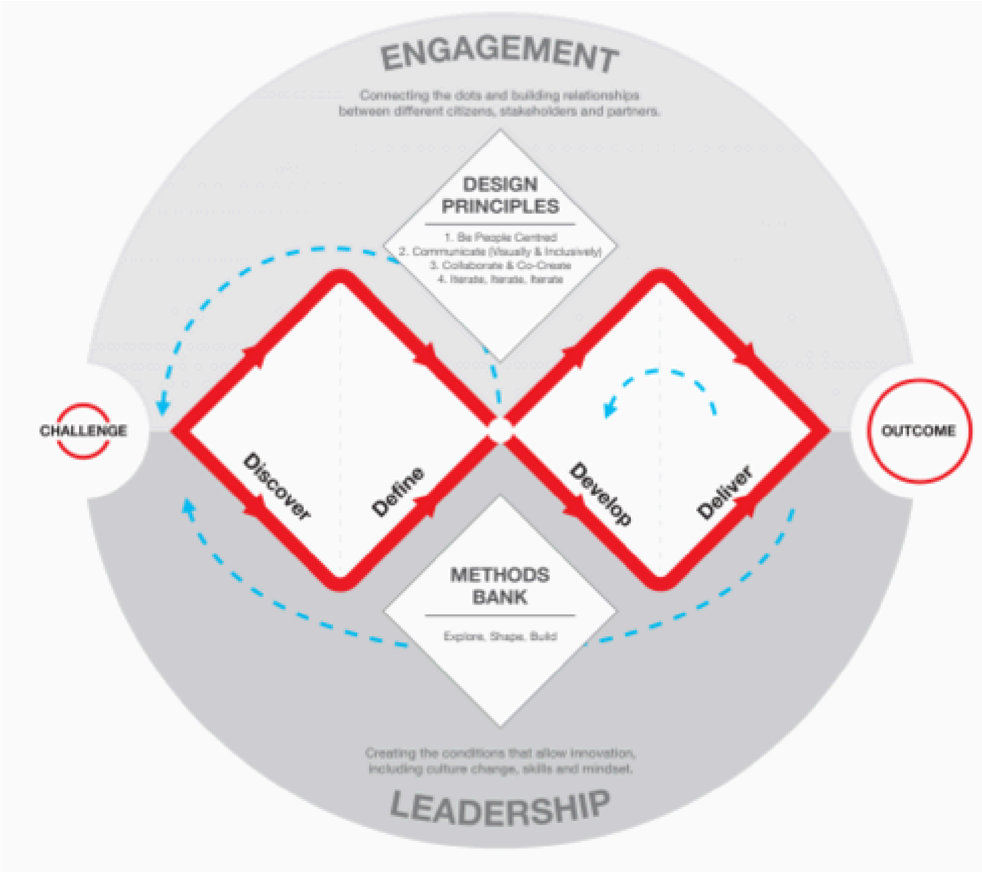


Figure 3.5: Double diamond design process. Reference: Design Council UK (2019)

The double diamond design process was adapted and modified to generate a project framework (Fig 3.6). The stages, steps and outcomes are visualised in figure 3.6. Methods of literature study, observations, analysis of artefacts and semi-structured interviews were used to understand Indian agriculture and the challenges faced by small and marginal farmers. These were used to generate morphological visualisations of activities, tools and needs of small farmers for rice farming. The outcomes of research were then analysed and twenty six factors were defined for consideration while developing design intervention. Based on the issues for farmers identified in the literature review, rice threshing is the focus for the studio research project. The researcher also developed a theoretical framework to inform and drive ideations, design choices and design decisions during concept generation and evaluations. An iterative process was then followed to develop concepts, refine them for manufacture, fabricate, assemble and test to arrive at a refined human powered, low cost, portable threshing device.

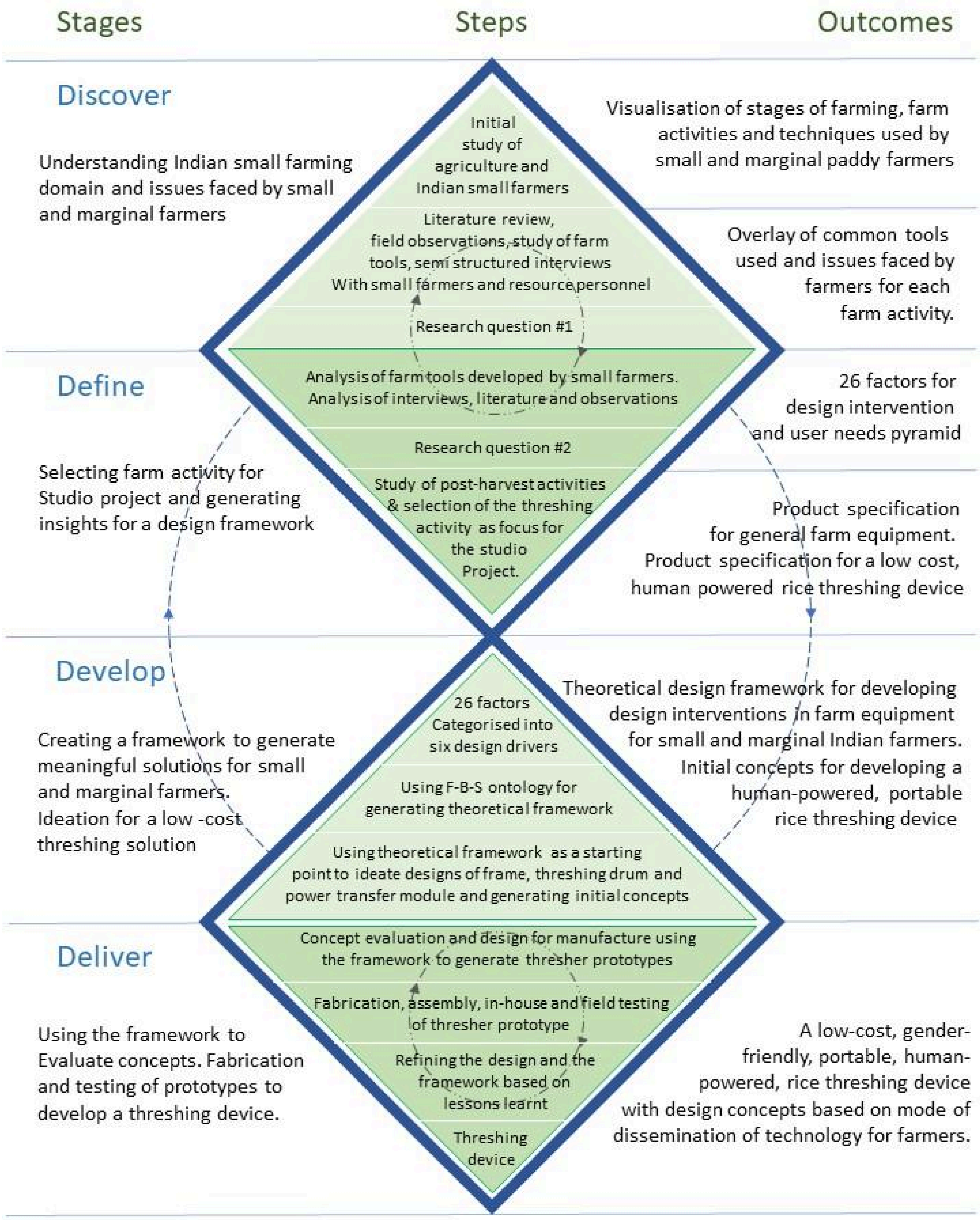


Figure 3.6: Project research framework

3.4 Research and design methods

The scope of the research consists of a theoretical component of generating a design framework as well as a practical component of developing a solution for threshing activity. Hence the researcher used a combination of methods from following two methodological approaches.

a) Design Based research (DBR) which is research by practice of designing and testing an intervention (Anderson et al., 2012), and

b) Action research, which can be defined as the act of combining theoretical research and design practice through change and reflection while solving an identified problem. (Avison et al., 1999)

Methods like field visits, semi structured interviews, observations of farm activities and tool manufacturing, and study of artefacts were used to understand the domain and derive insights for generating framework and a product design. The primary method of capturing the user needs and wants was through interviews and observations.

3.4.1 Semi-structured interviews

Interviews are a way of understanding a participant's perspective, stance, and opinions on a particular topic through the act of asking questions and engaging in a discussion. They can be broadly categorised as structured, semi-structured and unstructured depending on the constraints the interviewer chooses to impose on the questions to be asked or the direction in which the discussion progresses. Semi-structured interviews have been used in the course of the research. Saunders, Lewis and Thornhill (2009) also call this a qualitative or a non-standardised method. This is a hybrid interview technique which provides benefits of structured interviews like predetermined themes and some initial questions while allowing the researchers enough flexibility to adapt the questions and direction of interview in case new topics are introduced by the participants that can aid the data collection process (Dina Wahyuni, 2012). This also allows researchers to modify or improve their primary and initial questions after each interview in order to refine the collection of information with each subsequent interview till a saturation point is reached.

3.4.2 Observations

Along with semi-structured interviews, observation of farm activities and review of artefacts helped derive insights that were then used as design values and drivers. Observation is a commonly used method by designers and researchers for qualitative research. According to Simons (2009), observations also allow the researcher to either play the role of just observer or an active participant in the observation to help create a comprehensive image and make sense of the context. Observation thus helps understand the context, setting, and people to generate deep and rich understanding leading to design insights. Observations can be categorised as structured and unstructured and allow the observer to be present in the natural setting (Robson, 2002). Apart from cross-check, sense of the setting, and rich description, Simon (2009) suggests that observations can help understand institutional values and give a voice to less articulate people while capturing the experience. The researcher used observations as a method to triangulate and cross-check the data obtained through study of literature, review of artefacts, and semi-structured interviews. The data obtained through observation was also used to understand problems, needs and values of the small and marginal scale farming community in rural India.

3.4.3 Sketching

The research used design methods of morphological visualisations, sketching, prototyping and product testing to generate ideas and develop them to arrive at a refined design. Sketching is one of the most ubiquitous skills used by designers to visualise and communicate ideas. Sketching also works as an important thinking tool during the early phases of idea generation and conceptual design (Fish et.al, 1990; Purcell, et.al 1998). Fish and Scrivener (1990) argue that sketching helps in translating the descriptive to depictive, which especially helps in creative problem solving and communicating mental imagery of physical artefacts that would occupy space after fabrication. Suwa et al (1998) also claim that along with acting as an external memory, sketching essentially enhances thinking as it provides visual cues to the designer during and after the process. According to Cross (1999), sketching provides recognition of important features and problem structure as it helps the designer to understand and simultaneously handle multiple levels of abstraction. Sketching also helps in the transformation of mental idea into a physically coherent form, through process of moves and arguments based on dialectics of "seeing as" and "seeing that" modalities (Goldschmidt, 1991; Onkar et al., 2009) Hence, sketching on both paper, and computer aided drawing (CAD) has been used as the primary method to generate, detail, refine, and evaluate ideas during the divergent stage of the design process along with prototyping and testing to evaluate concepts during later stages.

3.4.4 Prototyping

Prototyping is an important method in the design and development process as it allows the designer to examine part or whole of product features, form, and functionality. It is typically used in the mid and end-phases of the design process as a tool to test, refine, and develop design concepts. After sketching multiple and diverse ideas in the initial stage, iterative prototyping in early phases helps the designer to shortlist, discover, and improve upon the functional ideas quickly in order to arrive at an effective and usable product concept (Camburn et. al., 2017). Otto and Wood (2001) define a prototype as a way of approximating a single or multiple features of a system, service or a product using an artefact. Usually, in different industries prototypes are used to develop and explore new concepts and to finalise and achieve specifications (Schrage, 1993). Hence prototypes are used in initial stages for concept generation (Hess and Summers, 2013) and in later stages for evaluating and shortlisting a set of refined concepts (Lennings et al., 2000). In this research an iterative prototyping process has been used where the researcher shifted from sketches to quick prototypes during idea generation in the divergence stage, and full-scale prototypes were created for testing and validation of usability and functionality. Where learnings from each iteration of prototyping and testing was used to improve and refine the final thresher concept.

3.5 Conclusion

This chapter has outlined the theoretical stance, the design process, and the research as well as design methods used to meet the research aim and objectives. A mixed method approach using aspects of action research and design based research has been used to investigate and identify the problem and to generate a design intervention. The research and design process is adapted from a double diamond process which allows both scholarly reflection as well as iterative design stages to generate research and design outcomes. The following chapters will outline and detail the research and design methods and outcomes at various stages of the study.

4. Exploring avenues of design intervention in farming (Discover + Define)

4.1 Chapter objectives and structure

The previous chapter provided an outline of theoretical stance, methodology and methods used along with the research framework that was followed during the course of the study. This chapter (Fig 4.1) explains the steps that were followed in the Discover and Define stage of the research.

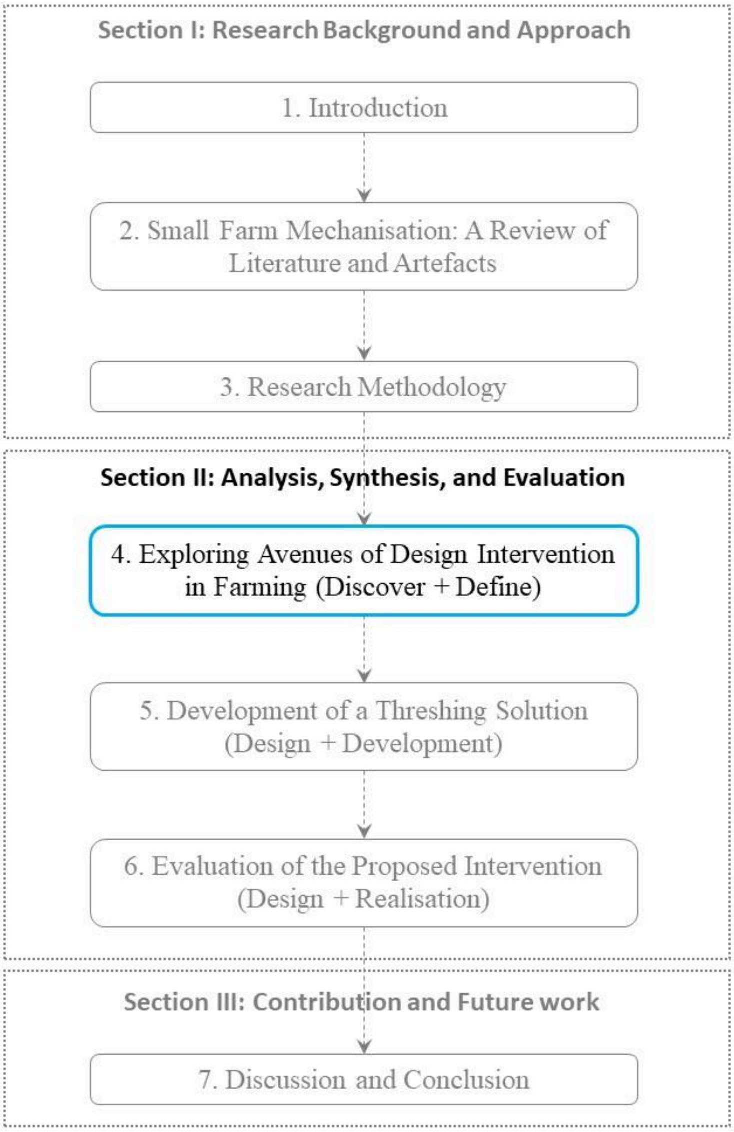


Figure 4.1: Exploring avenues of design intervention in farming (Discover + Define)

In order to design and develop appropriate, context-specific solutions, a designer needs to understand various parameters that need to be considered for designing and evaluation of these solutions. The following work was done in two stages to understand the domain of agriculture, needs of small Indian farmers and factors which affect tool design.

In stage one, in order to understand farm activities, an example of rice farming was selected to understand tools used at different stages and needs of small scale farmers. The needs were identified by conducting field visits and an informal workshop with rice farmers.

In the second stage, factors affecting farm tools were identified through field visits and informal discussions with farmers and researchers. Solutions developed by farmers as well as common farm activities were studied. The parameters derived from the fieldwork and discussions were then classified under an existing design framework.

The work done in the first two stages helped in gaining a preliminary understanding of the ground realities and issues affecting small farmers. This work also helped in understanding and provided a direction for further work.

4.2 Field visits and observations (stage 1)

To get an overview of farm activities and to identify needs of farmers with regards to these activities the researcher visited four villages in western Maharashtra (Darakwadi, Vighawali, Amale, and Naigaon), four villages in the tribal district of Northwest Madhya Pradesh (Meghnagar, Kheda, Dharampuri, and Rakhadia) and one village (Taleigaon) in Goa (Fig. 4.2). Activities of threshing, milling, transplantation and weeding were observed along with an informal discussion with villagers regarding general farming-related issues.

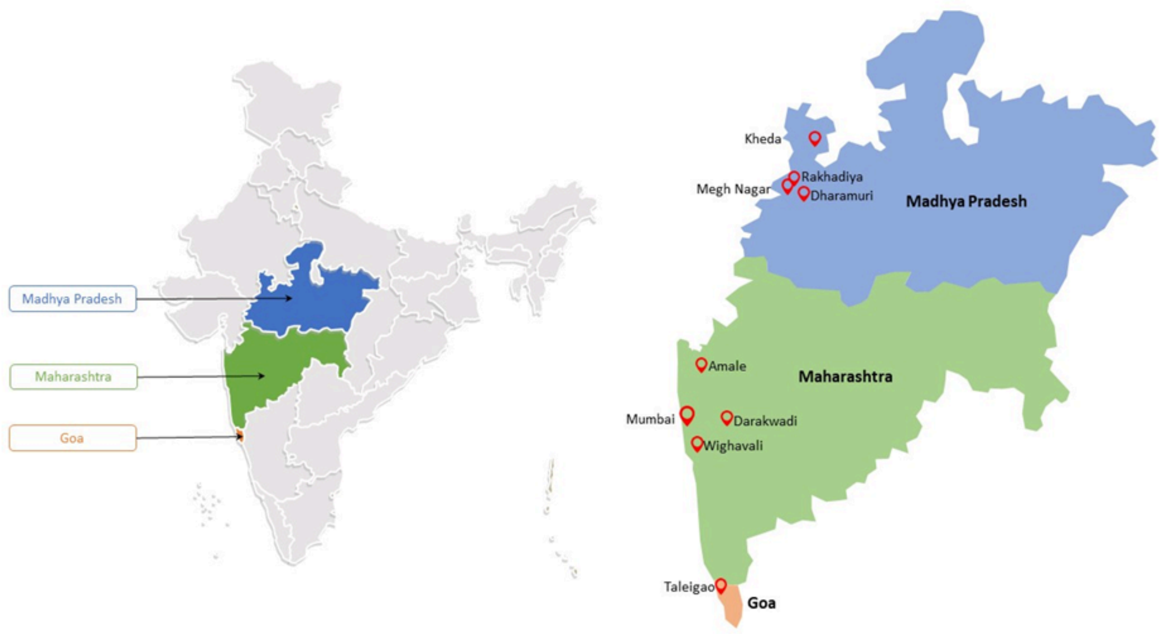


Figure 4.2: States and villages visited during first year

The research started with a study of literature, rice farming and tools used at different stages. A mind map of stages of rice farming as well as tools used at each stage was prepared for better data visualisation. This mind map was then used as a reference to conduct a workshop at a small-scale rice farmer's meet at Darakwadi village to understand their needs. The researcher then visited the Amale village to understand and consolidate the needs and wants through observation and informal discussions with the farmers.

4.2.1 Generating morphological chart to visualise data

According to the International Rice Research Institute (IRRI) (n.d.), stages in farming any crop can be broadly divided into three segments, pre-production, growth, and post-production. Pre-production deals with activities involving the preparation of land by the farmer before planting the crop. Growth deals with all the activities from planting, and nurturing the crop till harvest. Post-production stage consists activities from harvest till transporting the crop output (Pai et al. 2021).

To aid visualisation of stages of farming, a map was created to understand the flow of activities and operations (Fig. 4.3). The map has a base layer of activities in a typical farming cycle starting from preparation of land for sowing to harvesting and storage along with operations or techniques used for each activity. Then an overlay was created where different tools typically used for each activity by farmers were added to this map (Fig. 4.4). The information regarding tools and stages of rice was collected from resource person at BAIF Development Research Foundation (formerly known as Bharatiya Agro Industries Foundation), report on Indian small scale farmers by Food and Agricultural Association (FAO) of the United Nations (Singh et al. 2002), and a website about paddy farming in India (International Rice Research Institute (IRRI) n.d.).

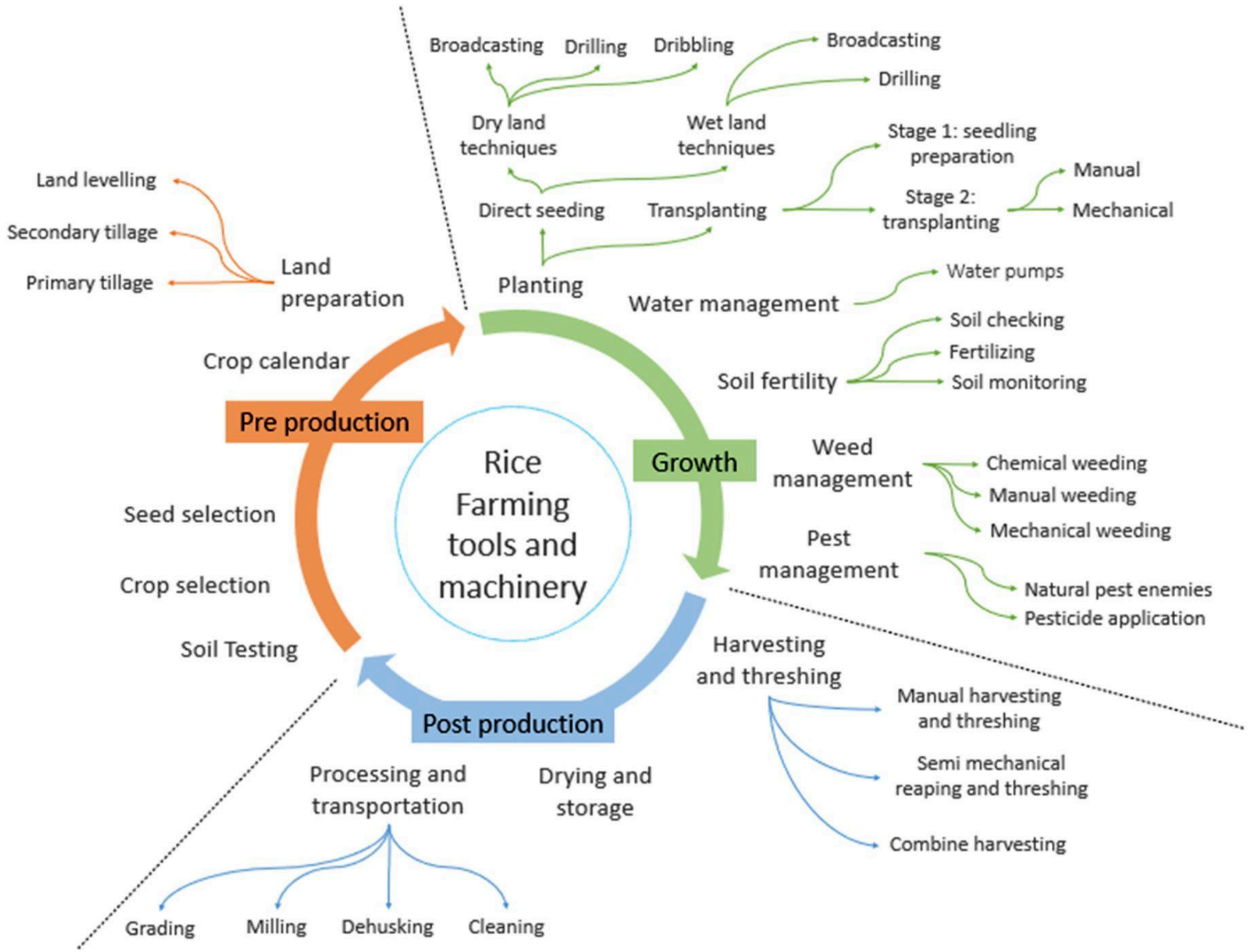


Figure 4.3: Flow of activities and different operations in rice farming. Reference: Pai et al. 2021

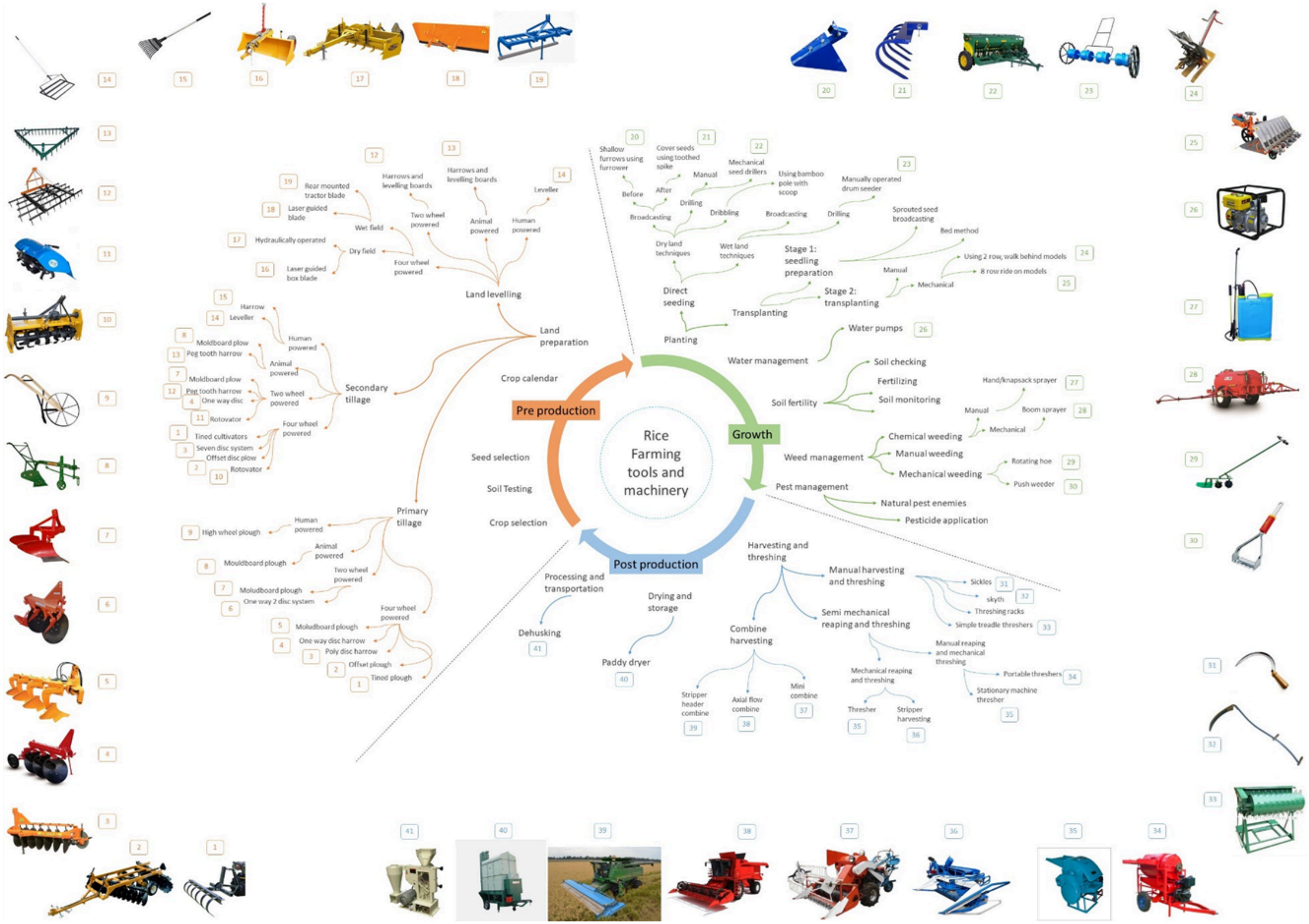


Figure 4.4: Overlay of tools used in rice farming

4.2.2 Field visit to Darakwadi

A lot of government organisations as well as NGOs regularly conduct farmers meets in the state to raise awareness about new rice varieties, agricultural tools, techniques, and government policies. A similar meet was organised by resource personnel from Sahyadri school and BAIF at the village of Darakwadi, Rajgurunagar, near Pune, Maharashtra. The purpose of the meet was to introduce small-scale farmers to rice varieties as well as low cost and sustainable organic farming techniques. The researcher conducted an informal workshop at this meet to understand their needs and issues regarding farm implements used at various stages of rice farming.

Around 30 small-scale farmers hailing from various places in Maharashtra attended this meet. The meet began at the field of one of the farmers, who has been working with a resource person from BAIF to grow multiple varieties of rice to create a seed bank (Fig. 4.5). These seeds are then sold to farmers at nominal rates at Bhimashankar farmer's producer company ltd. This company is run by farmers of this village in a cooperative manner.

The farmers were then shown the visualisation of farm activities, techniques, and tools. The researcher decided to use the visualisation as a prompt during the informal workshop with farmers to understand their needs at each stage of rice farming. A group discussion about farm implements and the issues that small scale farmers face with existing solutions as well as the features that they require was conducted.

Figure 4.5: Field with different varieties of rice

4.2.2.1 Research objective. The objective of the workshop was to understand the tools that small-scale rice farmers use at various stages of rice farming and to figure out needs of small-scale rice farmers with respect to farm implements.

4.2.2.2 Methodology. The issues and needs were identified using informal discussions and a focus group meeting. A small workshop was conducted where tools available at each stage of farming were discussed. This was followed by understanding the farmer's use of these tools and the issues arising at each stage.

4.2.2.3 Observations. Following issues were identified during the course of the discussion

General Issues identified during the discussion:

1. Non-availability of labourers in the villages
2. Farmers are unable to invest in fuel for fuel-powered machinery
3. Farmers find it difficult to rely on electrical tools due to frequent power cuts
4. Since the water levels have been going down for the past few years. The current situation at most farms is that the farm level is above the water level.
5. Whenever the farmers tried to install solar-powered pumps for irrigation, they realised that the batteries were either stolen as they were expensive and required maintenance costs in terms of replacement every few years.
6. Weeding is a labour-intensive process which has to be done manually in paddy fields as the existing weeders do not work in wet soil. The manual technique requires frequent bending, which leads to injuries.
7. Similarly, seeding and transplanting of rice are also laborious tasks, especially when seeds need to be planted at a required distance. Transplanting, currently, is one of the most laborious and difficult tasks for the farmers as they have to pluck and prepare saplings for transplanting, transport them to the field and plant them at a specific distance between the plants.
8. Among post-harvest activities, threshing of rice is one of the most labour-intensive activities; the current pedal-thresher is operated using one leg and requires a lot of pressure and puts a strain on the legs during the operation.

4.2.2.4.Insights. The farmers believed the current solutions are either too expensive or not well designed to meet their needs. Hence there is a need for a user centric approach which involves the stakeholders at some levels of the design process (at least to understand the needs and for validation) which seems to be missing at the moment. The following needs were identified on the basis of discussions and observations.

1. Need for manual, portable solutions
2. Zero budget solutions wherever possible

3. There is a need for a portable, manually operated pump which can be transported to and from home as required. Should not require fuel or electricity to run.
4. Need a seeder which can dig up the land, drop at least 2 seeds at the required distance, and cover the soil
5. Need a manual, mechanical tool for transplanting, which can transplant saplings without damaging the roots
6. The transportation and creation of saplings for transplanting needs a simple solution like probably a portable nursery
7. A rotary pedal type thresher would be easier to operate and could lead to less fatigue.

These needs were then mapped as an overlay onto the initial mind map to understand the current state of tool usage and deficiencies in farm implements for small scale paddy farmers (Fig. 4.12).

4.2.3 Field visit at Amale

In order to observe and understand the needs of small-scale farmers and state of their tools and farms, the researcher visited a small village of Amale, located in Thane district of Maharashtra (Fig. 4.6). The village consists of 310 people and 72 households, who are almost entirely dependent on agriculture or related activities for their livelihood. This village has around 18 small scale farming households.

Unlike the last visit where a farmer's meet was already organised, this visit was intended so that farms could be visited and discussion with the farmers can be had in their village so that tools, implements and farming operations could be observed.

4.2.3.1 Research objective. The objective of this visit was to observe and understand the tools and methods used by the small-scale farmers in order to derive insights about their needs and wants.

Figure 4.6: Village of Amale

4.2.3.2 Methodology. Using farm visits along with informal discussion with farmers to understand the issue with tools and techniques that they use. Their homes were also visited to observe the living conditions as well as storage of implements, seeds and harvest.

4.2.3.3 Observations. The following issues and observations were noted based on the farm visit and discussion.

The Farmers in the village currently use a wooden plough for land preparation and levelling before the seeds are planted. This plough is locally made in the village and costs around Rs. 500/- (not including the metal tip). It is held by one hand by the farmer while his other hand holds the stick and ropes to control the bulls pulling the plough. However, during monsoon, the wood absorbs water and becomes heavier as the wet mud sticks to the plough (Fig. 4.7), increasing the weight to approximately 30-35 kgs. It is very difficult for the farmer to turn the plough as he has to lift the plough with one hand while steering the bulls. They cannot use any heavier machinery as during the monsoon the river floods and the access to the village by tractors or other vehicles is cut off.

For weeding, farmers either remove the weeds using a traditional hoe (Fig. 4.8) or uproot them by hand (Fig. 4.9). However, the weeds cannot be uprooted completely using these methods. The roots remain in the soil and grow up again within a few days making this task repetitive, strenuous as well as labour intensive.

Figure 4.7: Wooden plough with mud sticking to it

Figure 4.8: Weeding using traditional hoe

Figure 4.9: Weeding by hand

Currently the village gets electricity from a solar micro grid. However, since the batteries need maintenance and replacement, the farmers can only rely on electricity generated during the day by the panels. This is used to power a single 5 Hp water pump which can cater to only 2 farmer's plots in a day. There are 18 farmers in the village. Even with effective scheduling and dividing, the water is not enough to irrigate all the farms effectively. This coupled with lowering of water level in the river along with monsoon season ending earlier than expected, dried up most of their rice crops (Fig. 4.10) and they were unable to harvest it. The village also has a treadle pump which is not used as it puts a lot of strain in their thighs and legs and is very inefficient.

Figure 4.10: Dried rice fields

Figure 4.11: Knapsack sprayer

The farmers use cow urine as a pesticide which is sprayed using a knapsack sprayer. The sprayer tank has a capacity of 15 litres. (Fig. 4.11), which is heavy and puts a lot of strain on their shoulders. Also, for an average plot around three to five sprayers are required which is either labour intensive or painful and tiring for one person.

The farmers currently use long shears or a sickle to cut the Jasmine flowers and rice. However, the shears put a lot of strain on their forearms and elbows.

For Jasmine flowers, the farmers create saplings by planting twigs from harvested plants in a small bag filled with soil. These are then watered regularly till they are ready for planting. These are then planted at five feet from each other. For rice, farmers start preparing the land by creating layers of dried hay, leaves and grass, which is then mixed with soil and burned to create a layer of soil which is tilled for planting rice. Once the rice saplings are ready, they are planted according to the farmers' judgement at one to one and half feet from each other in a square pattern. This whole process requires a lot of bending. Also care needs to be taken while transplanting rice so that roots are not damaged. This is labour intensive and very strenuous for the farmers as transplanting is done by hand.

Historially the grains were stored in large baskets made of bamboo strips and covered with a fabric. The grain was mixed with Nibarghacha pala (leaves of a local plant), leaves of Nirgudi (Chinese Chaste tree) and salt to protect it from insects. However, the bamboo in the surrounding jungle has restarted its growth cycle, hence the length of bamboo is small and cannot be used at the moment to make these baskets. Hence the farmers use plastic drums which are not as effective at storing grains.

The data from the workshop as well as field visit was compiled and then needs were identified and mapped as an overlay over the previously made mind map (Fig. 4.12). This led to an understanding of the gaps in existing solutions which helped later identify specific focus areas for design intervention (Pai et al., 2021).

4.2.3.4 Insights. There is an urgent need for design and development of ergonomic, low cost, context specific, locally manufacturable tools and machines which respond to the needs, wants and aspirations of the small scale and marginal farmers (Pai et al., 2021). The existing solutions on the market seem to be designed with a top down approach which either have high running costs or do not cater to these farmers needs completely. These tools also affect technology diffusion and adoption by small scale farmers as these farmers are reluctant to invest in new machinery (Pai et al., 2021).

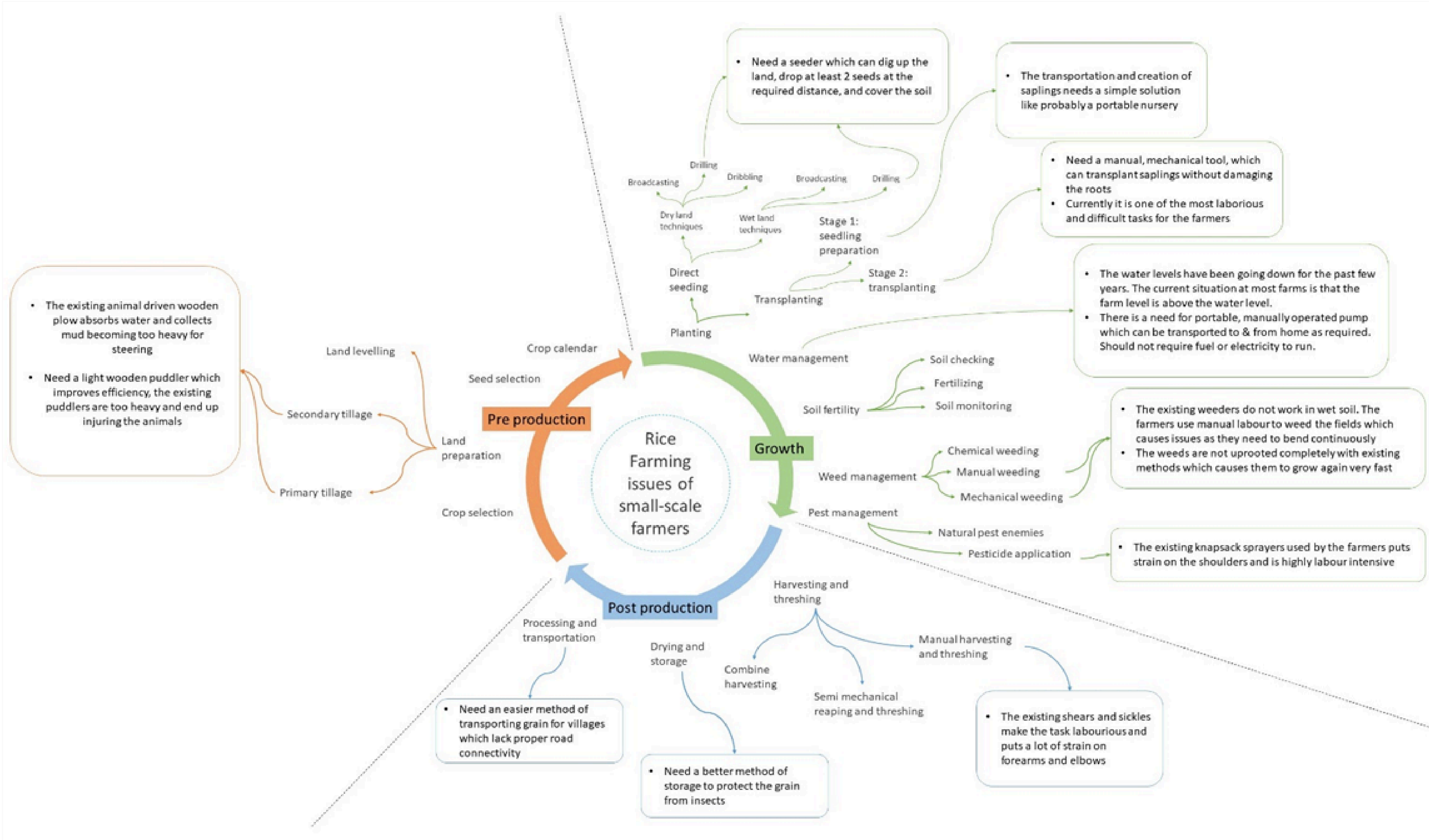


Figure 4.12: Overlay of needs on visualisation of rice farming activities

4.3 Field visits and observations (stage 2)

In the second stage of initial field visits, the researcher decided to study farming activities to observe and understand the needs of Indian small farmers regarding farm implements. The objective was to identify needs and tools used by the farmers to derive possible parameters which can then be used in a framework to design farm implements. The stage started with a field visit to Wighawali village in Konkan region of Maharashtra and the village of Taleigao, Goa. Based on the field visits and workshop conducted previously, a tentative list of parameters was prepared and refined. Two more field visits were conducted at Jawahar and Naigaon villages of Maharashtra. The observations and discussions during the field visit as well as documentation of tools developed by farmers was used as a basis to develop additional parameters. These parameters were then classified under various factors of human, technology, and environment. Then the top seven crops were identified on the basis of annual production, and their stages in farming were mapped to generate a standard set of activities (Fig. 4.26).

4.3.1 Understanding needs of farmers in Konkan region

We started the second stage with a field visit to Wighawali village in Konkan region of Maharashtra and the Taleigao village, Goa. The Konkan comprises 720 km^2 of western India, consisting of coastal regions from Maharashtra, Goa and Karnataka. Since the primary crop of this region is rice, the region in Maharashtra is also known as the rice bowl of the state. However, urbanisation and industrialisation have led to a steady decline in rice farming over the years (Shinde 2017).

In Wighawali, needs were identified using informed discussions and observation. The researcher also met two farmers in Goa as well as a social activist, who has been instrumental in establishing progressive farmers clubs across the state to provide support and awareness to small farmers and to prevent their land holdings from conversion. This social activist is also well versed with issues that the small farmers face and provided insights about the same.

4.3.1.1 Research objective. The objective of these visits was to observe and understand the needs of small-scale farmers in the coastal Konkan region.

4.3.1.2 Methodology. Informal discussions along with observation of post-harvest activities

4.3.1.3 Observations. Despite the availability of a threshing machine, small farmers from Wighawali prefer using old metal drums for threshing (separating grains from straw) (Fig. 4.13) due to the following reasons:

- The machine requires three or more labourers to operate, each labourer charges around 50-700 rupees per day which is unaffordable.
- The output of machine threshing is a mixture of hay, grains and dust (Fig. 4.14) compared to the output of manual threshing (Fig. 4.15). The machine threshed grain also gets cut and requires additional activities to separate it from hay and dust.

Figure 4.13: A farmer threshing grain manually

Figure 4.14: Output of machine threshing

Figure 4.15: Output of manual threshing

Most of the small farmers cannot afford tractors and modern machinery as the rent is too high. Also, since the farmers do not understand these machines well, they must rely on an operator to run the machine and tractor which is an additional cost.

The villagers in Wighawali still use a 'Gharghanti' (small manually operated traditional flour mill) (Fig. 4.16) to mill the grains. This device is either placed permanently inside the house or just outside the house where it also serves as a meeting point for women of the village.

Figure 4.16: Manually operated flour mill

Most of the small-scale farmers in Konkan are primarily skilled in agriculture and semi-skilled or unskilled at other rural trades. The lack of other skills limits the possibility of off-farm employment when the yield is meagre due to unpredictable monsoons, drought, and crop disease.

A lot of coastal farms have sandy soil which creates drainage issues. Traditional drainage pathways are also slowly getting blocked due to urbanisation and construction, leading to farms either getting flooded or dried too soon.

Few small-scale farmers have managed to improve the yield and become successful through farming. They managed to do so by shifting from traditional paddy farming to producing exotic vegetables like red cabbage, Chinese cabbage, and yellow watermelons. These farmers were also receptive to new technology and adopted greenhouses, hydroponics and small machinery to improve their output.

The issues faced by small scale farmers in coastal areas are lack of proper access to farms, poor soil quality (in terms of fertility), salty water in bore wells, uncertain rains, high cost of cultivation, and lack of efficient, portable machinery.

Based on the field visits and workshop conducted previously, a tentative list of parameters was prepared and refined. The researcher did two more field visits at Jawahar and Naigaon villages of Maharashtra.

4.3.2 Understanding community managed projects

In the drought-prone region of Purandar, Pune, Maharashtra; a charitable trust known as Gram Gaurav Pratishthan (GGP) was established in 1972 to enable sustainable rural development in Naigaon village. Popularly called pani panchayat by the locals, this organisation provides training in organic farming, advocates equitable distribution of water, and provides support for education and health domains in rural India

Since Naigaon village is in a rain shadow area, the farmers shifted from lift irrigation to bore wells. However, overdependence on bore wells as well as drilling new bore wells led to the depletion of aquifers. The village has 102 bore wells which were dug to irrigate water-intensive crops like sugarcane and rice. GGP started a movement to solve the water crisis. They suggested equitable distribution of water; community managed wells and irrigation projects, sustainable cropping patterns and planting less water-intensive crops like drumsticks, custard apple, jowar and onion in place of rice and sugarcane. The visit was arranged with the plan of understanding the activities of this organisation, visit nearby farms to observe work done for water conservation and sustainable farming. The researcher also got an opportunity to see various tools developed by farmers with the help of a local metal workshop.

4.3.2.1 Research objective. The objective of visiting Naigaon was to understand the formation of cooperative projects for equitable distribution of water as well as to understand the requirement of small-scale farmer’s tools.

4.3.2.2 Methodology. Informal discussions and brainstorming sessions were conducted with members of GGP, farmers from surrounding villages, engineering students interested in rural development, and observations during farm visits.

4.3.2.3 Observations and insights. The villagers have shifted from planting rice and sugarcane to drumsticks, chickpea and onions. They use organic farming methods along with vermicompost, greenhouses and canals along with sustainable farming methods to renew and conserve resources as well as soil fertility. This shift in farming methods has increased the yield over time. The farmers have also started animal husbandry using cows and chicken to supplement their diet as well as income. Community ownership and management of resources and conservation projects have led to better resource management and sustainable farming.

The farmers of the village have developed their tools with the help of the local metal workshops. By and large, the tools are developed for post-harvest activities like cutting (Fig. 4.17 to Fig. 4.19), plucking (Fig. 4.20 and Fig.4.21) and drying. Some tools have also been designed for weeding and harrowing (Fig. 4.22).

Figure 4.17: Tool for cutting twigs

Figure 4.18: Sickle

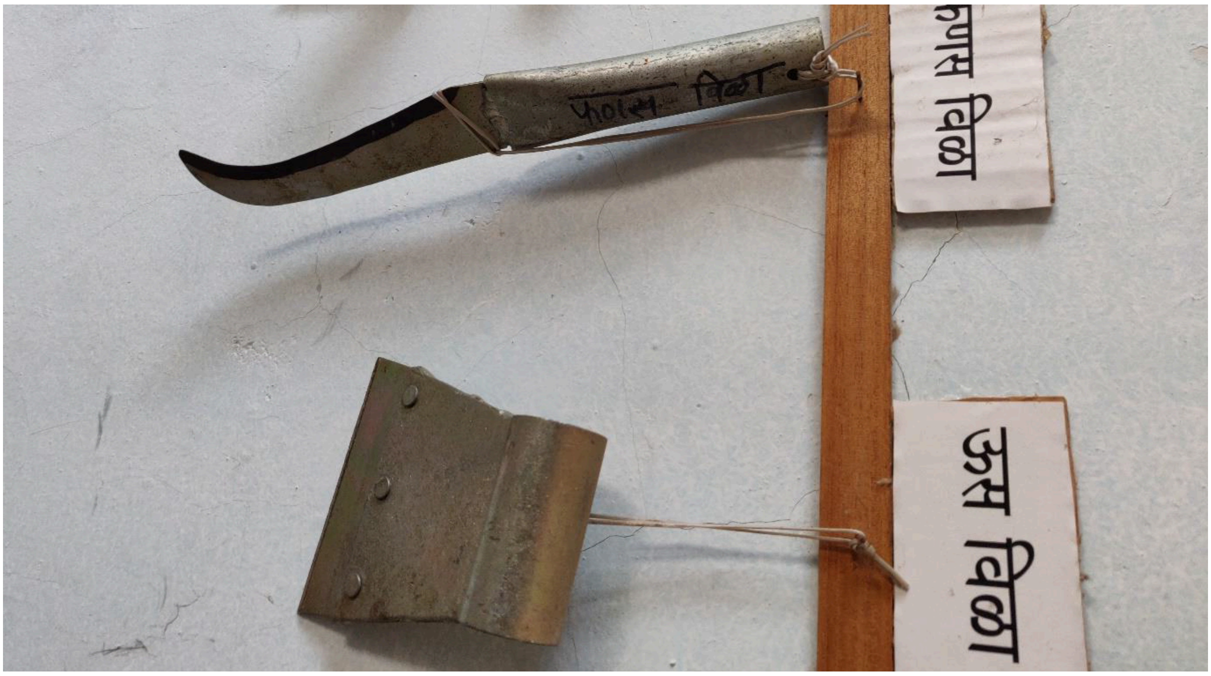


Figure 4.19: Sickle for jackfruit and sugarcane

Figure 4.20: Plucking tool

Figure 4.21: Plucking tools for Chickoo, Lemon, Figs, and Mangoes

Figure 4.22: Tools for weeding

Most of these tools are made using locally available material as well as recycled waste. The tools are robust, have minimal moving parts, and are context specific (Pai et al., 2021). The tools developed by small farmers are quite interesting as they use readily locally available material like Galvanised Iron (GI) pipes, metal channels, Polyethylene terephthalate (PET) bottles, nets and bamboo to create tools which help them in weeding, harvesting and cutting. The manufacturing processes for combining these materials also seemed to be dependent on locally available skill sets of smithy, carpentry, welding and weaving. The existence of these tools clearly highlights a gap in available solutions in the market and also the need for developing an ecosystem where such tools can be designed using similar techniques and locally available material and skill sets while keeping in mind ergonomic and safety requirements.

We then conducted field visits to four villages (Kheda, Dharampuri, Rakhadiya, and Megh Nagar) in Jhabua district, Madhya Pradesh. The objective of these visits was understanding farming needs of small farmers in tribal areas of central India and studying community-managed projects and holistic rural development initiatives. The observations and insights regarding needs of small and marginal farmers were quite similar to the visits conducted in Amale and Darakwadi. The issues related to manual weeding and harvesting were present in these locations, however due to the nature of the region, the farms were not on level land. In these locations the farms followed the contour of the land across smaller hills which had a shallow rounded slope and gradient. Hence the farmers in these locations were much more concerned with both affordability and portability of the equipment.

4.4 Generating possible design directions and morphological visualisations

4.4.1 Identifying common activities across crops

We took seven top crops of India based on annual production across categories of grains, pulses, coarse cereals, and cash crops . These crops, in no particular order are rice, wheat, cotton, sugarcane, finger millet, chickpea and groundnut. The researcher then decided to create morphological visualisations that might aid us in finding patterns.

4.4.1.1 Objective. The objective of this activity was to check if any trends or commonalities that were hitherto missed emerged out of maps which could probably aid in selecting farm activity for design intervention that could be then scaled to multiple crops easily.

4.4.1.2 Methodology and outcome. Various activities under the three segments of pre-production, growth and post-production as mentioned earlier were mapped for all other six crops similar to the one done for rice (Fig. 4.23 to Fig. 4.25) Then a common set of activities was extracted from these maps (Fig. 4.26).

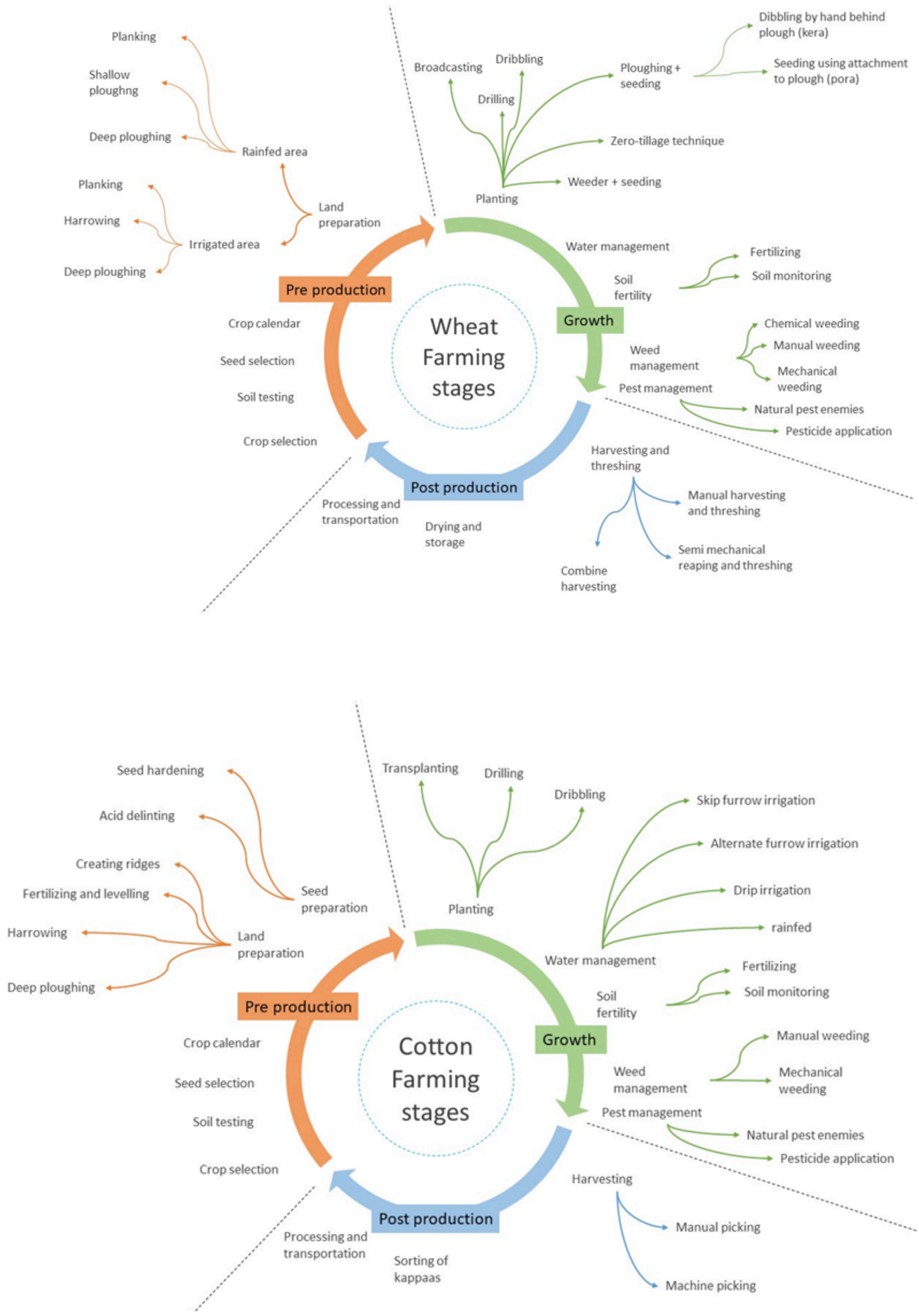


Figure 4.23: Wheat and Cotton farming stages

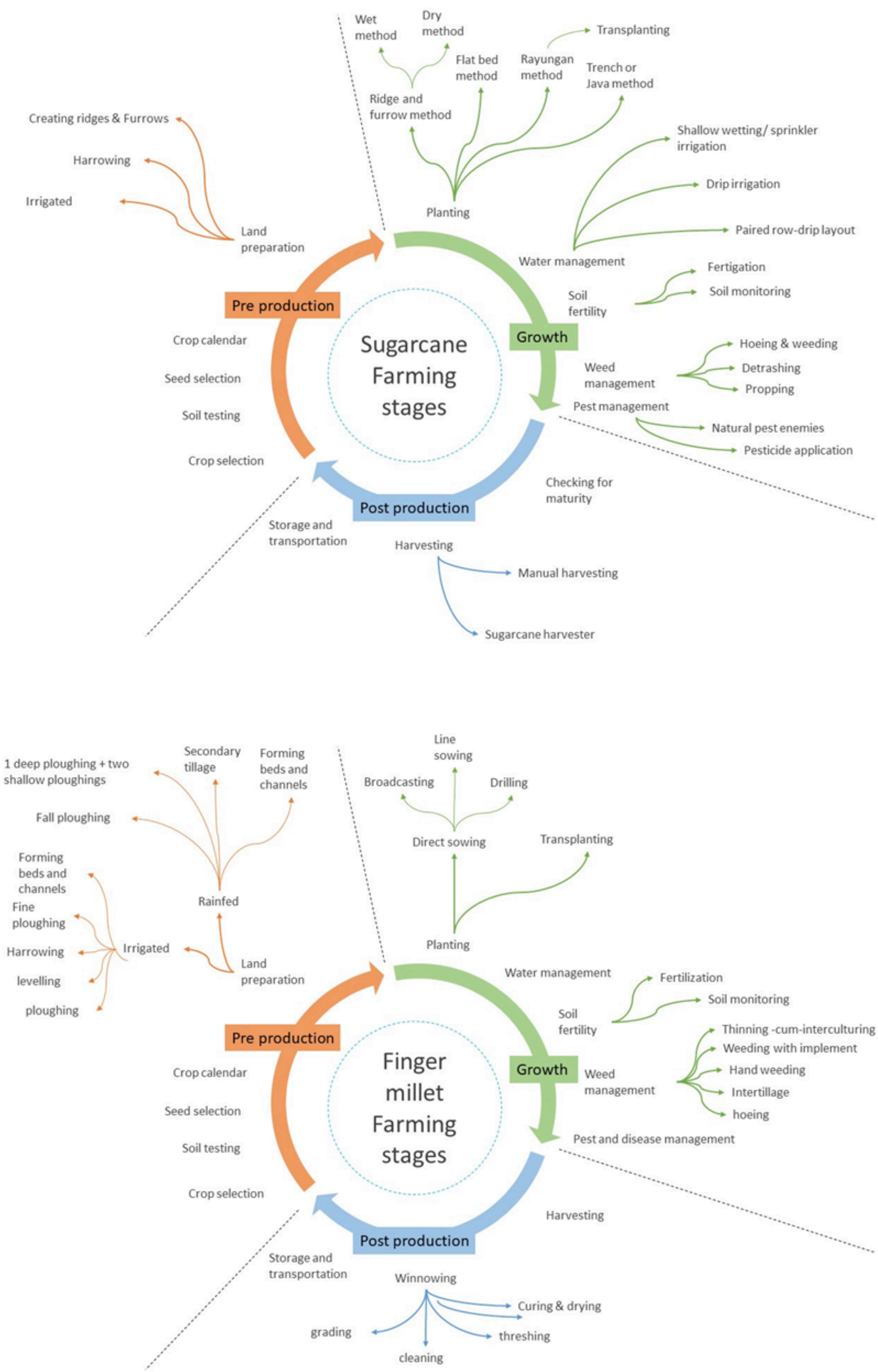
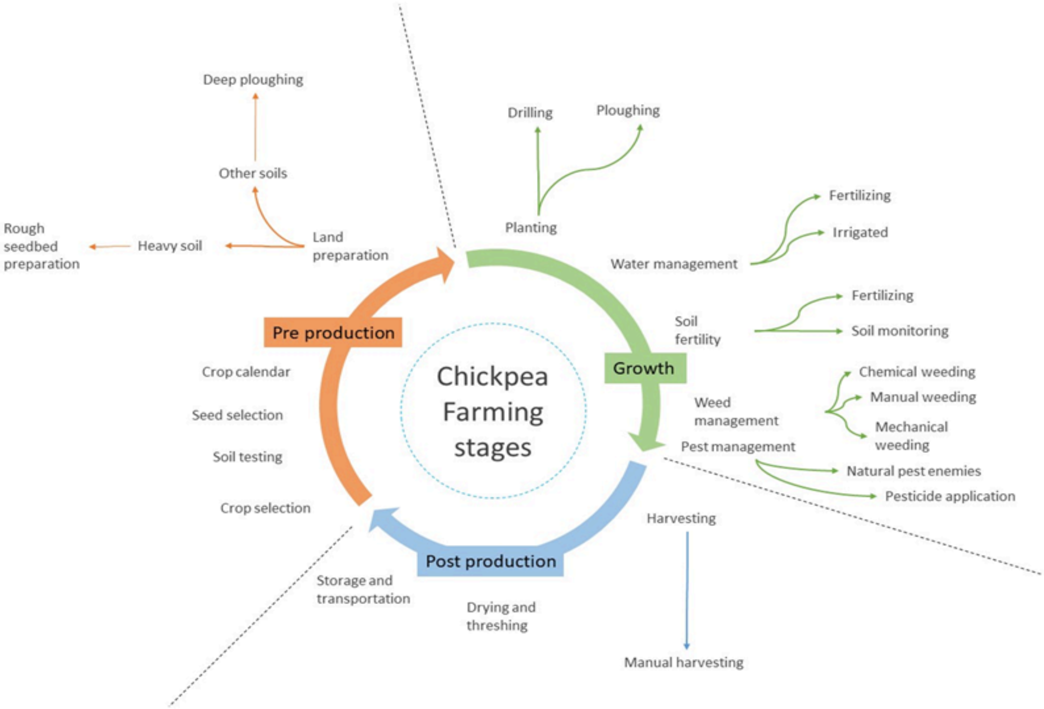


Figure 4.24: Sugarcane and Finger millet farming stages



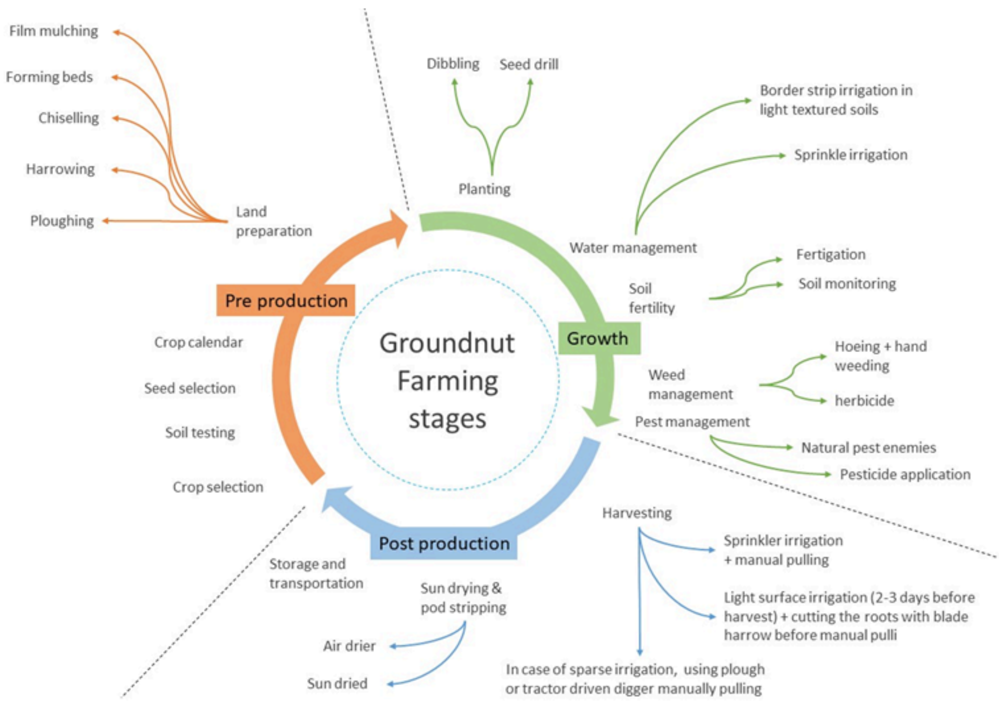


Figure 4.25: Finger millet and Chickpea and Groundnut farming stages

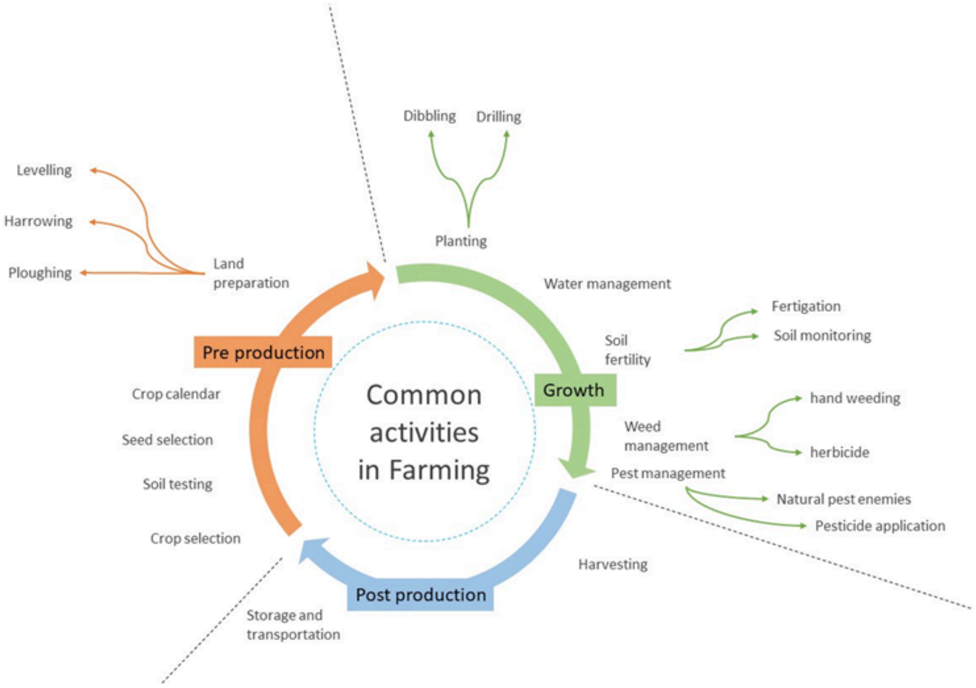


Figure 4.26: Common activities in farming

4.4.1.3 Observation. It is noted that primarily the activities which change are land preparation, sowing and harvesting. Apart from these three activities, by, and large all other activities are common across various types of crops.

4.4.2 Identifying possible directions for design intervention

Based on previous field visits, workshop, existing tools and informal discussions, the following possible design directions were discussed (Fig. 4.27).

Simple manual tool: These are simple handheld tools; these can be manufactured easily and are the cheapest farm implements available. Most traditional tools used by small scale farmers fall under this category. They are affordable as they usually cost less than ₹ 5000/- (94.12 AUD). They are portable and can be mostly used in all terrains. These tools also are slow at executing the activity. example: Sickle

Complex manual machines: These tools and machines are manually operated but have a more complex mechanism compared to simple manual tools. They are also low cost and usually cost between ₹ 500 to 10,000/- (approx. 10 to 190 AUD). They can be used in most terrains and have a higher speed or output compared to simple manual tools e.g. Two row rice transplanter

Simple animal/motor driven implement: These are complex machines but are small and can be driven by small motor or animals. These are costlier and and cost up to ₹ two lakh (3800 AUD), they are not as portable as the previous two categories, however, they have a much higher output and efficiency compared to manual machinery, e.g. Power tiller

Simple animal/motor driven implement: These are complex machines but are small and can be driven by small motor or animals. These are costlier and and cost up to ₹ two lakh, they are not as portable as the previous two categories, however, they have a much higher output and efficiency compared to manual machinery, e.g. Power tiller

Complex tractor attachments: These are complex implements that take power from a tractor or are pulled by a tractor during the activity. They have a much higher output and efficiency compared to manual machinery, e.g. Rotovator

Figure 4.27: Examples of possible directions in tool design. Clockwise from top left, simple manual tool (sickle), complex manual tool (Rice transplanter), simple motor-driven equipment (power tiller) and complex tractor attachment (rotovator)

4.5 Defining design drivers and factors

In order to design appropriate future proof solutions for small and marginal scale farmers, one needs to understand the changing dynamics of needs, wants and aspirations of these farmers. It is essential an that a human-centric approach is adapted to ensure that all the identified needs are holistically met while identifying the gaps in existing approaches (Pai et al. 2021).

However, the users may not always be able to identify their own needs, as a more holistic and wider view of the problem is required to develop lasting successful solutions. There is a need to understand and map the parameters which affect tool design which can ideally lead to a design checklist and later to a framework for developing sustainable, appropriate solutions for the rural areas.

A study of literature along with observations and discussions during field visits as well as documentation of tools developed by farmers led to the generation of a list of parameters which might affect tool design.

The following factors were identified and defined (Pai et al., 2021).

1. Ease of using: The machine should be easy to use and operate.
2. Ease of learning: Learning to operate/use takes minimum time, or learning curve is gradual when a new machine is introduced.
3. Ease of manufacture: The machine should be manufactured using a local technical ability or using readily available manufacturing processes.
4. Ease of recharge/refuel: The tool/machine should use readily available fuel /power sources (use of diesel/kerosene or larger efficient batteries that can be recharged manually)
5. Cost of manufacture: Using the economy of scale or standard readily available base material/ mechanisms (e.g. bicycle sprockets and ratchet)
6. Capital costs: Purchase of land, equipment, building or construction (e.g., bunds, canals, wells, fences and sheds)
7. Running costs: maintenance costs, labour costs, rent, fuel/fodder cost etc.
8. Ergonomic design: comfortable to use/operate with minimal risk of injury along with a reduction in effort, gender-friendly
9. Functional aesthetic: a form which is culturally and functionally appropriate
10. Type of ownership: personal, shared, institutional
11. Portable: Easy to move/transport across diverse terrain

12. Utility: able to do multiple tasks for similar crops or the same task for a wide range of crops or useful for on-farm as well as off-farm activities
13. Modular/quick change over: able to quickly reconfigure for different tasks or ability to quickly change attachments
14. Robust: less likely to fail/ works under different climatic conditions
15. Use of farm animals: using draught animals which provide farm power as well as a source of fertiliser and pesticide through excrement
16. Locally available raw material: Using material available in or around the farm and the village.
17. Locally repairable: can be repaired using local know-how or readily available standard spare parts/ materials
18. Easy to dismantle/dispose of: biodegradable materials/easy to dismantle different materials for scrap and recycle
19. Easy of upcycling: using standard materials which can be reused for other purposes, the form of parts allows additional utility after dismantle
20. Ease of Recycling: Allows the product to be dismantled into components that can be recycled or disposed appropriately and responsibly by ensuring the use of biodegradable materials where possible
21. Low emission/pollution: uses power sources and methods of power generation that minimises the harm to the environment
22. Quality of output: considering traditional wisdom into account to determine what the farmers consider a good output as they are more sensitive to subtle differences in quality of the produce.
23. Gender-friendly: taking gender roles into account along with how the product would fit around the other activities to be performed.
24. Power generation: the mode of power generation or transmission that would drive the artefact.
25. Availability of infrastructure: considering the type of infrastructure available in terms of transport, mobility, and storage
26. Culturally appropriate: The artefact to be created needs to fit in the culture of the place and time. This is especially critical in a multicultural country like india. Ex. In some cultures the gender roles might be rigidly defined ot the apparel to be worn might have an effect on 1) the way a product is used as well as 2) considerations related to safety

There are interrelationships and dependencies between the factors themselves, which needs to be examined for each project as the priorities and dependencies will change based on context and type of design intervention.

Type of ownership and infrastructure will have an impact on drivers like power source, portability, costs of procuring and maintenance. For example, if a device is individually owned, the farmer might prefer a human-powered locally manufactured solution as it reduces both running and capital costs and allows easy understanding and maintenance. However, if it is community-owned, the machine could be powered using electric motor or fuel engine as the cost of ownership and running costs are shared, also as a community (like and NGO and farmers society), it becomes easier to access and demand infrastructure projects (like setting up solar panels or getting an electricity connection). Similarly, access and availability of infrastructure would also have an effect on modes of portability and mobility, power sources and aspects of collapsibility for easier storage. The 26 parameters identified above were mapped onto a Design Futures (DeF) framework developed by Dr Sugandh Malhotra (Fig. 4.28) and then classified under various factors of human, technology, and environment.

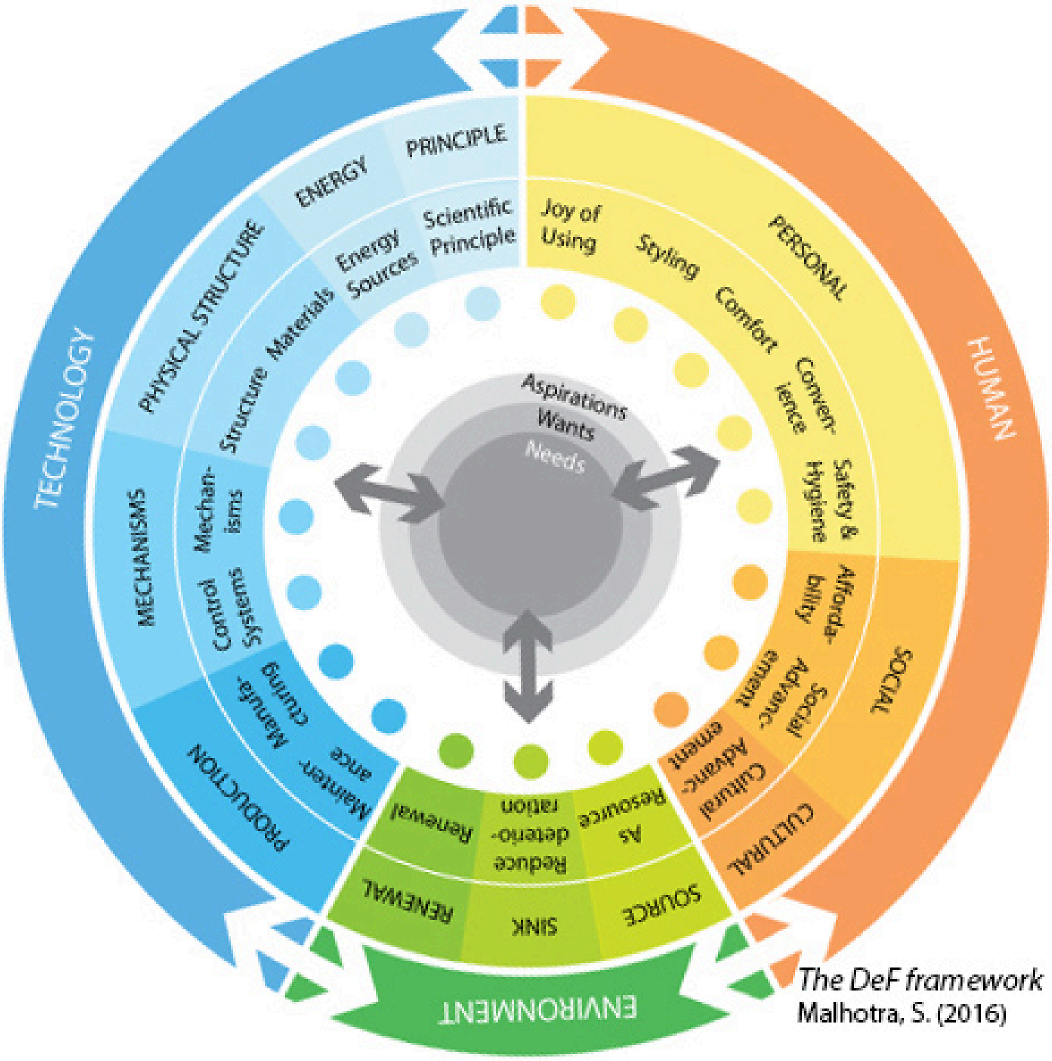


Figure 4.28: The Design Futures (DeF) framework. Reference: Malhotra (2016) http://sugandhmalhotra.com/2018/06/01/research-framework-for-forecasting-design-possibilities/ (as seen on 06-05-19))

The affinity of each derived parameter was checked concerning the factors arising out of human, technological and environmental considerations. The parameters were then classified under the three considerations to create a matrix (Fig. 4.29). The purpose was to try and come up with a tentative generic checklist for designing farm implements which can later be validated by trials of implements developed using the checklist.

HUMAN								
Parameters	**Personal**					**Social**		**Cultural**
	Joy of using	Styling	Comfort	Convenience	Safety & Hygiene	Affordability	Social Advancement	Cultural advancement
Ease of maintenance				✓				
Ease of using				✓				
Ease of learning				✓				
Portable				✓				
Ergonomic design			✓		✓		✓	
Type of ownership				✓		✓	✓	
Running costs						✓		
Capital costs						✓		
Functional aesthetic	✓	✓						✓
Utility				✓		✓		

TECHNOLOGY								
Parameters	**Production**		**Mechanisms**		**Physical structure**		**Energy**	**Principle**
	Maintenance	Manufacturing	Control Systems	Mechanisms	Stucture	Materials	Energy Sources	Scientific principle
Ease of manufacture		✓				✓		
Locally repairable	✓			✓		✓		
Robust	✓			✓	✓	✓		
Modular (flexible)	✓			✓	✓			
Cost of manufacture		✓				✓		
Ease of recharge/refuel							✓	

ENVIRONMENT			
Parameters	**Source**	**Sink**	**Renewal**
	As resource	Reduce deterioration	Renewal
Locally available raw material	✓		✓
Easy to dispose		✓	
Easy to recycle/upcycle		✓	
Use of farm animals*			✓
Low emission/pollution		✓	

* considering ethical treatment

Figure 4.29: Mapping parameters under considerations of Human, Technology, and Environment

A user needs pyramid (Fig 4.30) adapted from the pyramid of customer needs (Van Hagen, 2011) was then generated to assign a hierarchy to parameters identified during research. Then the outcome of this research, literature review and the pyramid was used to generate product specification for a farm machine for small and marginal Indian rice and wheat farmers.

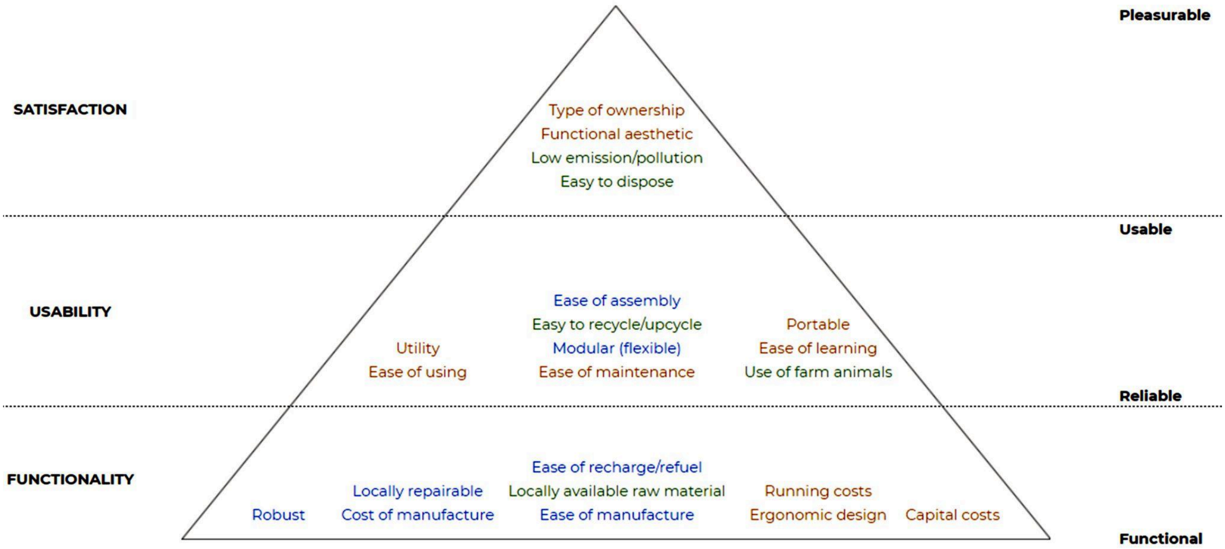


Figure 4.30: User needs pyramid

4.6 Design specification

The outcome of the field research, literature review and the user needs pyramid was used to generate a product specification for a farm machine for small and marginal Indian rice and wheat farmers. The following product specification developed from the literature study and research outcomes.

1. Ergonomic, gender-friendly and easy to use
2. Affordable, efficient and effective (compared to existing popular solutions)
3. Lightweight and portable
4. Is locally manufacturable or at least locally repairable
5. Uses Human power as an energy source

At this stage the researcher has focussed on the research objective of developing appropriate, affordable, context-specific and gender-friendly rice threshing solutions for small Indian farmers. In order to answer the research question 'How can design intervention in farm implements be used for sustainable agricultural intensification of rice farming for small and marginal farmers of the Western Ghats And Coastal Plains in India?', the decision was taken to develop farm equipment during the studio research part of the PhD. The objective of designing a machine was also for verification and validation of the design framework while developing a design intervention for small and marginal-scale farmers. The design framework was developed and refined using the 26 parameters during the various stages of designing and testing the machine. The first step was selection of farm activity.

Based on morphological visualisation and understanding of needs, the researcher decided to look at various post harvest activities. Three activities of threshing, cleaning, and milling were identified based on grain losses and the amount of physical effort required to perform these activities using traditional methods. These activities are defined as follows.

Threshing: The process of separating grain from the rest of the harvested crop. Traditionally, in Maharashtra and Goa, grains are threshed by trampling the harvested crop under feet, and hitting the bundles of crop on metal drum or wooden flats.

Cleaning: The process of separating impurities like unfilled grains, weed seeds, straw, pests, and soil particles from threshed grain. Cleaning can be further categorised into winnowing and screening. Winnowing involves separating lighter material like seeds, unfilled grain, and straw by pouring threshed grain slowly from a height in wind or in the path of a fan or blower so that heavier grains fall on the ground and lighter impurities are blown further away. Screening is used to separate heavier impurities like soil and stones using a small sized screen to sieve threshed grain.

Milling: Milling is the process of removing outer layers of husk (or hull) and bran to get white rice. Traditionally milling is performed by pounding of grain using mortar and pestle or by passing the grain between a hand mill where two circular stone discs grind and remove the layers using friction.

After studying these activities, threshing was selected because of following reasons,

1. It is a time dependent activity as the grains should be threshed at 18-20% moisture content to prevent shattering (FAO 2019).
2. Threshing accounts for 14 % and 24 % of all post-harvest losses in rice and wheat farming (IRRI 2019).
3. Threshing contributes to 14.6% of all farm injuries with 13.1 moderate to severe accidents/ 1000 threshers /year (Nag et al 2004).

We then studied existing devices, the most commonly used mechanical threshing device being the pedal thresher (Fig 4.31) . In these threshers, the operator holds the bundle of harvested crop over a rotating toothed drum. The drum in turn is rotated using a foot pedal which mechanically transfers power through a great train.

Figure 4.31: Manually operated pedal thresher. Adapted from Khadatkar et al. (2008)

Following issues and deficiencies were observed in existing pedal threshing solutions.

1. There is no support for hand while threshing. Since it is a day long process fatigue is developed after holding hands continuously.

2. Height of the platform from the ground is not suitable for all humans.
3. Pedal size doesn't accommodate all human feet.
4. Not easy to transport over bunds and farms.
5. Wooden threshing flats and pedal decays over time

Based on study of existing methods and solutions, as well as field and literature studies, the following detailed product specification was generated for a threshing solution.
To design a machine to thresh grain, it should,

1. Be ergonomic, gender friendly and easy to use
2. Affordable (comparable or cheaper than existing human powered threshing device)
3. Effective, and efficient (in terms of grain output/hour or bundles threshers/hour compared to traditional methods)
4. Lightweight and portable
5. Separate grains while retaining whole stalk (which will provide additional income as stalk is used in paper industry, thatching, fodder, bedding, mushroom cultivation and fuel for cooking when mixed with cow dung and dried)

Target user: Small and Marginal paddy farmers
Target Location: Western Maharashtra and Goa

4.7 Conclusion

This chapter has provided details of how field observations, interviews, and literature was used to understand the domain of small and marginal farming along with the needs of the farmers. The analysis of data collected from these sources was then used to generate morphological visualisations of farm activities, tools used, and needs of the small and marginal-scale farmers. This process also helped in identifying directions of possible design intervention and, and parameters that need to be considered for designing such interventions. The 26 parameters were then classified into categories of human, technology, and environment, and were then mapped onto a user needs pyramid. The chapter ends with identifying the focus of the studio research project where the post-harvest farm activity of threshing was chosen for generating a design intervention and a product specification was generated for the same.

5. Development of a threshing solution (Design + Development)

This chapter (Fig. 5.1) details the stages of development for generating a low-cost, bicycle-powered thresher. The chapter explains how alternative solutions were generated for each module of the thresher, and concepts were created and evaluated. Then the design work and further fieldwork, interviews, and study of artefacts were used to further refine and categorise the 26 factors into six design drivers and generate framework structures that could aid the design process.

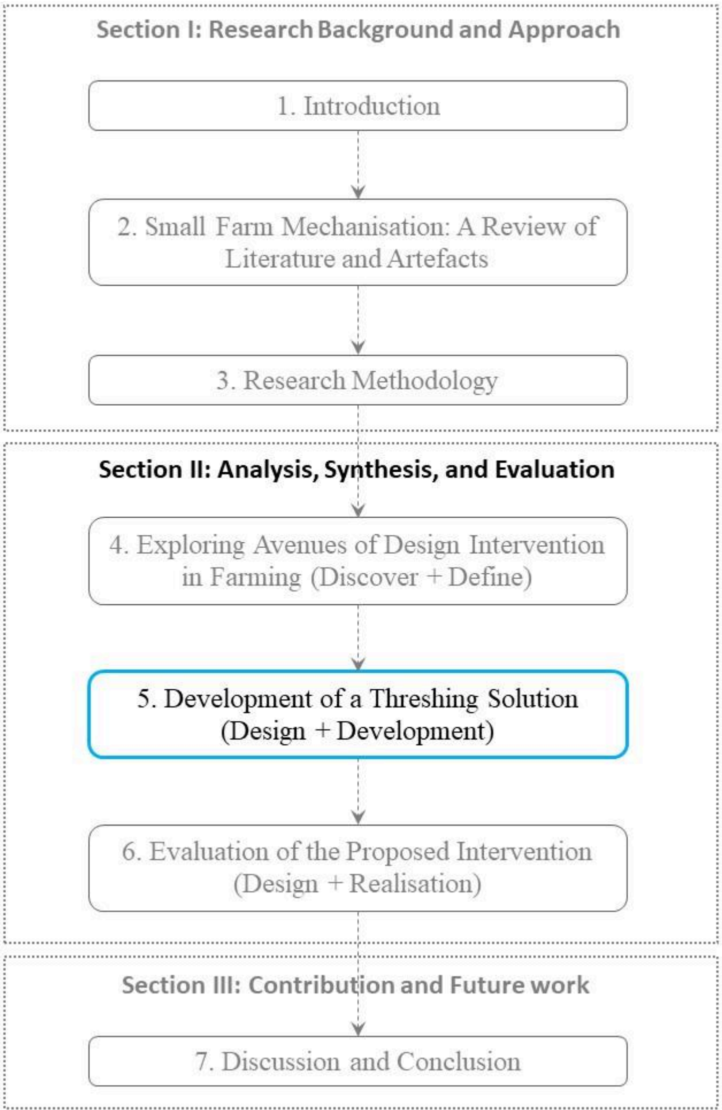


Figure 5.1: Development of a threshing solution (Design + Development)

5.1 Design objective

The objective was to generate ideas for a portable, low cost device that can thresh rice effectively and efficiently.

5.2 Ideation

At the end of the previous stage, the researcher decided to design a machine for threshing (separating the grain from rice). Threshing is a time-sensitive activity as it is dependent on the moisture content of the grain. The second stage started with a study of existing solutions. The objective was to find possible design directions and identify where our proposed design could be located with respect to existing solutions.

5.2.1 Identification of possible intervention spaces

In order to find design direction and intervention space vis-a-vis existing products, the common solutions available for threshing were mapped on a Hedonistic-Emotional-Ascetic-Technical (H-E-A-T) diagram (Fig. 5.2). The H-E-A-T framework (Das 2002) maps design contributions along the axis of the hedonistic-ascetic continuum, and emotional-technical continuum needs in order to generate insights. The framework also helps in understanding quality of needs in four quadrants of Hedonistic-Technical needs, Ascetic- Technical needs, Ascetic-Emotional needs, and Hedonistic- Emotional needs (Singh, 2014).

We interpreted the two continuums as follows:

Hedonistic - Ascetic: In terms of designing a low-cost context-specific device as farmers, the researcher interpreted the Hedonistic side as a bespoke, personal, exclusive device, and the Ascetic end would be interpreted as a mass-manufactured, social and inclusive device.

Emotional - technical: Here, the emotional end was interpreted as a low-fidelity, simple, makeshift (jugaad), and upcycled device. Whereas, the Technical end was interpreted as high fidelity, complex, high-tech device.

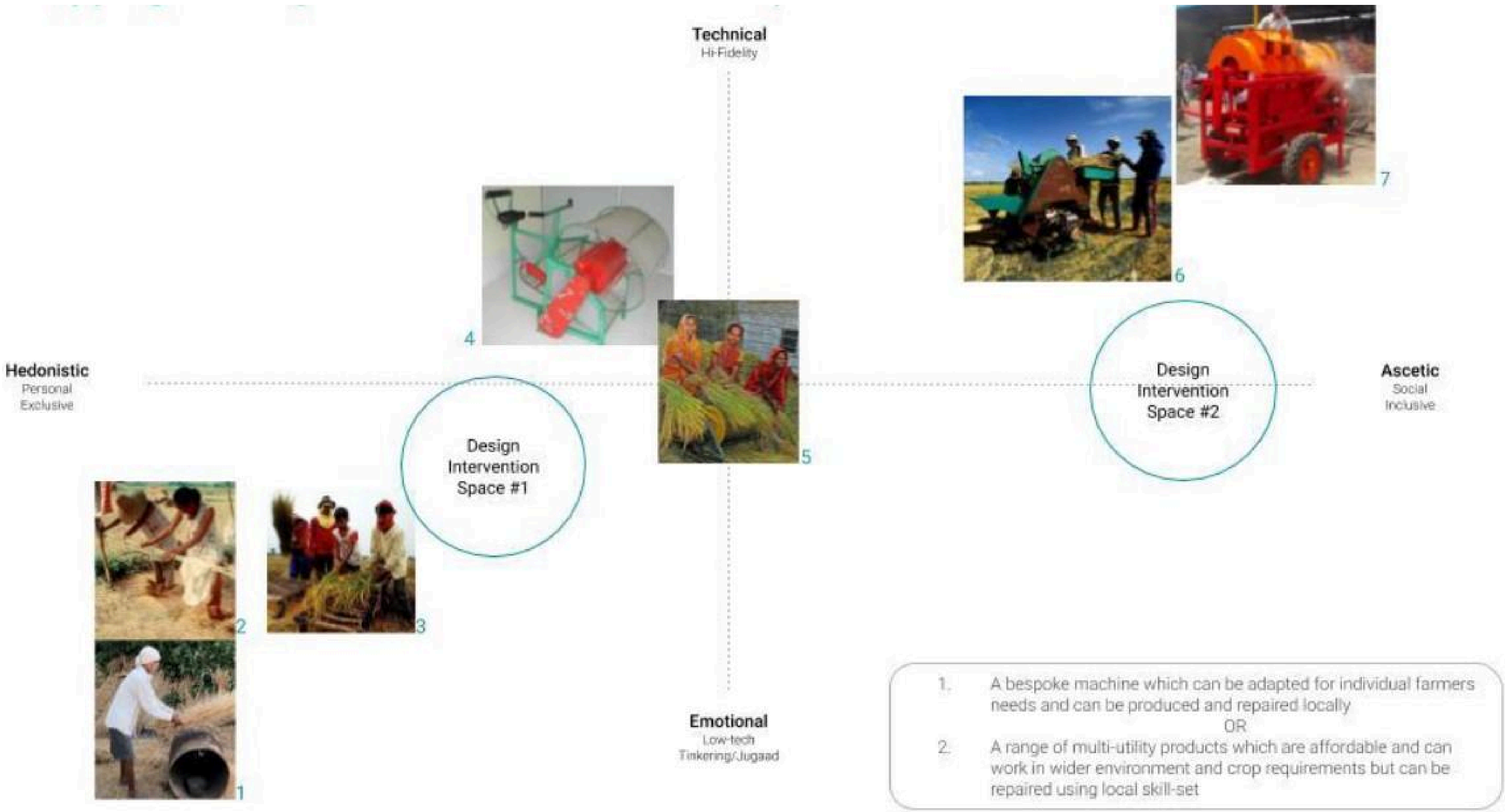


Figure 5.2: Mapping existing threshing solutions on a H-E-A-T framework

We plotted both the traditional tools and techniques like beating on a drum or wooden flats, trampling the grain below feet and modern devices like various pedal threshers and motorised threshers along these two continuums.

There were two possible intervention spaces that were identified. The first one was an idea of a bespoke machine adapted for an individual farmer based on the context and which could be produced and repaired locally using readily available materials. However, it would be designed to allow it to be adapted and scaled up to different contexts and locations. The second space was a range of affordable multi-utility products that can be used in a wider range of environments and for different types of crops. However, they need to be designed so that they are easily repairable at a local level using available skill sets.

Once the possible intervention spaces were identified, the next step was to study the most popular mechanised threshing equipment.

5.2.2 Elements of thresher

Apart from traditional threshing methods like beating and trampling, some small and marginal farmers use a human-powered pedal thresher machine. The pedal thresher (also known as treadle thresher) is one of the most widely used threshing equipment for rice threshing. It uses a crank and a pedal board that is operated by one foot to drive a threshing drum. Farmers hold bundles of cut rice plants over the drum so that the panicles of rice get hit by the loops on the drum. This hitting and combing action removes the grains from the plant while retaining the bundle of hay in the operator's hand.

The existing paddle thresher was studied first, categorising the elements of the thresher into four major categories (Fig. 5.3):

1. A chassis: In the existing pedal thresher the chassis is the sturdy frame made up of welded MS angles.
2. Drivetrain: The drivetrain consists of a pedal, pedal frame and fulcrum crank, gear train, and flywheel.
3. Threshing drum: The drum is made from two co-axial metal discs with bearings which are connected using metal flats. The metal flats are fitted with staggered wire loops or rasp bars.

4. Guard: The guarding is made from the metal sheet and creates a barrier between operator and moving elements of the machine.

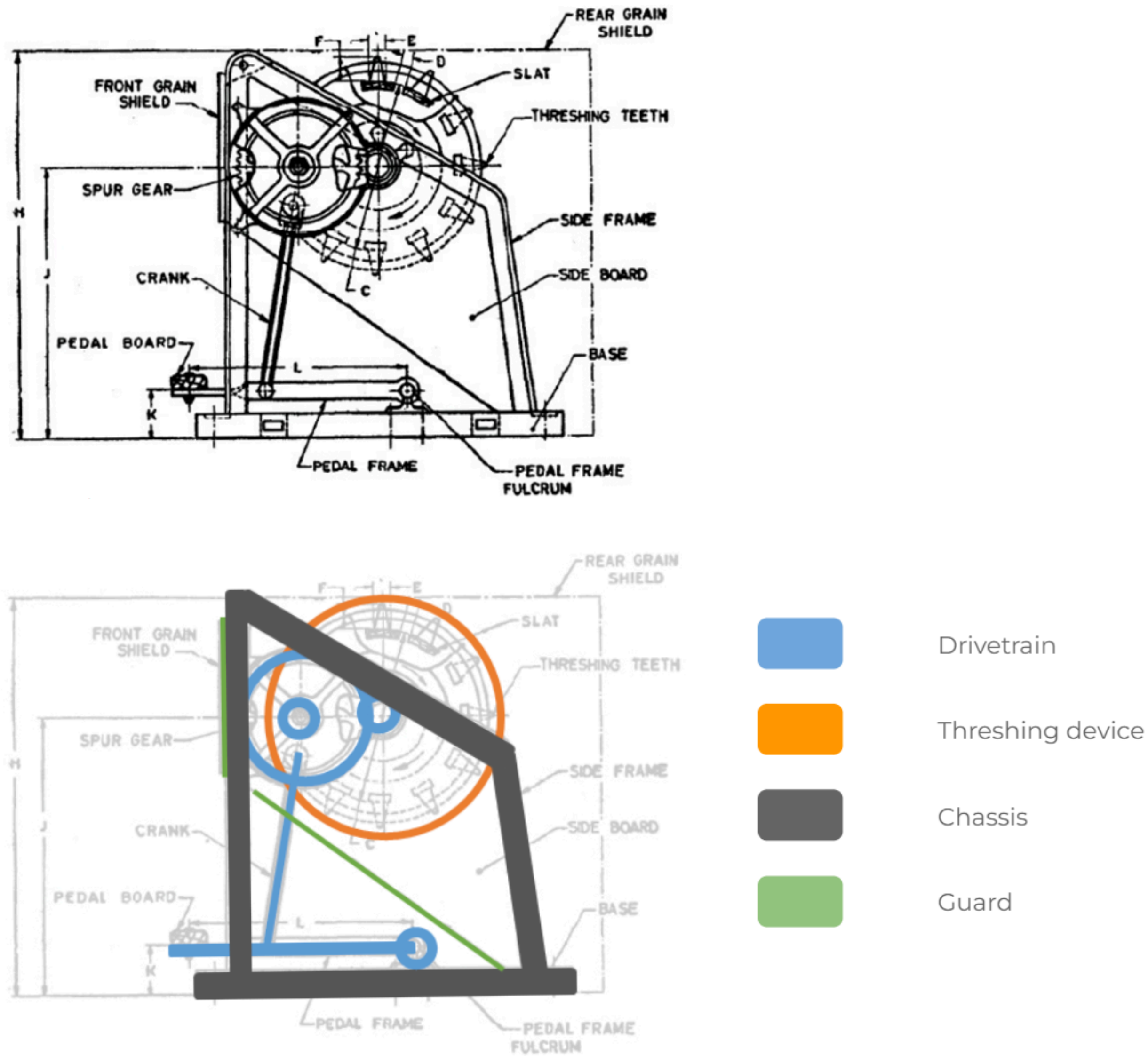


Figure 5.3: Elements of a pedal thresher. Reference: ISI (1982)

Categories of operator position, power source, and threshing action were added to these existing elements and a morphological chart was generated where possible alternative materials and methods were explored (Table 1).

The researcher also identified following major issues with existing pedal thresher which could be resolved on while developing a new concept,

1. There is no support for the user's hands while threshing; since it is a day long process fatigue is developed after gripping bundles in hands continuously.

2. Height of the platform from the ground is not suitable for all humans.
3. Pedal size doesn't accommodate all human feet.
4. It is not easy to transport over bunds in farms.
5. Wooden threshing flats and pedal decays over time

Table 1

Morphological chart for elements of a pedal thresher

Chassis	**Power source**	**transmission**	**Primary action**	**Operator position**	**Safety**
MS weldment	Manual	Chain drive	Combing	Standing	PMMA guards
Bolted SS/ Al channels/ sheet	Animal driven	Belt drive	Impact	Recumbent	Upcycled cloth
Wooden flats	Electric motor	String drive	Grinding	Upright sitting	
Lashed bamboo	Diesel engine	Shaft drive	Rubbing		
Reconfigured bicycle frames		Linkages			

5.2.3 Initial ideation for elements of threshing device

The morphological chart generated using various elements of a threshing device was then used as a basis for creating a mind map at the initial stage of idea generation where some of the promising options were detailed and visualised (Fig. 5.4). Sketching was then used as a primary method to synthesise and communicate ideas for each of the elements. The ideas were refined using scaled mock-ups, CAD models, and a full-scale low fidelity volume model.

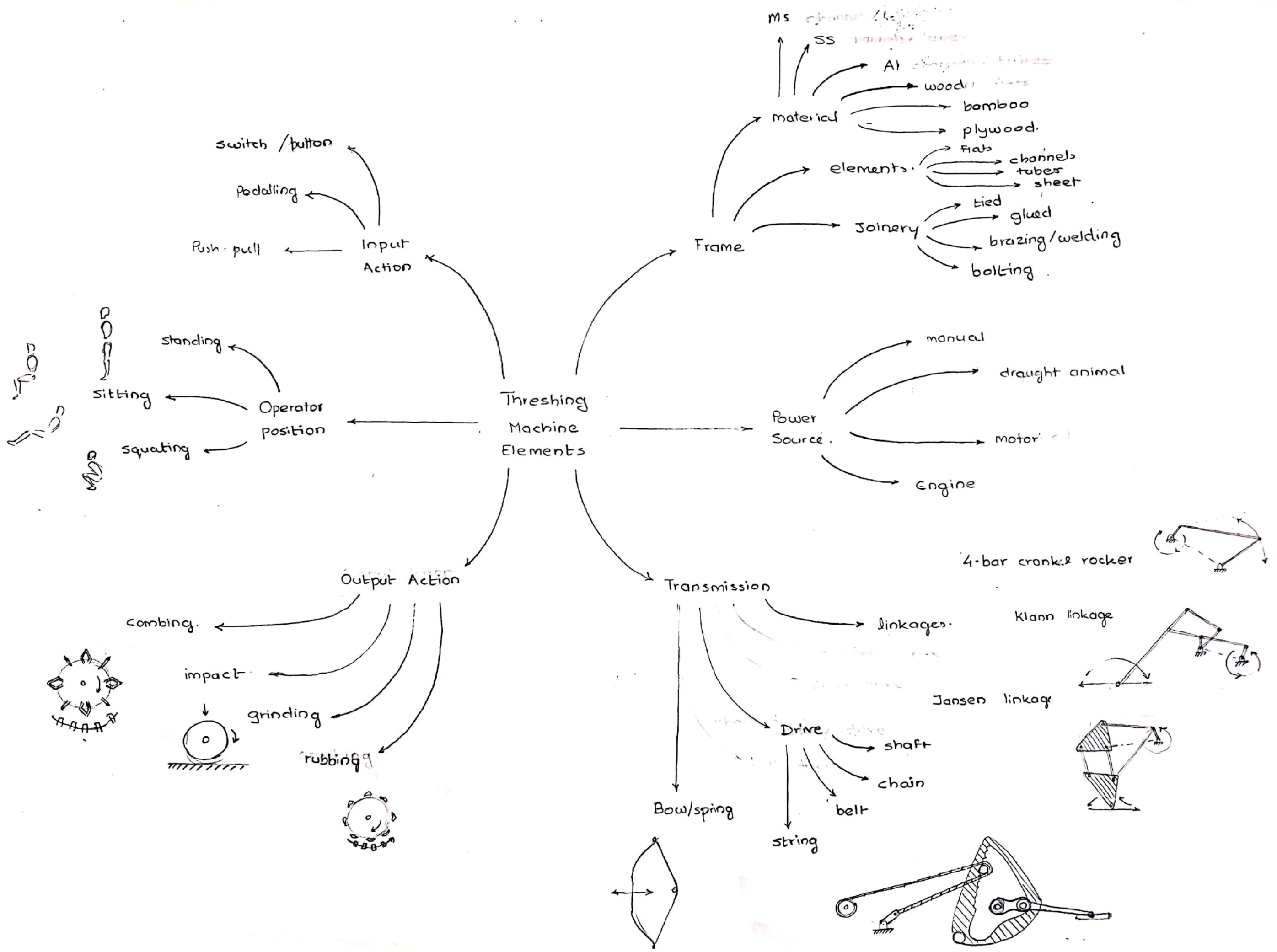


Figure 5.4: Mind map for initial ideation for different elements of a pedal thresher

5.2.3.1 Power generation and transfer. After exploring various options and existing examples of using human power in farms, the researcher decided to use a bicycle (the chain-chainwheel-freewheel setup) as the primary source of power generation and transmission. The bicycle is one of the most ubiquitous modes of transport in rural India where only four percent of the farm owners own two to four wheeled equipment (Government of India, 2011). The researcher chose pedalling as the primary action for generating power and driving the thresher because for moderate to high power requirements, pedalling is one of the most efficient actions along with rowing (Moore, 2017). Also, according to Wilson (1977), conventional bicycle pedalling can produce maximum power output from the rider. The third and most important reason for using pedal power was that it would make the operation of the machine a bit more gender neutral especially since bicycle effectively transmits power using "the most powerful muscles in the body (the thigh muscles), in the right motion (circular pedalling motion), at the right speed (60-80 rpm)". (McCullagh, 1977)

The first step was to ideate multiple ways in which power could be transferred from the bicycle to the device. Following four options were explored, 1) friction drive (Using another wheel with cycle treads in contact with cycle tyre), 2) using a disk mounted on spokes and rope drive (ex. bicycle driven knife sharpening device), 3) direct transmission from rear axle using extended shaft and coupling, and 4) using additional chain drive with gears.

5.2.3.1.1 Friction Drive. In this option, the intent was to use the rear wheel of the bicycle as the driving wheel. A rubber driven wheel (of required friction coefficient) would be then connected to the rear wheel in a way that the rubber tyre of the wheel would touch the driven wheel and transfer rotation. This could be transferred either keeping the driven wheel parallel or perpendicular to the rear wheel depending on the device setup (Fig. 5.5). The friction driven wheel is in turn connected to the threshing drum.

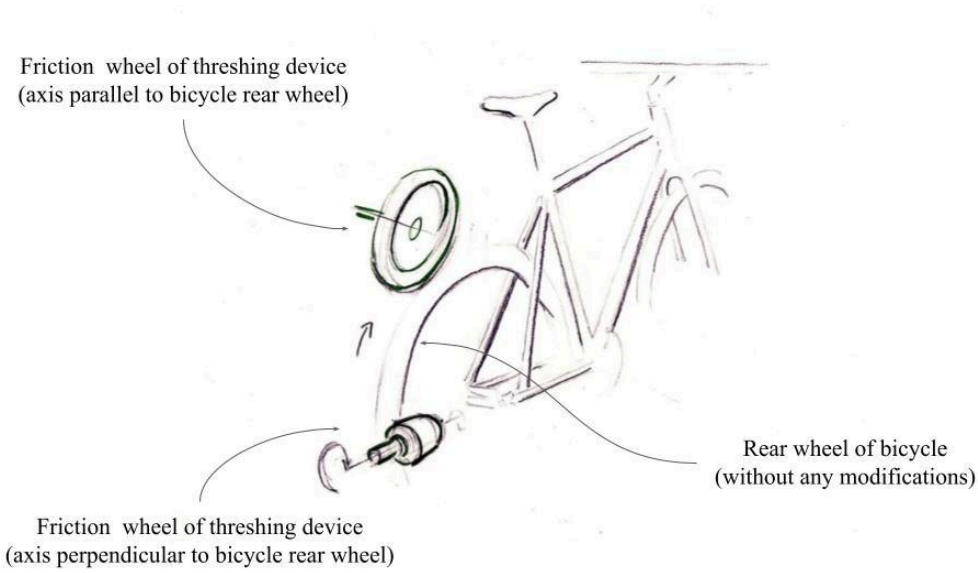


Figure 5.5: Friction Drive

5.2.3.1.2 Rope Drive. This idea is based on the bicycle driven knife sharpening devices that are quite common in India (Fig. 5.6). In this approach, a pulley disc is attached to the spokes of the rear wheel. This pulley is connected to another pulley mounted on a shaft which connects to the threshing drum. The rotation from the rear wheel of the bicycle to the threshing drum is transferred using a rope (Fig. 5.7).

Figure 5.6: Bicycle operated knife sharpening device. Reference: Make Life Easy (2018)

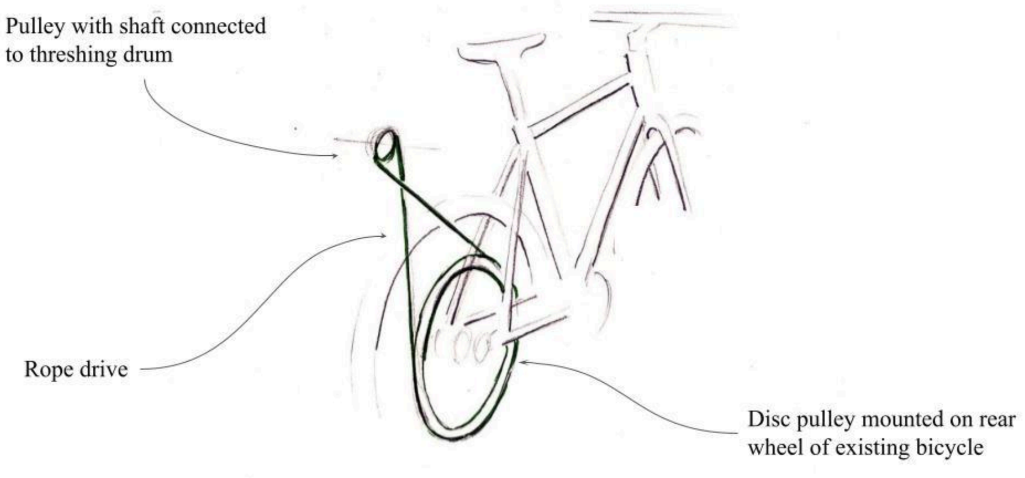


Figure 5.7: Rope drive

5.2.3.1.3 Direct transmission. In this approach the shaft of the rear wheel hub of the bicycle is extended. This extension is connected to a shaft from the threshing device using a coupling (Fig. 5.8). This arrangement allows direct transmission of power from the rear wheel to the threshing device.

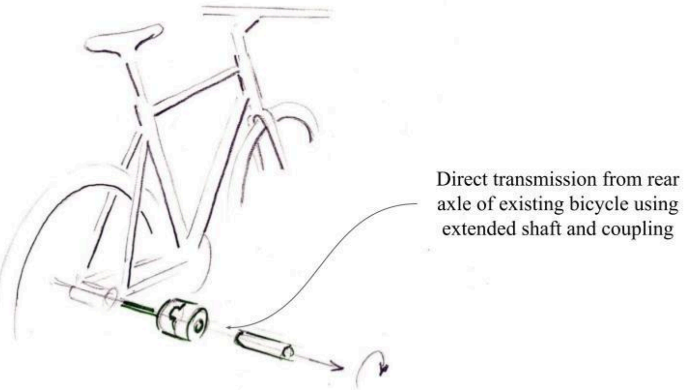


Figure 5.8: Direct transmission

5.2.3.1.4 Chain drive. Another way of connecting the threshing drum to the rear wheel would be to use a chainwheel-chain-freewheel transmission similar to the one used in bicycles. Here, the chainwheel would be mounted on the rear hub of the bicycle. The chain wheel is in turn connected to the freewheel mounted on the threshing device using a standard roller chain like the one used in bicycles (Fig. 5.9). This allows the use of existing standard bicycle components to transfer power with minimal losses.

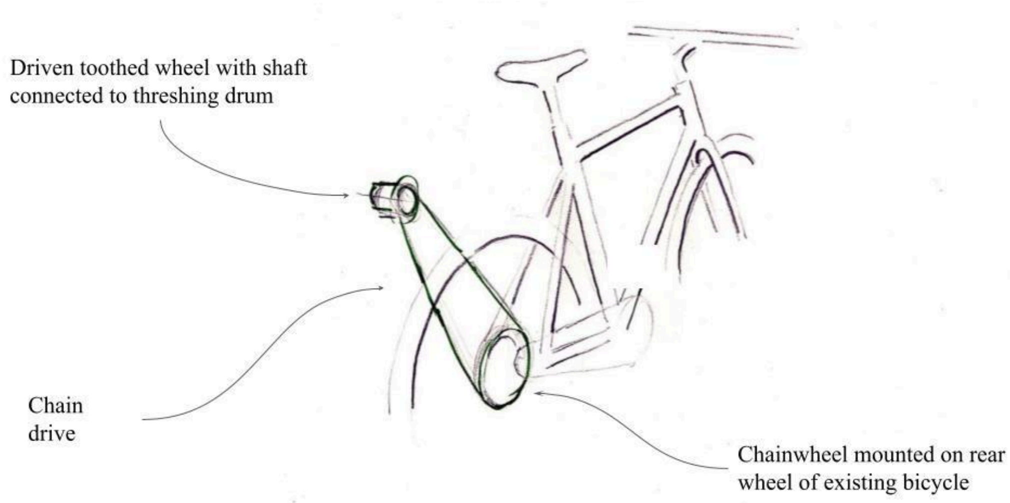


Figure 5.9: Chain Drive

Some of the more promising options were then detailed further to generate concepts for power transmission to farm equipment using bicycles as a power source. The ideas were constantly informed, driven and evaluated using the factors from the user needs pyramid (Fig. 4.30), especially the factors from usability and functionality bands like ease of manufacture, ease of repair, ease of use and portability.

The multiple ways in which existing available bicycles would be used to generate power for the threshing drum was explored next. The four primary approaches were as follows:

5.2.3.1.5 Using friction drive on a standard bicycle. Figure 5.10 shows different ways in which a friction drive could be used to connect the bicycle to the device. This was also one of the possible design directions for a farm machine which uses any available bicycle without any modifications to draw power. The advantage here would be the ability to use any available bicycle in the village whenever required as opposed to keeping any one bicycle occupied only for one purpose. In this option, a stand with rollers will be connected to the threshing device chassis. The operator or farmer would bring any available bicycle and mount the rear wheel on the rollers. This would lift the rear wheel and keep it in place so that it can be used for power transfer.

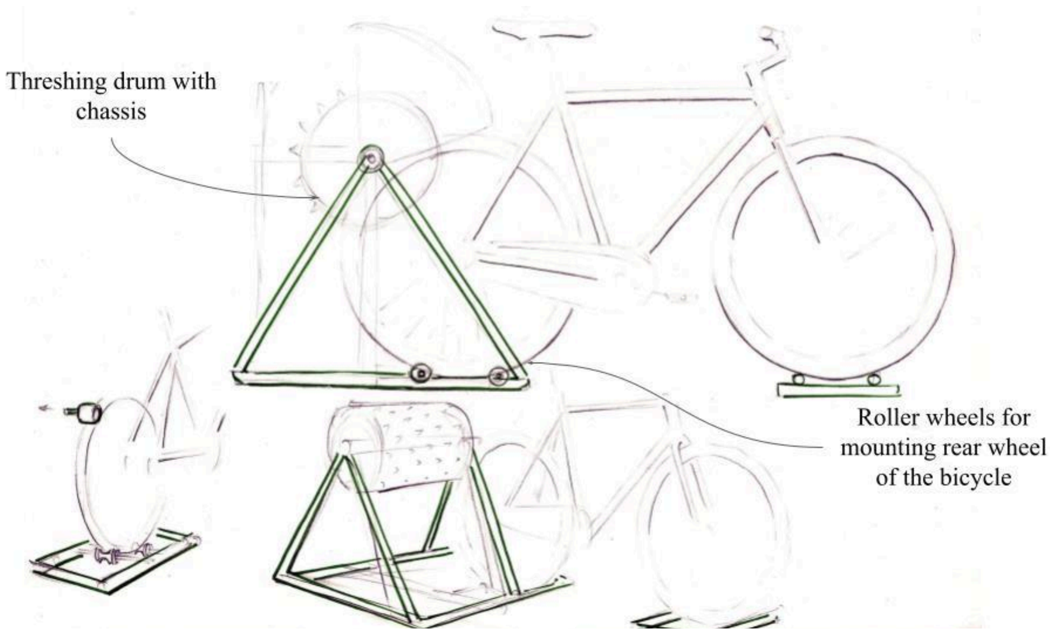


Figure 5.10: Friction drive using a bicycle without modification

5.2.3.1.6 Using a foldable structure with power transmission. This approach involves mounting a structure on the bicycle in such a way that it allows the bicycle to convert into a power generation device whenever the structure is engaged. The idea was to use an additional chain drive on a frame mounted on the cycle while also using the foldable frame attachments that can be replaced to get optimum height of driven shaft for different operations (Fig. 5.11).

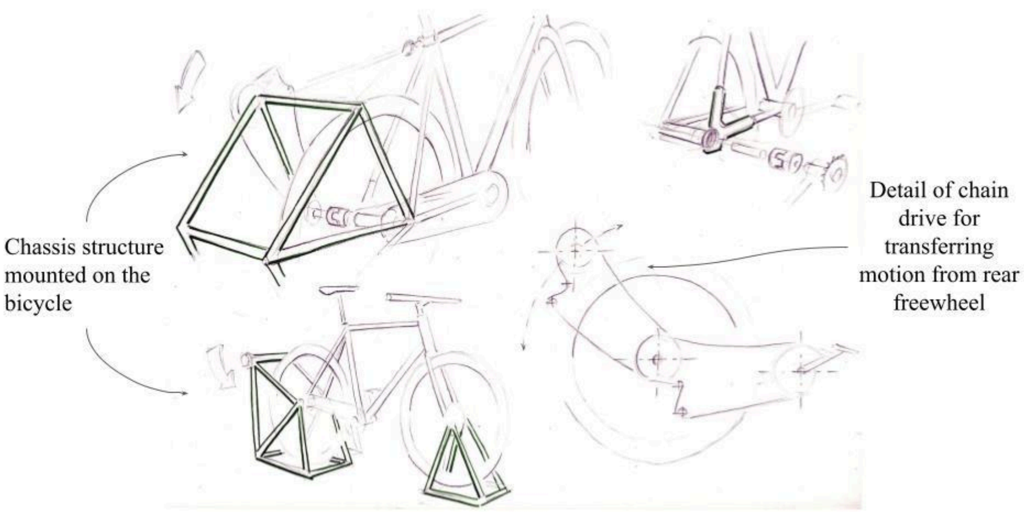


Figure 5.11: Using a foldable structure with power transmission

This approach could be used for not just for threshing but other activities like weeding by modifying the structure (Fig. 5.12).

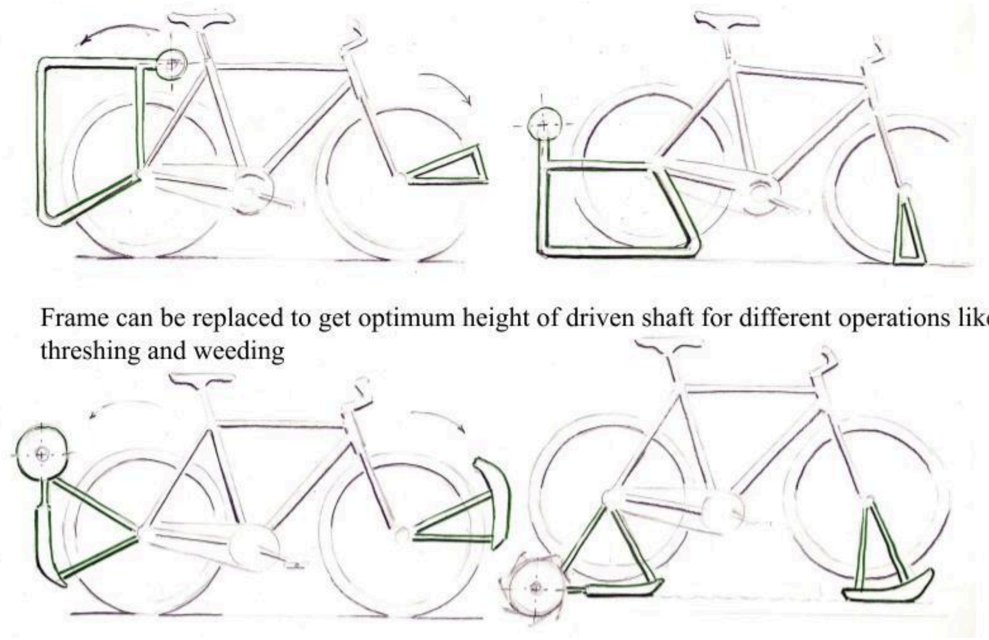


Figure 5.12: Using a foldable structure for threshing or weeding with some modifications

Further details were explored to visualise the design of brackets needed to mount these frames along with the possibility of extending the rear axle shaft for mounting brackets, frame and chain drive. (Fig 54).

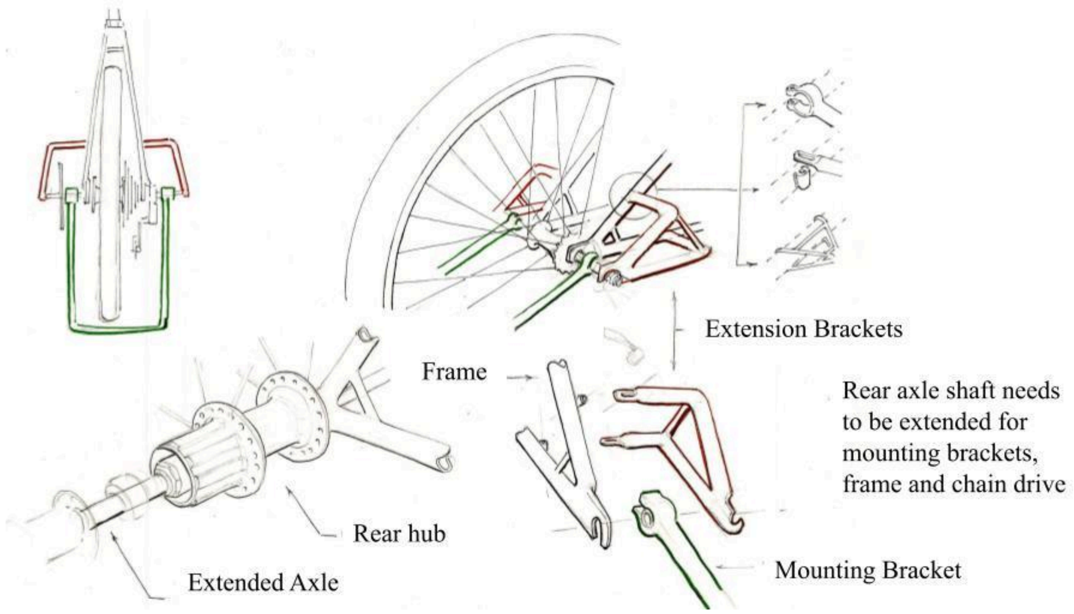


Figure 5.13: Joinery details for folding structure

5.2.3.1.6 Using a bicycle frame and chain drive without wheels. The researcher also worked on another design direction of using the frame and drivetrain of the bicycle with some modification, such as removing front or rear tyres and replacing rear hub. This idea was further divided into two variations. The fist one involved removing wheels and mounting a seat on handlebars for a comfortable recumbent posture (Fig. 5.14). For example, to use this setup for threshing, the rear axle needs to be connected to the threshing drum, and the rear axle ratchet mechanism is reversed. Also, additional gears and derailleur would be required to achieve a gear ratio of 1:4 - 1:7 necessary for adequate threshing drum speed.

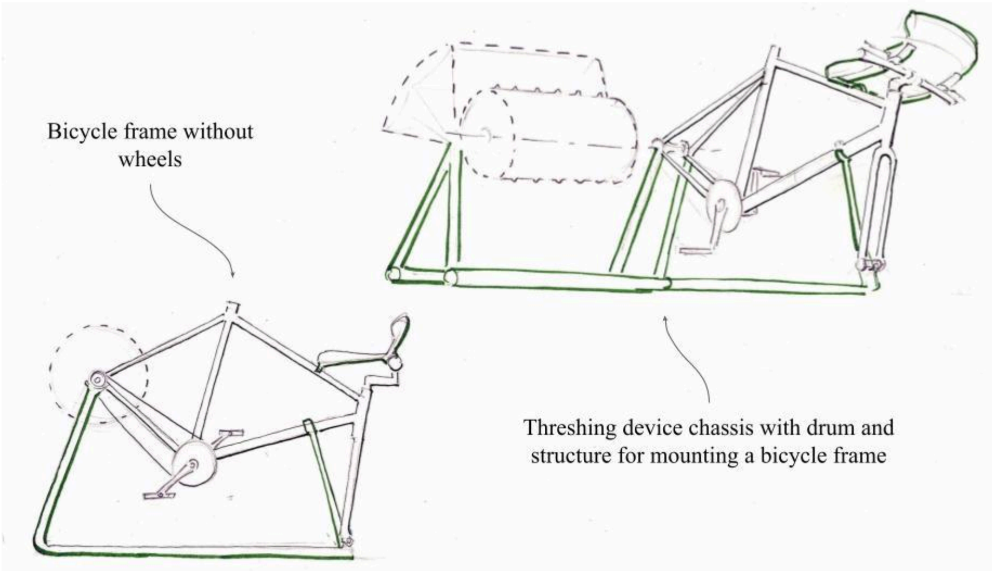


Figure 5.14: Using a bicycle frame and chain drive without wheels

Another variation of the same idea was to have a standing pedalling posture. This idea involved removing wheels as well as pedals and using linkages to achieve elliptical input. In this case, the rear axle needs to be connected to the threshing drum, and the rear axle ratchet mechanism is reversed (Fig. 5.15). Since ellipse and linkage length can be optimised for power stroke, higher torque can be achieved by this means negating the need for gears.

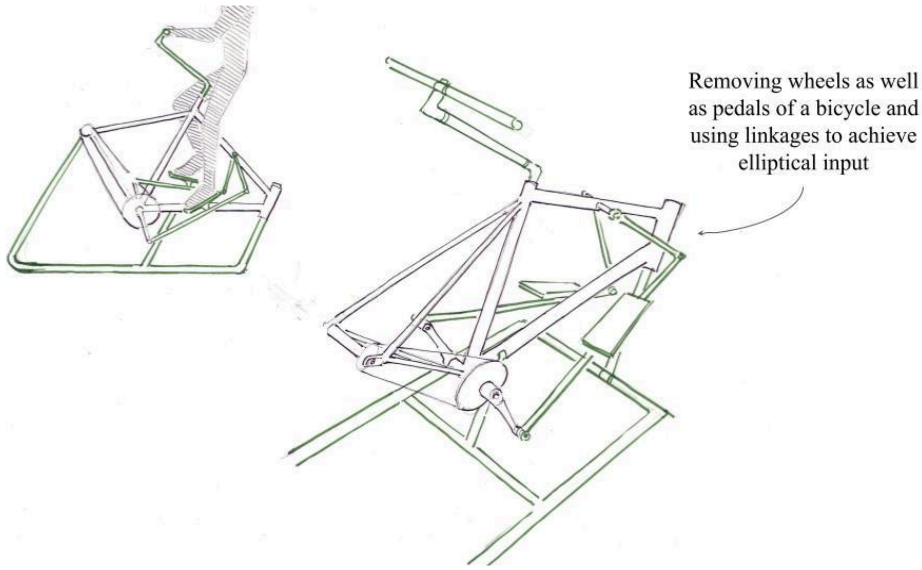


Figure 5.15: Using frame and drive for direct transmission with elliptical input

5.2.3.1.6 Harvesting a used bicycle for making new devices. The next design direction for power transmission involved cutting and dividing old bicycle parts for stationary and mobile activities. For example, figure 5.16 shows how stationary activities like threshing and dehulling will be performed using the rear axle and chain drive, and mobile activities like harvesting, weeding, spraying can be performed using the front wheel connected to a belt or string drive.

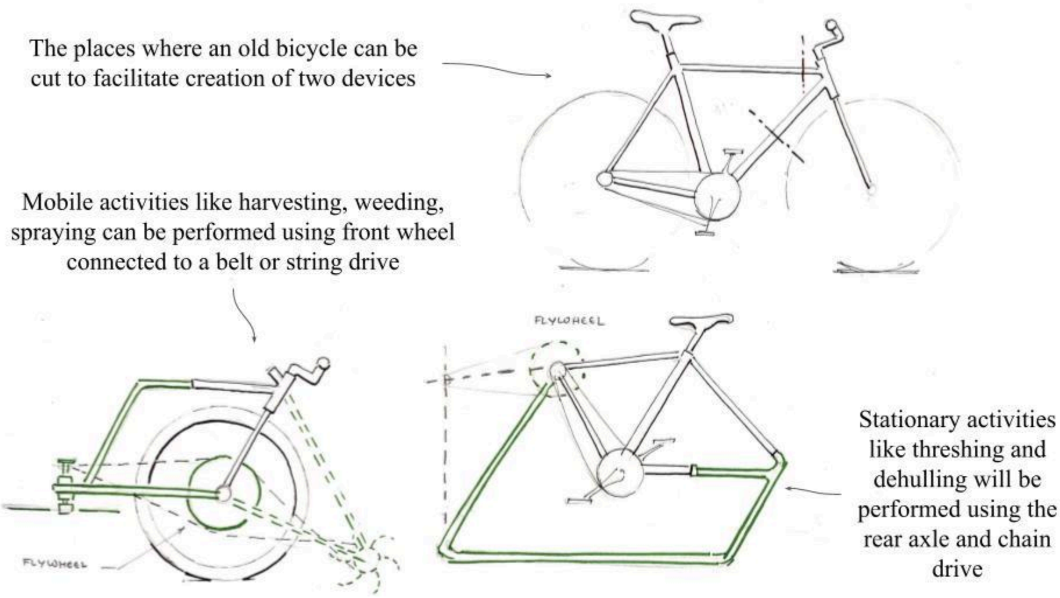


Figure 5.16: Dividing the cycle for stationary and mobile activities

Figure 5.17 shows the possibility of using front wheel and fork assembly with a pulley system. This setup could be modified for broadcasting seeds, pesticide spraying, transplanting, harvesting, and weeding using minimal change parts.

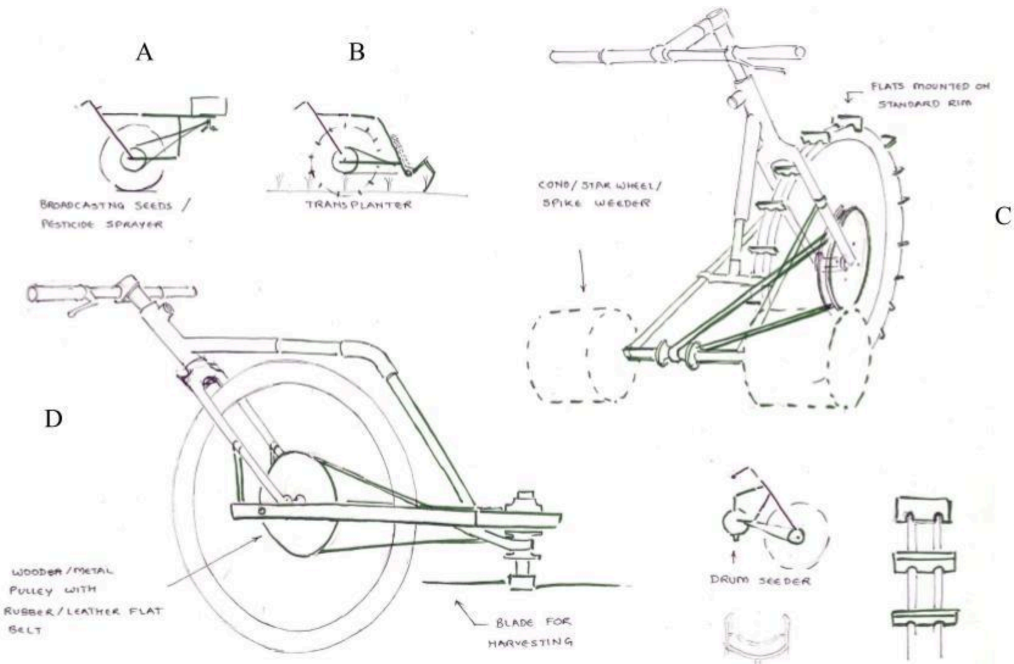


Figure 5.17: Using front wheel and fork assembly with a pulley system for A) Broadcasting/pesticide spraying, B) Transplanting, C) Weeding, D) Drum spraying, and E) Harvesting.

The next stage of exploration involved using the rear frame and chain drive of the bicycle for power take off. Figure 5.18 shows explorations of transferring rear axle rotation to power take off shaft.

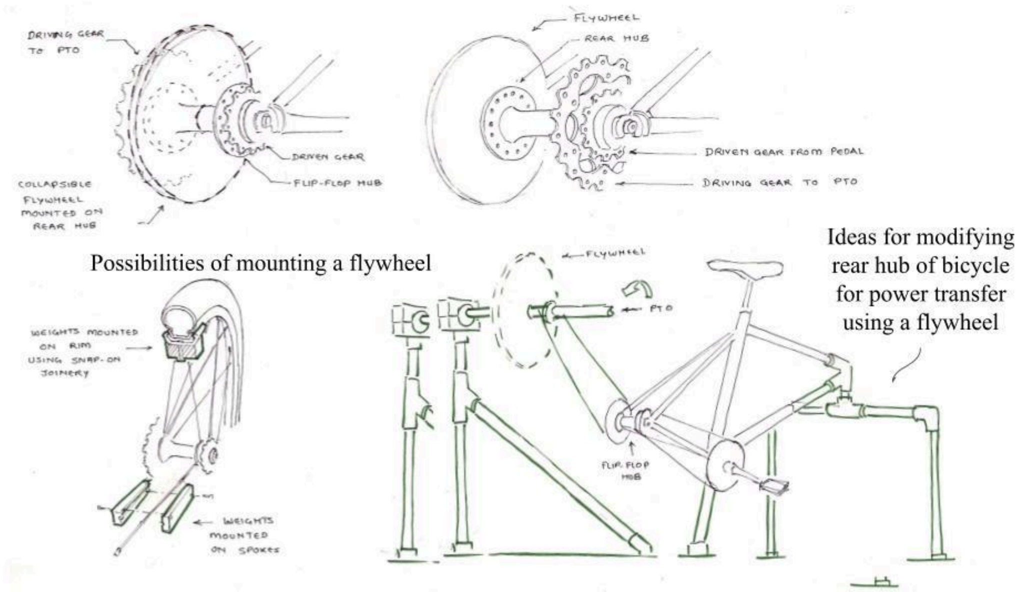


Figure 5.18: Transferring rear axle rotation to PTO shaft for stationary activities

5.2.3.1.6 Selected design direction. All the initial ideas for power transfer were then evaluated using values and hierarchy of the user needs pyramid. The focus is on portability, ease of use, ease of repair, affordability, and robust design. The researcher finally decided to go with a combination of two design directions 1) a farm machine which uses any available bicycle without any modifications to draw power, and 2) transmission from pedal to power take off shaft using chain drive.. Figure 5.19 shows further ideas and details of how this additional chain drive could be connected to the existing bottom bracket assembly of the bicycle.

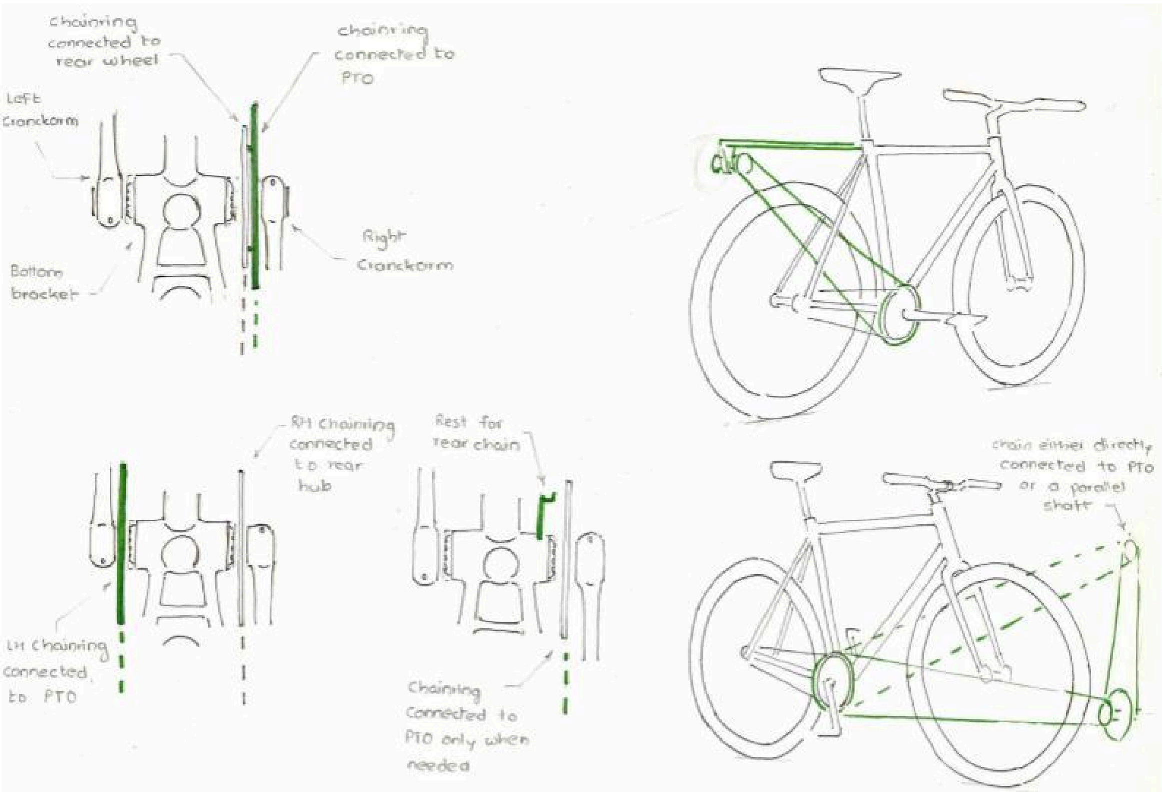


Figure 5.19: Joinery details of an additional chain drive for transmission

5.2.3.2 Frame design. While ideating different frame designs the researcher again referred to the 26 factors and user satisfaction pyramid and focussed on values of affordability, collapsibility and portability. The idea was to create a frame that can be carried either as a backpack, a trolley, or a carry-on attachment on a bicycle. Figure 5.20 shows four possible design directions were again envisioned, 1) a device that can be hitched to a bicycle, 2) a device that is mounted permanently above the front wheel of the bicycle, 3) a device that collapses into a backpack, 4) a device that can be pushed like a trolley.

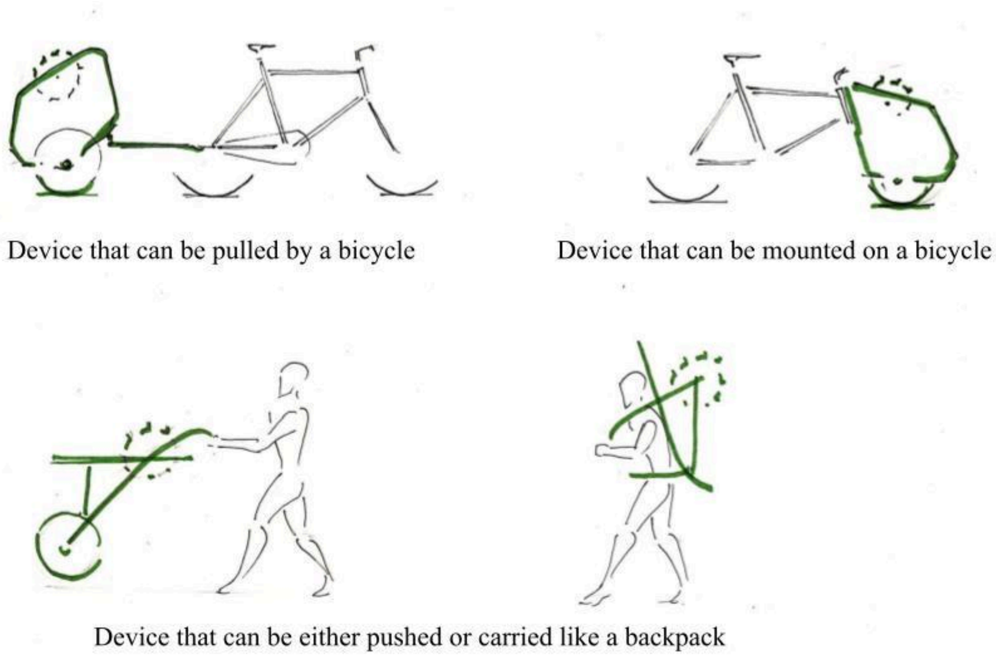


Figure 5.20: Four possible design directions

The researcher further detailed and developed the combination of design directions three (a device that collapses into a backpack) and four (a device that can be pushed like a trolley) into a frame design that could be folded into five possible configurations. (Fig. 5.21). To test the folding configurations a scaled mock up was created using wooden flats and rods (Fig. 5.22). However since the design had too many moving parts, the researcher then decided to simplify the frame design. Too many moving components increases the costs and complexity of manufacture and maintenance. The idea was to reduce the number of pivots so that the design can be simplified and convert it into either a foldable frame with two configurations or a rigid structure.

The researcher also explored various forms of frames (Fig 65) to arrive at five possible designs (Fig 66) that could be developed further for evaluations. The objective was to generate a chassis design that has minimal visual weight, but is robust and can be manufactured and repaired locally. Out of the five directions, the idea of using minimal pivot and a robust central frame were

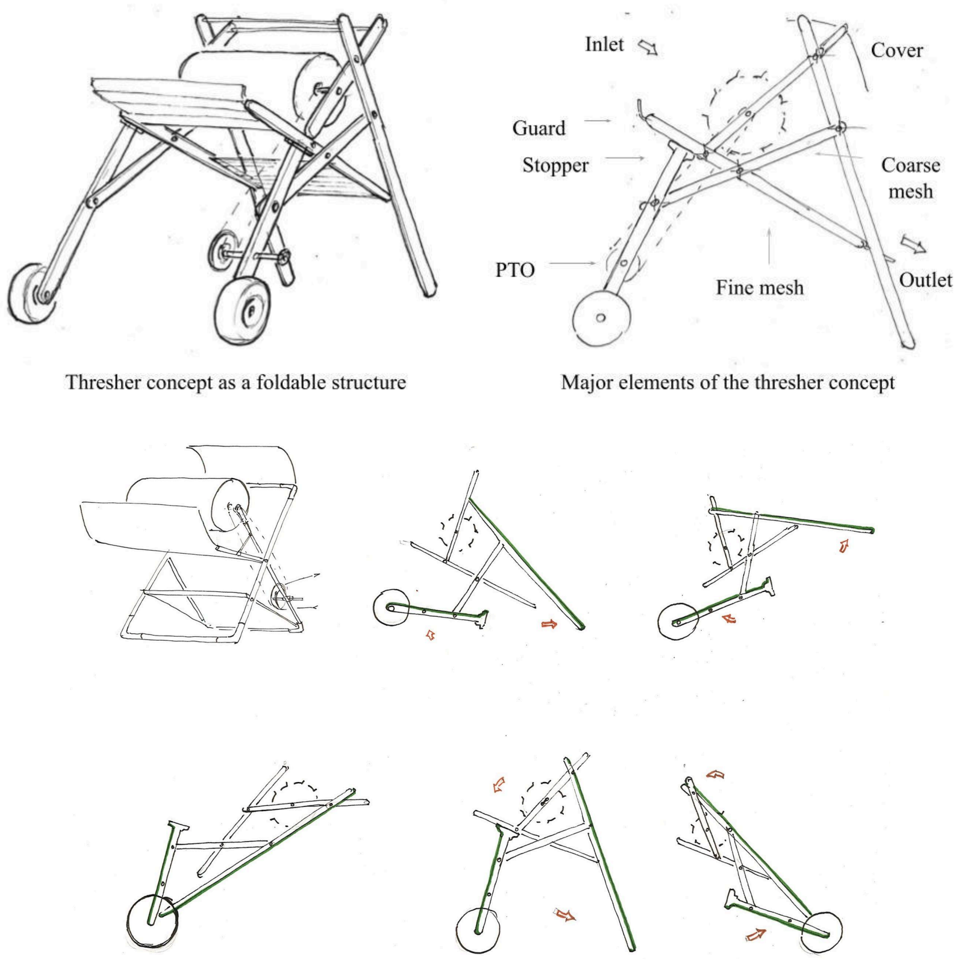


Figure 5.21: A collapsible design that can fold into multiple configurations

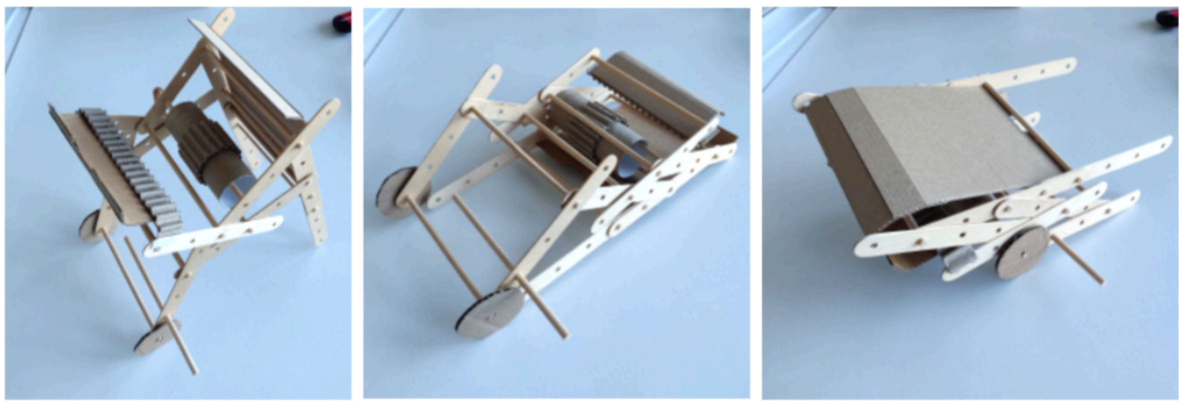


Figure 5.22: A scaled mockup to check the feasibility of the proposed frame structure

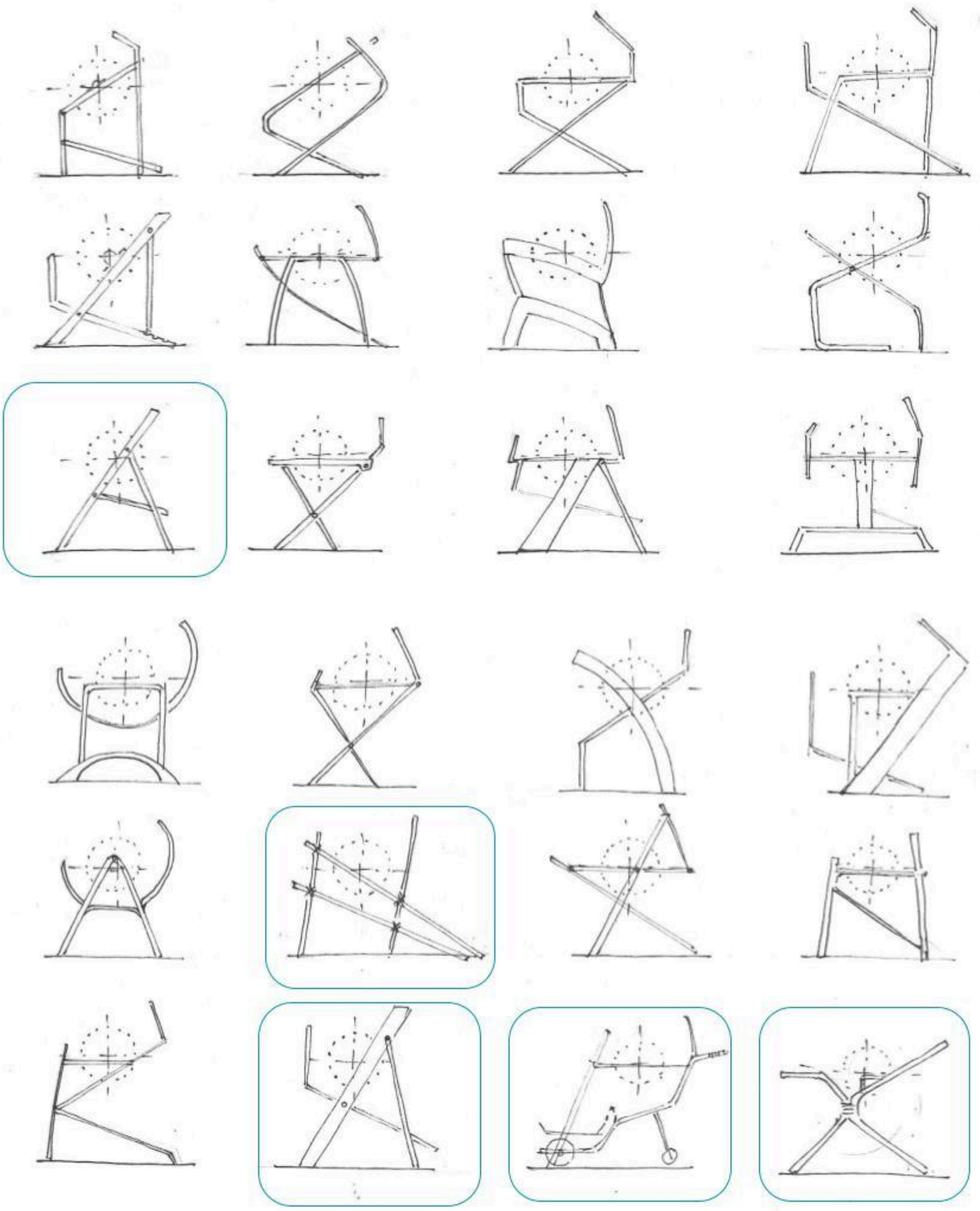


Figure 5.23: Explorations of simplified frame design with minimal pivots

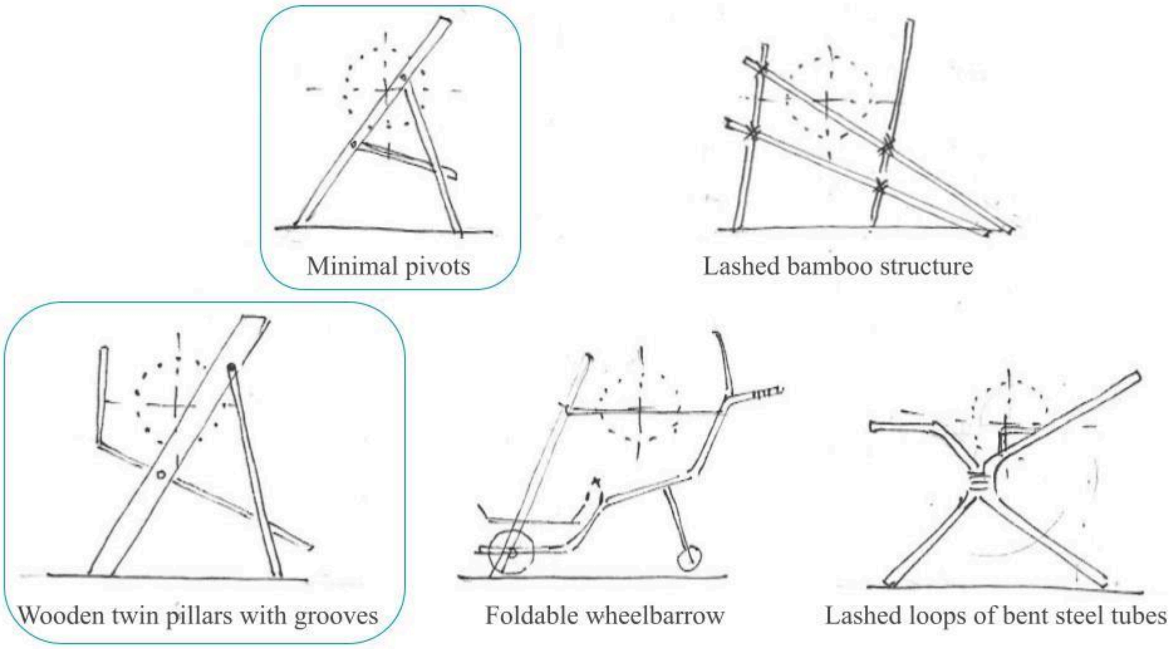


Figure 5.24: Five possible frame concepts

5.2.3.3 Thresher drum. For the design of threshing drum the researcher again focussed on factors of ease of manufacture, ease of use and robustness. The researcher wanted to initially develop a shaft with possibility of multiple attachments of teeth or flails for different grain types, hence the possibility of collapsible drum design for ease of transport was also explored.

Figure 5.25 shows exploration of a low cost threshing module where possibilities of avoiding the drum structure were explored. Here, rasps and flails were directly attached to a rotating shaft to reduce material and simplify manufacture. However, the researcher then decided to explore using two discs connected using various flats. The objective was to create a drum with mounts (Fig. 5.26) and a set of flats that could be interchanged depending on crop type in order to provide multi-crop threshing capability. Based on existing literature as well as parameters of ease of manufacture and use of locally available manufacturing skillset, the researcher arrived at a design where the drum would have wire loops on one side of the flats for threshing rice and possibility of adding another bar on the bottom side for other crops (Fig. 5.27).

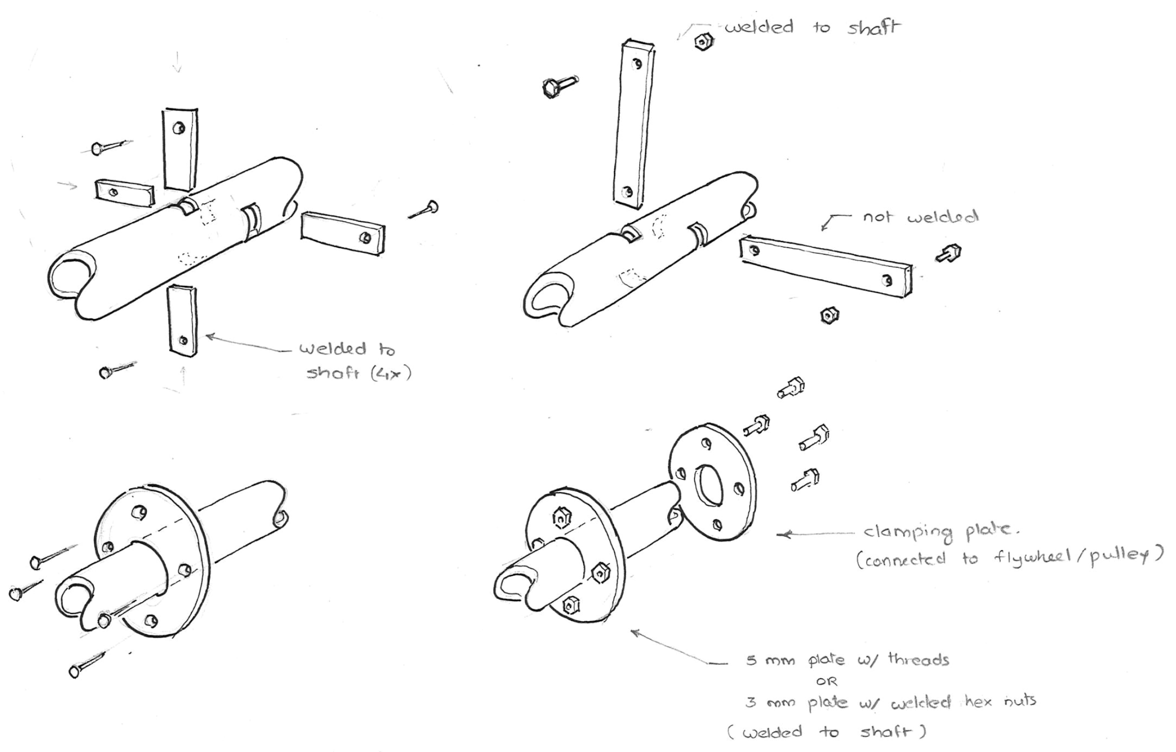


Figure 5.25: Ideas for creating a threshing drum as a shaft with mounts for flail or rasp bars

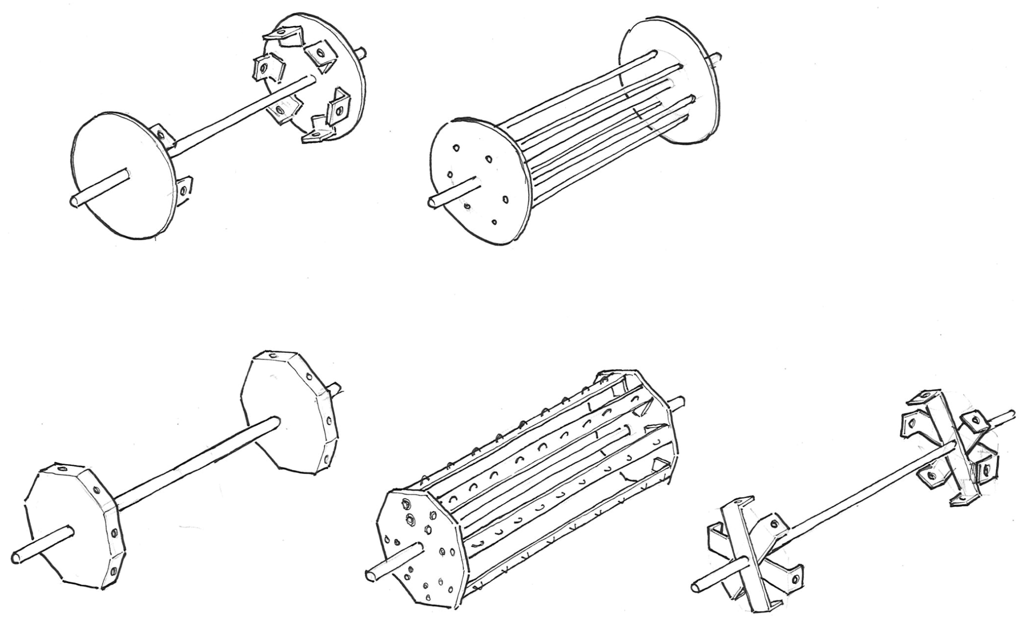


Figure 5.26: Ideas for creating a drum using disc with removable mounts for quick changeover

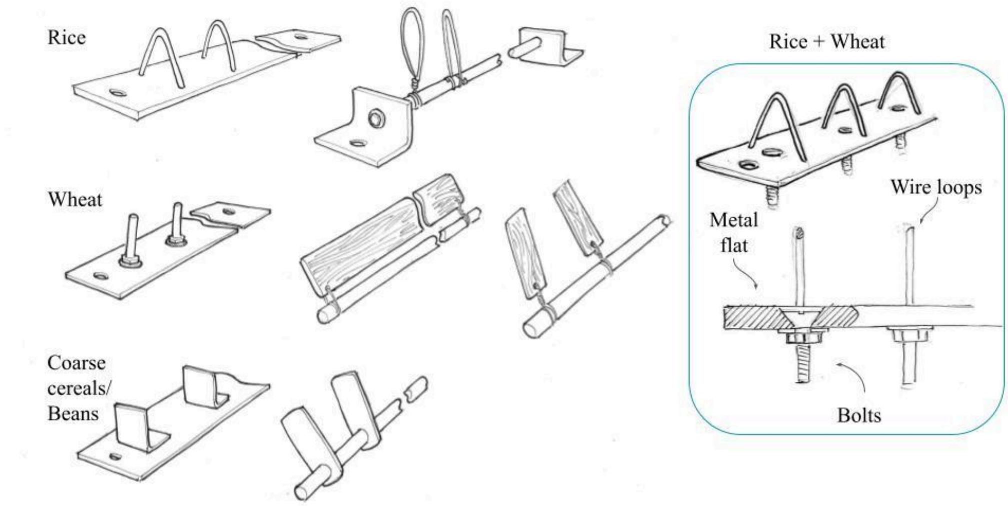


Figure 5.27: Ideas for set of flats to be mounted on drum for threshing grains with the selected design

Since the threshing drum was one of the functionally critical modules of the equipment, the researcher decided to only consider simplicity, ease of manufacture and robustness as primary criteria. The dimensions of the drum were derived from existing research done where parameters of threshing drum for rice threshing were optimised using wire loops mounted on flats (Singh et al., 2022). Three possible directions for drum design were conceived and the drum idea using the front and rear wheel of the bicycle was selected (Fig. 5.28)to reduce the number of bespoke and bought out components. This also aligned with the design direction of using bicycle components for power transfer. This decision was taken using the parameters of ease of manufacture, locally repairable, and affordability from the design framework.

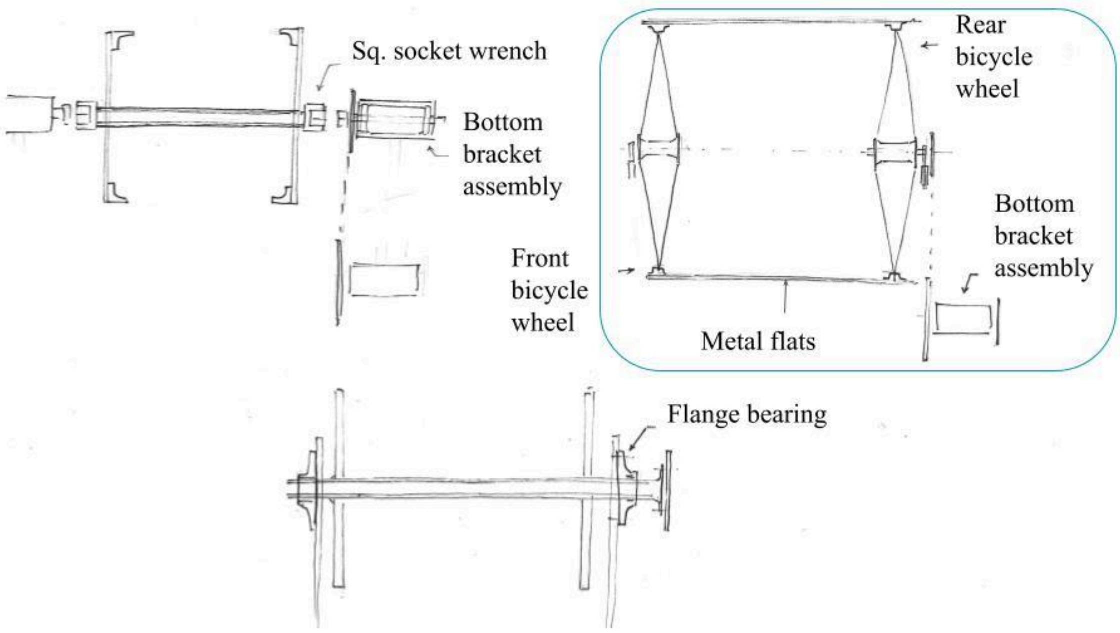


Figure 5.28: Ideas for threshing drum assembly with chain drive

5.2.4 Scaled mockups, CAD and low-fidelity models

The researcher initially used small scaled mock ups to evaluate and generate details of various ideas. Figure 5.29 shows mockups for the collapsible frame and drum which were created while sketching ideas for those elements. These scaled mockups were created using corrugated cardboard, wooden rods and wooden sticks. The objective was to identify possibilities of simplifying the frame and drum. These mock ups also acted as inspirations for the next set of ideas.

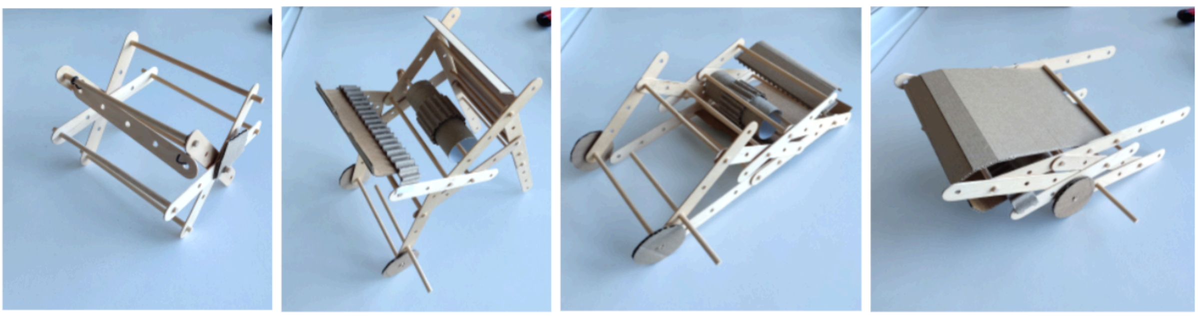


Figure 5.29: Mockup models for ideation of collapsible drum and frame

A full scale low fidelity volume model was also fabricated from cardboard to get a sense of height and length adjustments that might be required especially for hand rest and height of threshing drum (Fig. 5.30). The researcher used role-play and bodystorming as methods to finalise the height of the threshing drum. The height of the drum was then finalised on the basis of these activities and using anthropometric data of the Indian population.

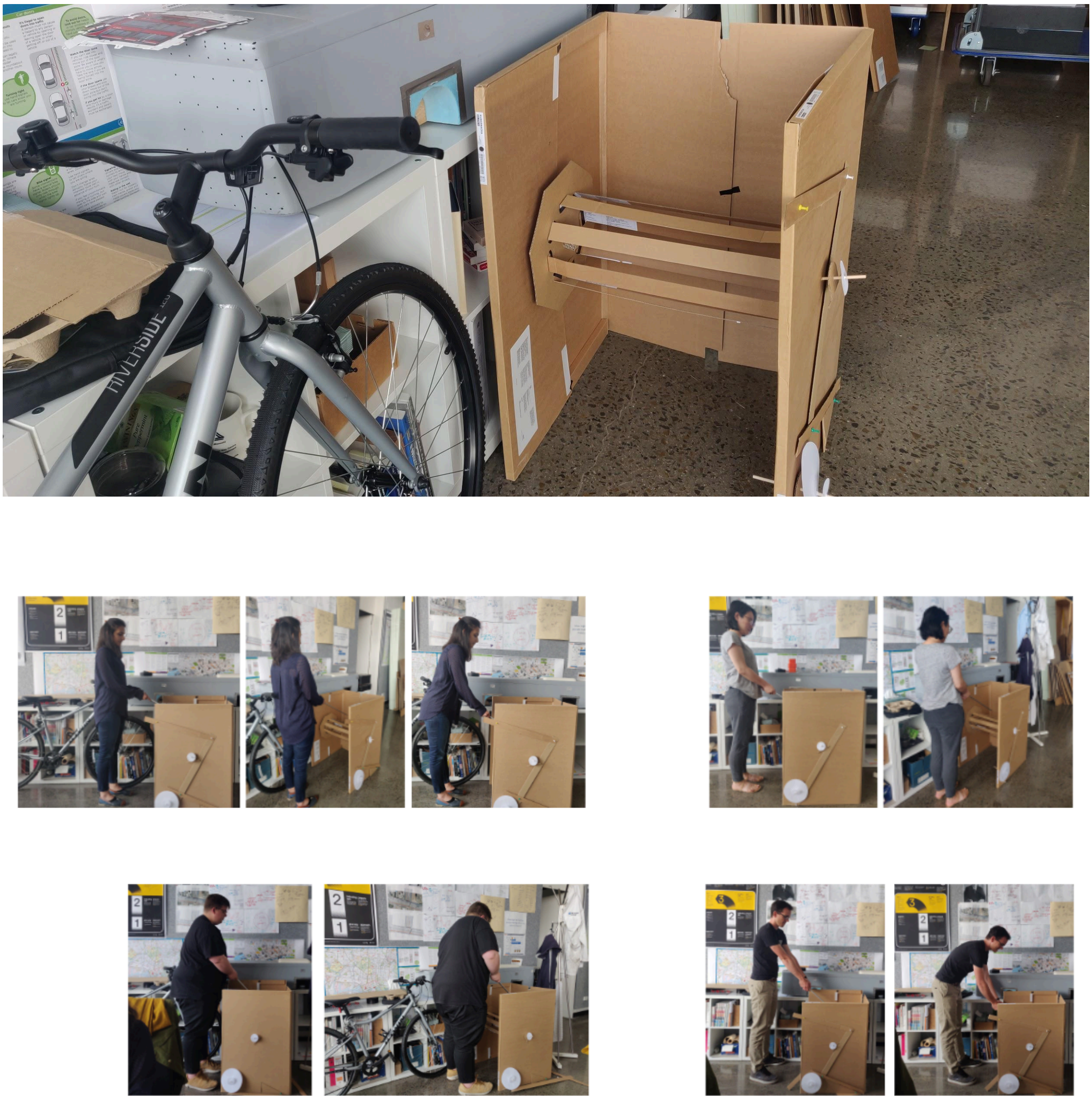


Figure 5.30: Full scale low fidelity prototype and bodystorming

The researcher also used Lego pieces as tools of creative ideation to generate various configurations of rigid frame designs (Fig. 5.31). This allowed further creative exploration using play and also helped get a sense of multiple joinery details that could be considered for prototyping.

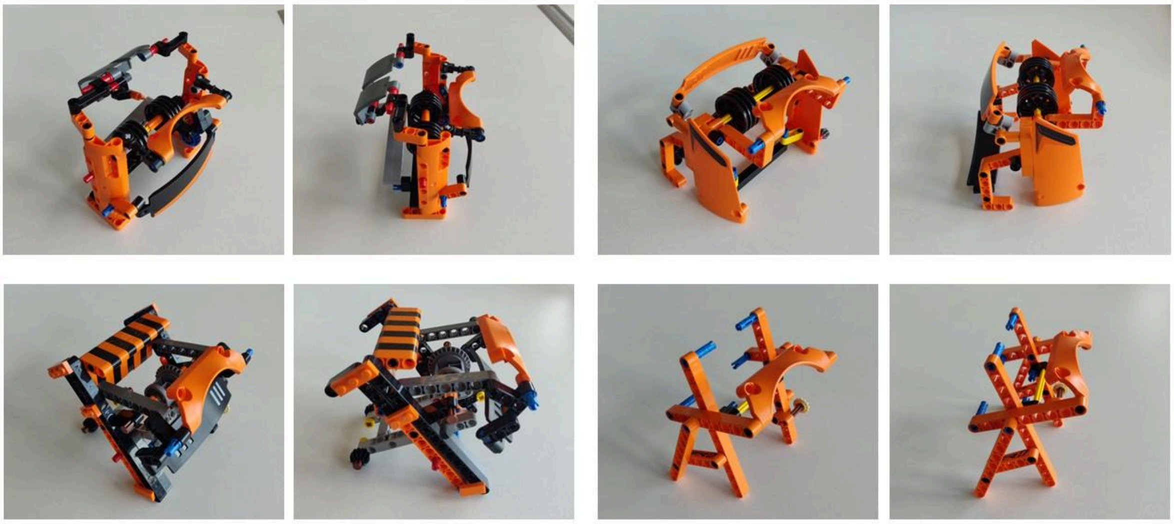


Figure 5.31: Mock ups of frame, drum, and guard

The selected ideas from ideation of power transfer, frame, and threshing drum along with learnings from making scaled mock-ups were used to generate three concepts of a foldable threshing device that could convert into a trolley with minimal moving parts and pivots. These three concepts were then detailed using low-fidelity volume models in Computer-aided design (CAD) software. The key considerations for selecting one of these concepts was informed by the parameters of ease of manufacture, ease of assembly, ease of repair as well as parameters of robustness, utility, and affordability. Out of the three, the concept where the frame consisted of bent pipes, was selected for further detailing (Fig. 5.32).

Figure 5.32: Low fidelity CAD volume models

5.2.5 Concept development and refinement

The resulting concepts were evaluated with respect to the product specification, and a concept was developed using computer-aided design (CAD). The materials and processes were then selected based on 26 values and user satisfaction pyramid. The researcher decided to use threaded GI pipes and connectors to build the frame. The rationale for material selection was based on the parameters of locally available material and ease of assembly. Similarly the threshing drum and the power transfer module were constructed using bicycle components and MS plates and wires. The researcher envisioned that the guarding could be made using upcycled saree quilts that are made in the village for the purpose of creating bedding using old sarees and clothes. This concept was further detailed and refined for making the first prototype frame. Figure 5.33 shows the concept in folded (transport mode) and unfolded condition (thresher mode).

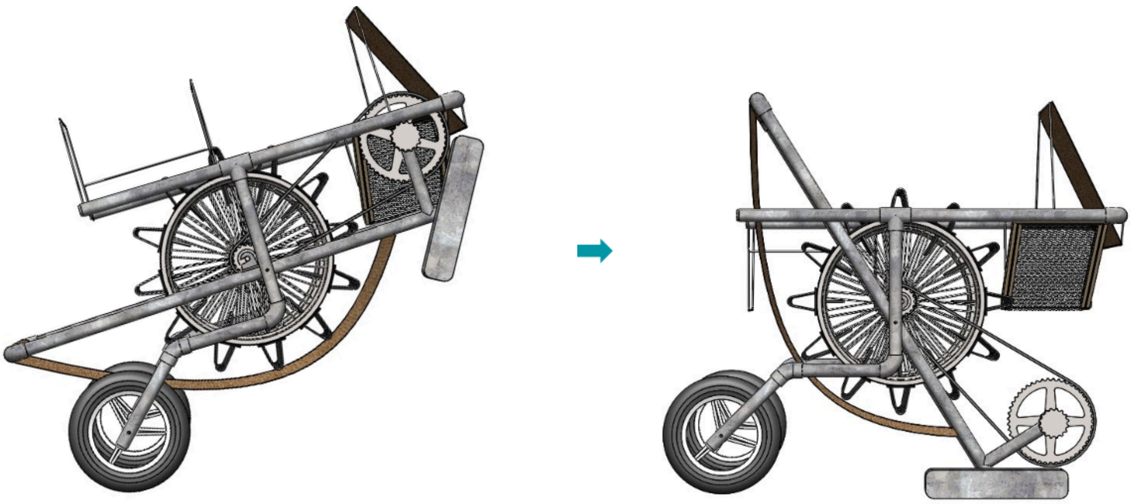


Figure 5.33: Medium fidelity CAD volume models

5.3 Design outcome

A refined concept was generated using CAD (Fig. 5.34). The steps of transporting, setting up, and use were also shown using a storyboard along with a sketch of a device with a bicycle (Fig. 5.35). The device is designed with a two operator setup in mind. One operator will pedal the bicycle while the other will hold bundles of harvested rice panicles over a rotating threshing drum to separate the grains.

Figure 5.34: Refined CAD model of the thresher concept

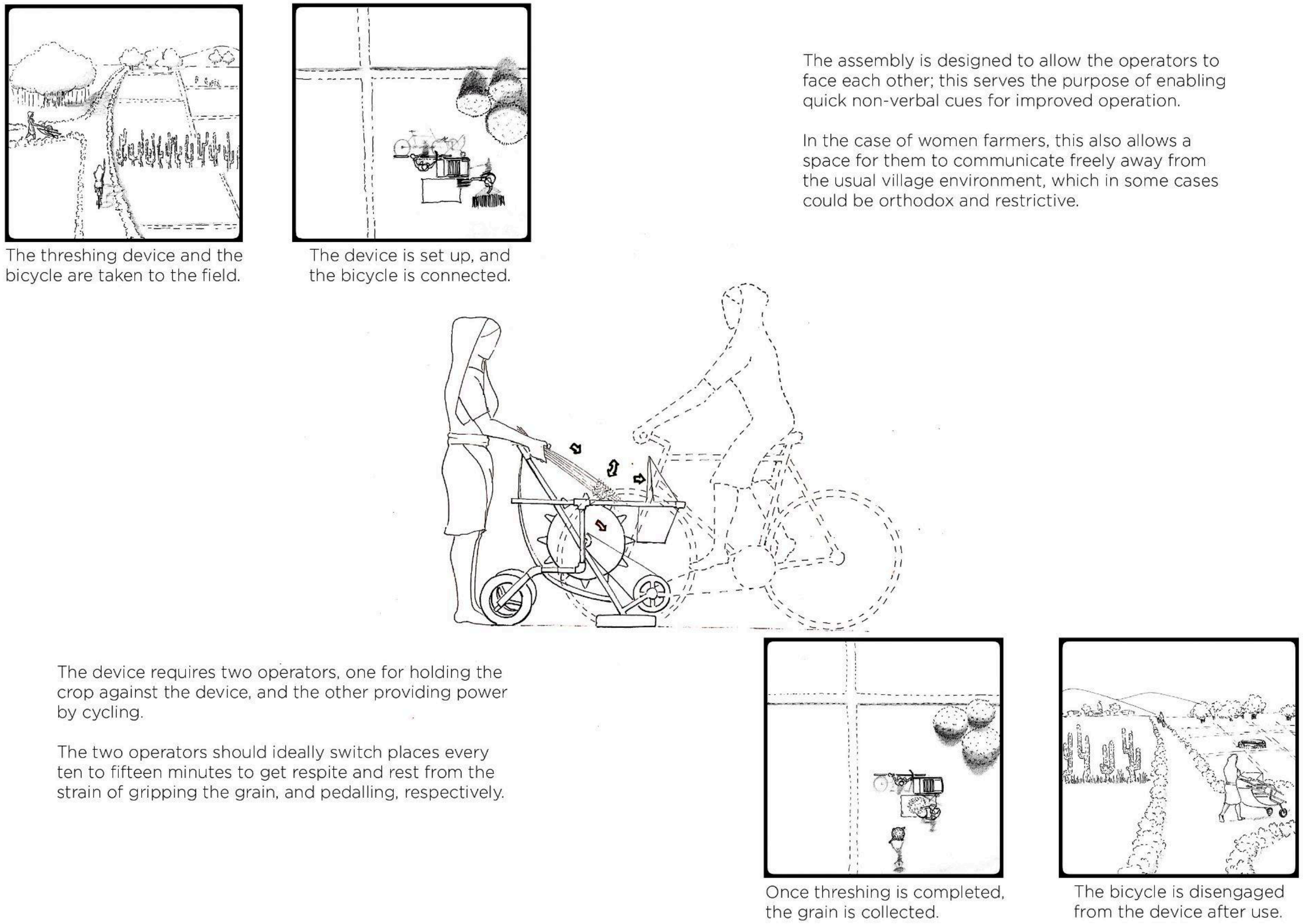


Figure 5.35: Setup of device and bicycle with storyboard of steps involved in the process

The features of the selected concept are as follows (Fig. 5.36) :

1. The manufacture involves using locally available components like upcycled clothes,galvanised pipes, and old bicycle parts for all functional modules
2. It is a collapsible design, allowing the machine to be towed or carried like a trolley when not in use.
3. When the machine is set-up, a fabric cover (made from upcycled saree quilts) prevents loose clothing from getting entangled in moving parts, a bracket is provided to hold the bundles of plants to be threshed.
4. A mesh filters and transfers the grains away from bicycle and device operators.
5. The two operator setup allows the operators to switch positions between tasks to avoid fatigue.

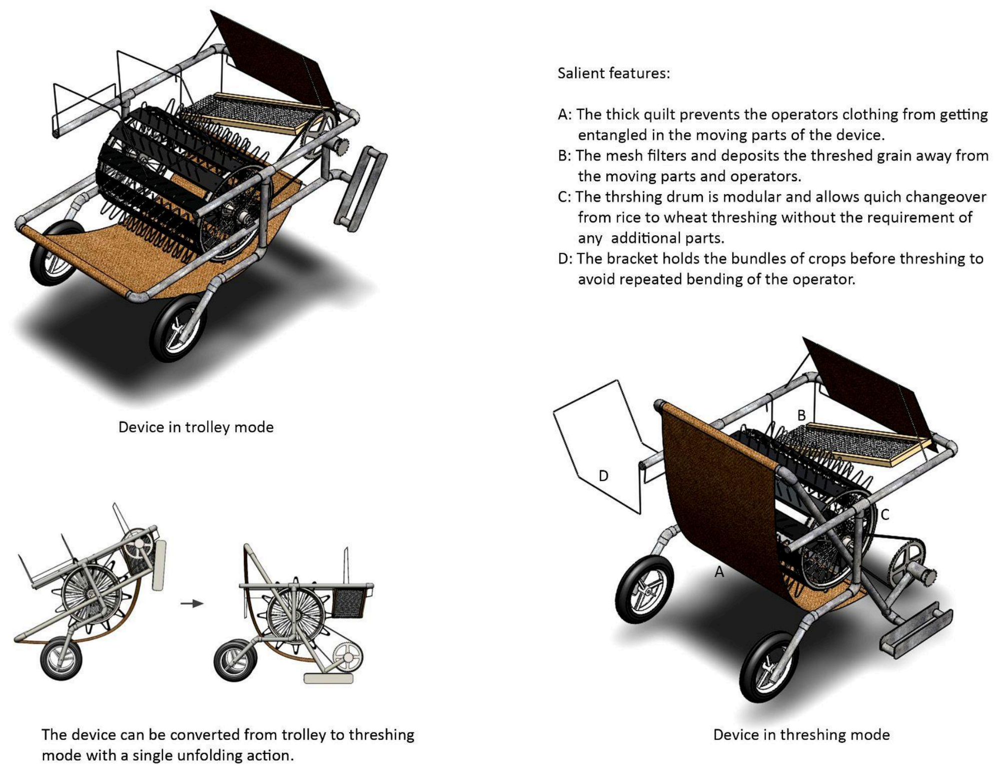


Figure 5.36: Salient features of the concept

The device allows the farmers to use any bicycle that they own as a power generating component. The device also provides the opportunity of using and re-purposing locally available material for construction like used pipes, bicycle parts, and saree quilts. The tools and processes required for assembly are selected based on the skill set of traditional rural artisans. The machine also uses the properties of these materials to make the device safer and more portable compared to existing solutions.

A full scale foldable frame of prototype 1.0 was then assembled using threaded GI pipes and connectors (Fig 5.37). This prototyping activity helped identify issues with the pivot marking and assembly using threaded pipe connectors. This also gave ideas for simplification of frame concept and improving manoeuvrability during the next iteration. Figure 5.38 shows the evolution of elements using ideation from the existing threshing device to the new concept.

Figure 5.37: Frame of prototype 1.0

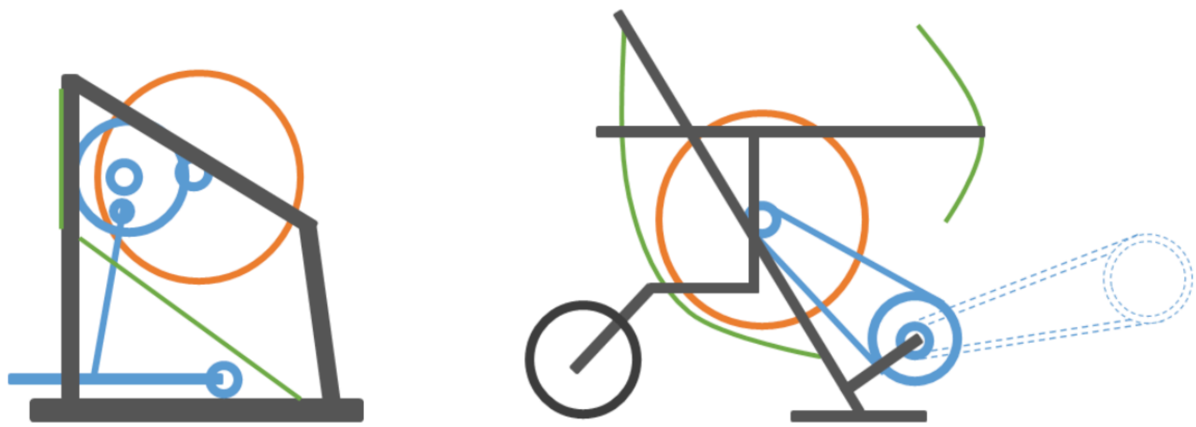


Figure 5.38: The difference between elements of existing device and new proposed concept

Before making further changes to the concept, the researcher decided to conduct field observations and interviews focussing on threshing activity. The objective was to observe the threshing process in a different region to understand the different techniques and needs that small farmers might have.

5.4 Field observations

In the first stage of field research, field visits were conducted in western Maharashtra and the state of Madhya Pradesh to understand small and marginal farming. The researcher decided to conduct one more round of field observations and interviews focusing on tools used in post-harvest activities like threshing, women's involvement in agriculture and issues faced by small and marginal farmers in the state of Goa. Ethics approval was provided through Monash University Human Research Ethics Committee (ID 25875) as well as the Indian Institute of Technology Bombay (IITB) Institute Ethics Committee (IITB-IEC/2020/062) for field observations, audio-video recording of farm activities, and conducting semi-structured interviews of farmers and resource personnel working in this domain.

India is a culturally diverse country. The farm techniques, tools, and difficulties related to farming tend to vary from region to region. Hence, the researcher used semi-structured interviews as a method to capture data. The semi-structured interviews were used as a method as it allowed capturing flexibility to adapt the questions and direction of the interview based on the responses of the participants. The interviews focused on prompts of farm activities, post-harvest farm techniques used, problems associated with selection, and tools. The researcher visited ten villages in the state of Goa (Fig. 5.39) to observe threshing activities (Fig. 5.40), manufacture of farm tools (Fig. 5.41), and establish contact with farmers for interviews.

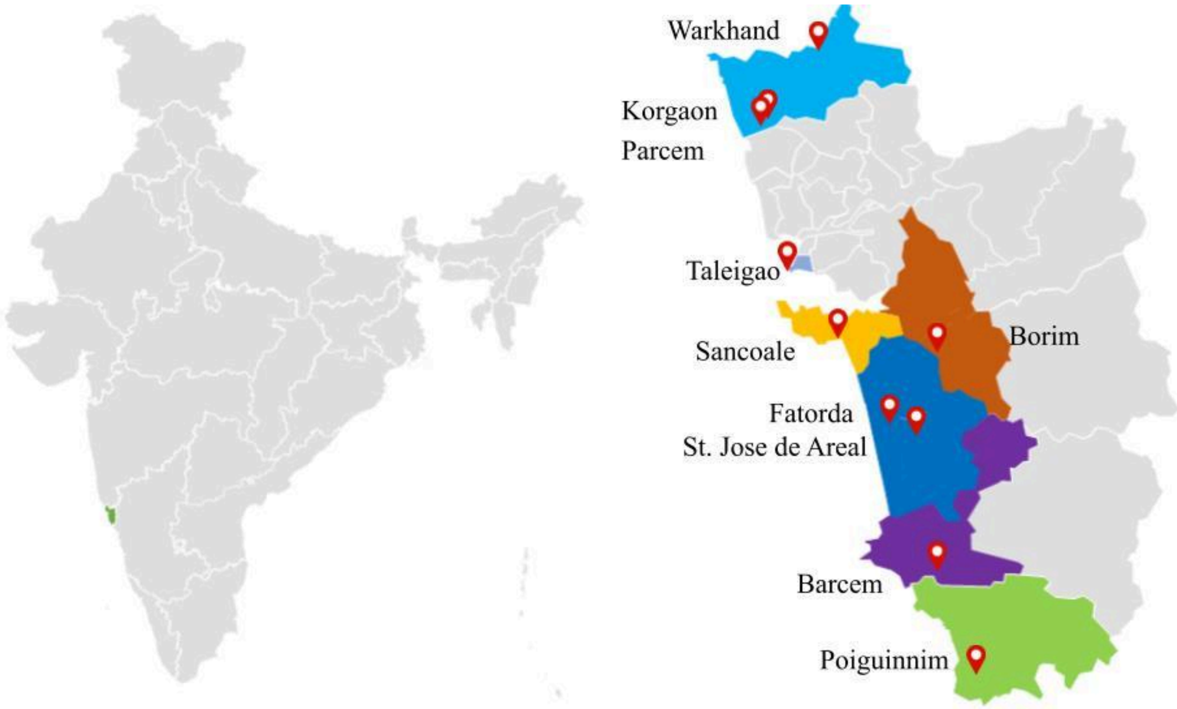


Figure 5.39: Locations of villages of the state of Goa where field visits and interviews were conducted

Figure 5.40: Traditional technique of rice threshing by trampling the grains under foot

Figure 5.41: The village blacksmith using forging to repair a farm tool

5.5 Semi structured interviews

The researcher conducted interviews with eleven farmers of Goa and two resource personnel from Maharashtra. Since the interviews were conducted in regional language dialects of Konkani and Marathi, the interviews were transcribed and then translated to English for analysis. The transcripts were then analysed by generating structural and descriptive thematic codes used to generate word trees. The data collected was then used to generate a map with overlays of farm activities, tools used and contribution of women in each of these activities. To further understand the domain, a stakeholder map was generated (Fig. 5.42) for small and marginal women farmers. These stakeholders were then mapped into factions. Their values, loyalties, and losses were identified using the data collected from literature and discussions.

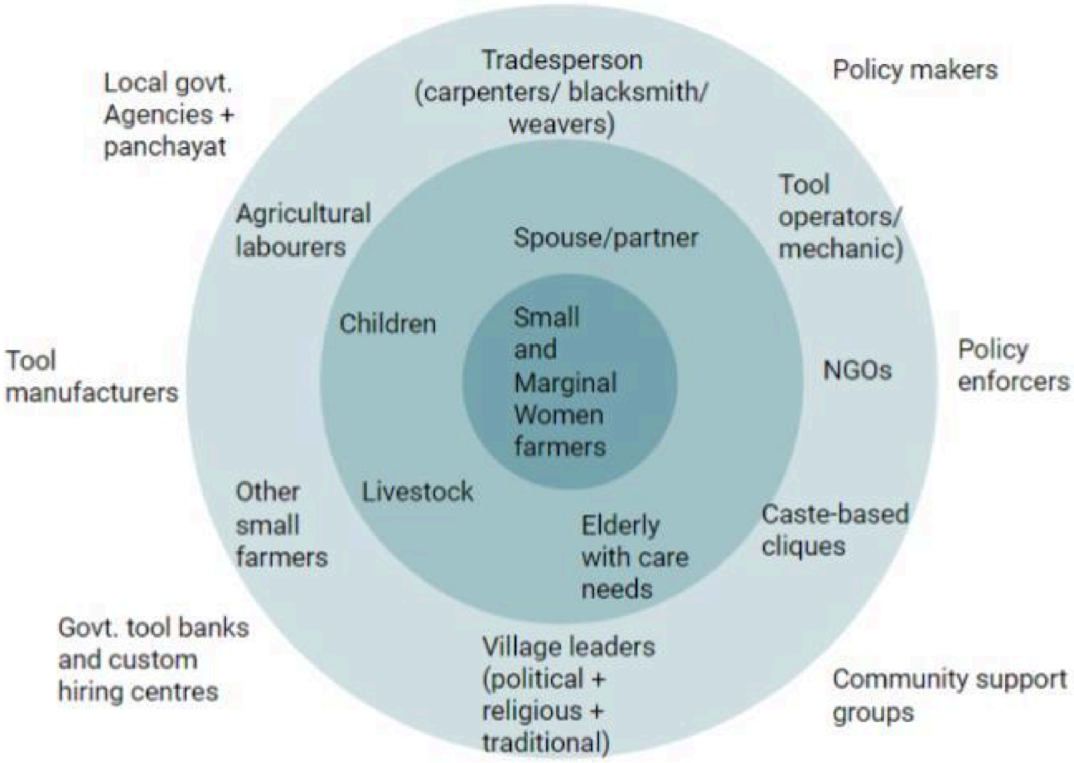


Figure 5.42: Stakeholder map of small and marginal scale women farmers

These activities helped generate insights about Goa's farming trend, issues faced by small and marginal farmers, and their expectations and reluctance in adopting new machinery and equipment.

Farmers are primarily reluctant to shift to using modern equipment because of following two reasons,

1. Existing machines do not work effectively on uneven lands or cannot access smaller upland farms.
2. During harvesting and threshing using most existing available machinery does not provide hay as a secondary output (hay is an additional source of income as well as cattle feed).

At the same time, some farmers are open to shifting from manual, traditional techniques to modern farm equipment, provided at least some of the following four criteria are met.

1. The cost of owning/renting and maintaining the machine is less than the labour cost required to do the same work manually; equipment needs to be an economically viable alternative to manual labour.
2. Time efficiency is better compared to the method/machine in use.

3. Institutional support and subsidies are provided for owning/renting equipment.
4. One machine can be used for multiple farm activities.

These interviews and activities helped identify the gap between existing threshing solutions and identified a space proposed machine concept could fill (Fig. 5.43). The proposed concept would ideally fill the gap between existing costly powered solutions and traditions low-cost but time consuming and labour intensive traditional techniques of beating or trampling the grain. These interviews and field observations provided directions for the next phase of refining and development of the threshing concept before field testing.

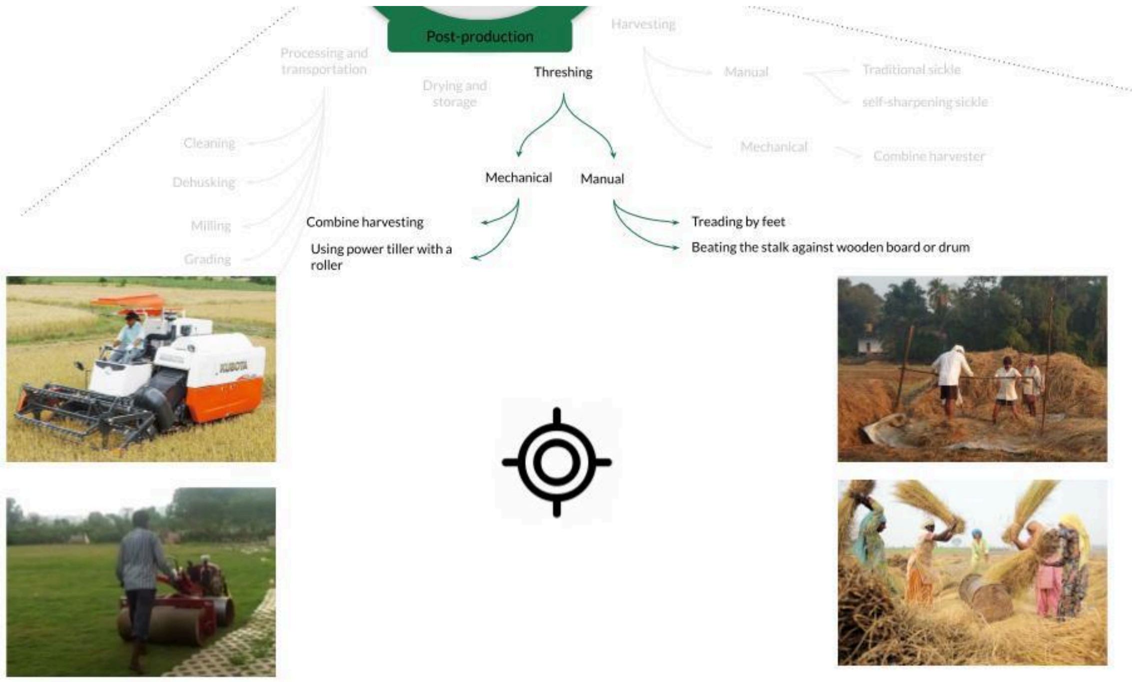


Figure 5.43: Identified gap in existing threshing solutions

5.6 Refining the structure for the framework

The next stage of research involved using the design process for developing the threshing concept refining the parameters which were used during this process to identify design values and to generate a framework structure. The objective was to identify design drivers that are critical for designing interventions in the area of Indian small scale farming and to explore structures that would aid in the design process.

In the initial phases of research, a study and analysis of existing data collected was conducted through study of literature, study of tools used by farmers, field observations and interviews.

This study along with design values of existing design frameworks were used to identify 26 factors that need to be considered while designing an intervention for small and marginal farmers. These factors were used as key parameters during initial ideation and concept development. There was a need to classify these factors under design drivers which could simplify the process of translating research and needs identified into a design brief, evaluating existing solutions and evaluating concepts during the design process. The 26 factors were classified into 6 categories based on the way the researcher referred to these factors and the thought process behind taking decisions during the process of designing a grain threshing machine for small farmers.

The researcher then tried to develop a frame by following a function-behaviour-structure (FBS) ontology developed by Gero (1990). This ontology has three components (Gero et al., 2004; Gero et al., 2014), a) function (purpose of the artefact), b) behaviour (characteristics and elements of the artefact), and c) structure (the relationship between elements of the artefact). This approach was adapted to divide the process of framework design into 3 categories of activities.

1. Function: This category is used to define the utility and purpose of the framework. The possible uses and intended stakeholders are as follows:
    a. Tool to classify and visualise needs and wants in a research space (Researchers/Designers/Engineers)
    b. Tool to aid in prioritising needs and wants during the generation of product specification (designers/Engineers/manufacturers)
    c. Tool to aid decision making during the ideation phase (designers)
    d. Tool to evaluate product concepts during the initial design phase (designers)
    e. Tool to validate the selected concept against existing solutions and the initial specification (engineers/designers)
    f. Tool to choose the suitable solution while selecting from existing solutions/products. (farmers/designers/researchers/engineers)

2. Behaviour: This category is used to define the attributes that the Framework needs to have to perform the intended function. The Framework ideally should behave as follows,
    a. Allow context dependent adaptation

b. Allow modification of process
c. Should not be treated as a recipe for success but as an aid and checklist
d. Should not be treated as a recipe for success but as an aid and checklist

3. Structure: This category deals with components of the framework and the relationships between them. The framework should ideally simplify the process of design by providing an easily understandable visual representation of the design drivers and factors which helps achieve the intended functions.

Two tentative structures using the factors and categories were generated. These structures were created for 1) Discover stage to help understand the domain as well as provide prompts for ideation, and 2) Define stage to aid in decision making and evaluation of concepts.

We also realised that developing interventions for small and marginal farmers is not just a technical challenge of providing better designed solutions. The challenge is also an adaptive one where a slight change in beliefs and behaviour would be needed for these farmers to shift from traditional methods to modern solutions.

5.7 Research outcomes

5.7.1 Morphological maps and overlay of rice farm activities and tools used in Goa

The data collected during field visits and interviews in the state of Goa was used to create a morphological visualisation of farm activities and tools used by small and marginal farmers of Goa (Fig. 5.44). These overlays along with the visualisations created for rice farmers of the state of Maharashtra during the first stage of research helped clearly identify the lack of efficient and effective low-cost tools and the reliance on labour intensive traditional techniques. Data collected during interviews and existing research work done by Dr. Smita Solanki to identify the contributions of women farmers in various farm activities was used to generate an overlay where the percentage of work done by women farmers was mapped (Fig. 5.45).

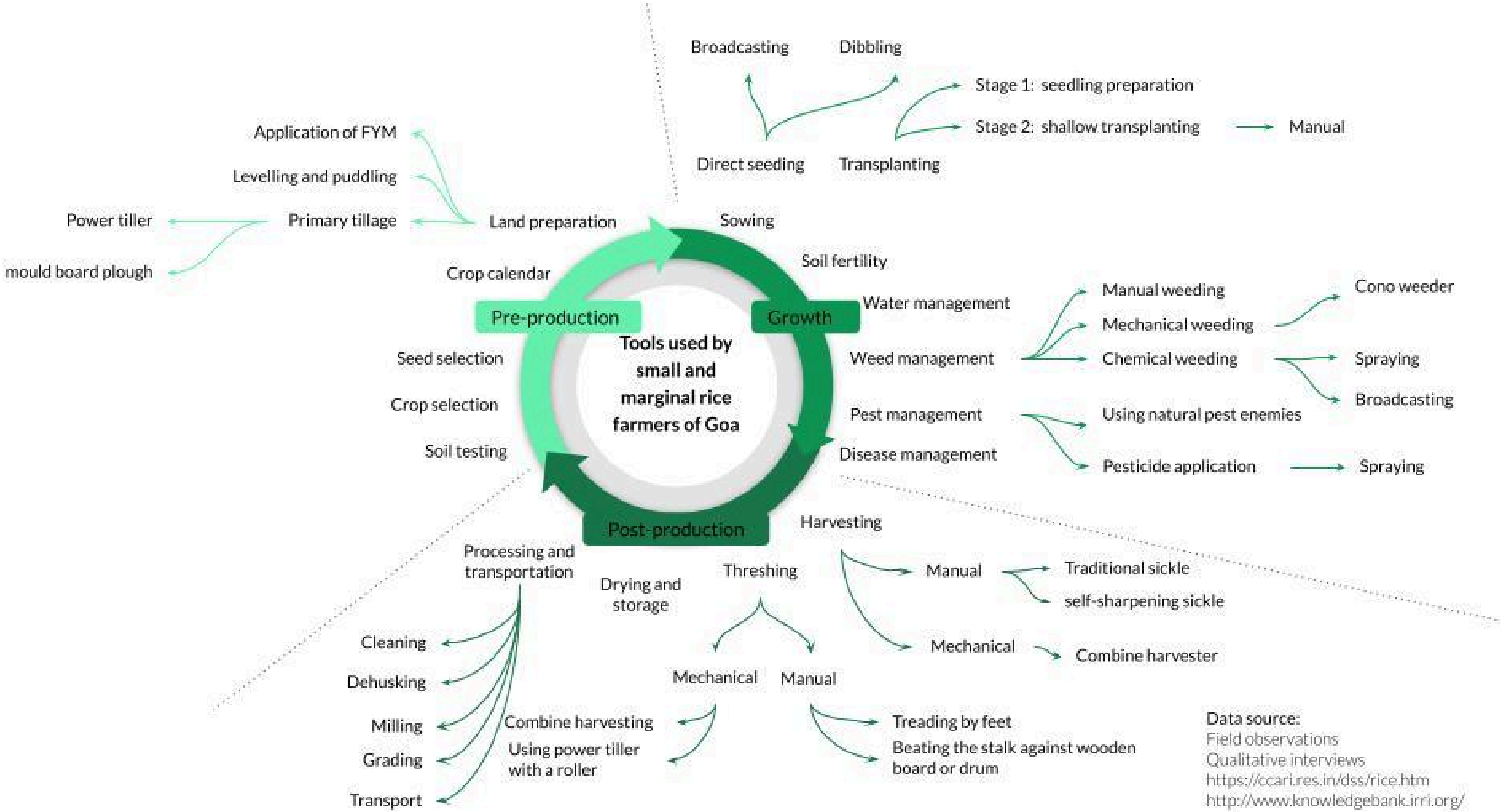


Figure 5.44: Map of farm activities and tools used by small and marginal rice farmers of Goa

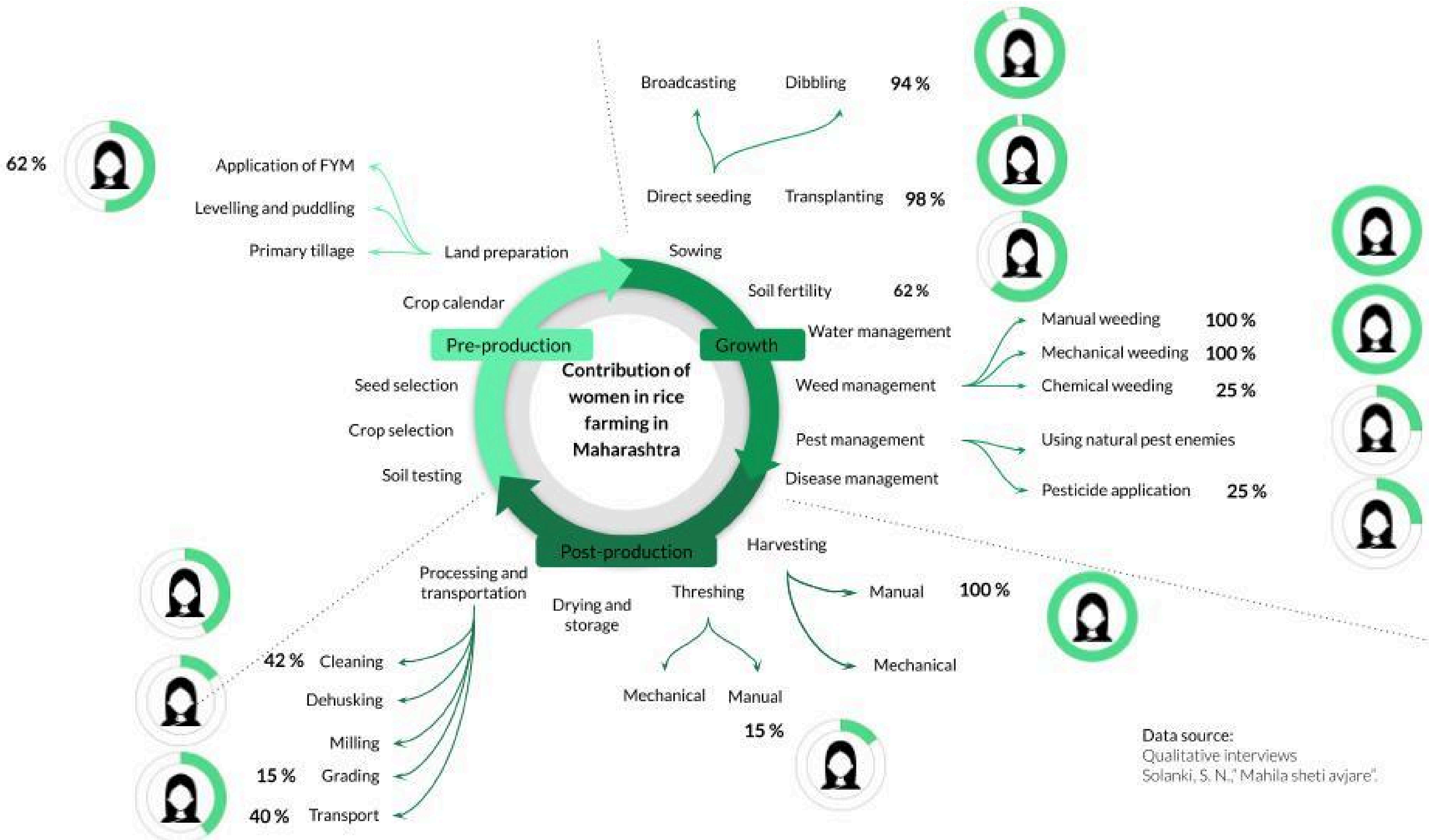


Figure 5.45: Contribution of women in rice farming activities

5.7.2 Categorisation of Twenty six factors into six design drivers

The six categories used to classify 26 factors are defined as follows:

Use: The quality of the artefact that deals with the function, usability and service

Make: The quality of artefact that deals with the manufacturing, materials and resources required for production

Afford: The quality of the artefact that makes it economical, affordable and appropriate in the chosen socio-economic context

Sustain: The quality of the artefact dealing with the lifecycle and impact on the environment.

Adapt: The quality of the artefact that enables adjusting to changing conditions and time along with allowing repurposing.

Adopt: The quality of the artefact that makes it acceptable and desirable while allowing ease of dissemination in the chosen user community.

The factors were classified under these drivers as shown in the following table 2:

Table 2

The classification of 26 factors into six design drivers

Design Drivers	**Factors to be considered**
Use	Ease of maintenance, Ease of using, Ease of learning, Ease of recharge/refuel, Ergonomic design, Portable
Make	Ease of manufacture, Locally available raw material, Locally repairable, Power generation
Afford	Cost of manufacture, Capital costs, Running Costs,
Sustain	Robust, Easy to dismantle/dispose of, Ease of Recycling, Low emission/pollution
Adopt	Functional aesthetic, Quality of output, Gender-friendly, Availability of infrastructure, Culturally appropriate, Type of ownership
Adapt	Utility, Modular/quick change over, Ease of upcycling

Out of these six drivers, The qualities of Use, Make and Afford are critical for the design of any meaningful artefact in the domain of Indian small-scale farming. The Criticality of the qualities of Sustain, Adopt and Adapt will change depending on the context and location.

5.7.3 Visualising the design framework

The following aspects were considered for visualising the structure of the framework.

1. There needed to be some indicator of the weighting of major categories, or the hierarchy of these categories or grouping (satisfiers/dissatisfiers)
2. There needed to be a way of showing connections or dependencies between these categories
3. There is a need to visualise the constituents of these categories in order to help translate and identify focus areas when a researcher or designer looks at existing data gathered from primary and secondary research. Also these categories and their constituent factors had to be assigned a weightage to aid decision making while ideating and concept generation.
4. The end customer would be satisfied while using a product as long as their needs, wants, and aspirations are being met. However, a designer in order to achieve the product satisfaction of the customer would have to use the values which are derived from study of user and context, and use these values as part of a framework along with design tools to achieve these objectives. Hence the framework should provide the relationship between the values and possibly their hierarchy which would help the designer make design choices and take decisions while developing and evaluating various concepts.
5. The researcher realised that for each stakeholder (i.e researcher, designer/tool manufacturer and farmer), the framework would have a different value proposition for each of the stakeholders and the visualisations should enable these value creations.

Following needs were identified and tentative visualisation structures were created for:

- Discover stage (for researchers/designers): A tool for problem identification and definition which would help to translate data into a problem statement/product specification for a design intervention (Fig. 5.46). The process would ideally involve matching the issues mentioned to a list of factors and categories in order to identify the importance of each factor and category for the context and activity. These categories and factors would also aid as prompts for generating ideas and concepts.
- Define stage (for researchers/designers): A tool to create a hierarchy of categories (Fig. 5.47) based on context and problem identified in order to classify them into needs (dissatisfiers) and wants (satisfiers). This tool could also be used to evaluate ideas and concepts during the design stage.

The researcher envisioned how these framework structures could be used during divergent and convergent phases of a double diamond design process based on the way the parameters were used during the design process for developing a threshing solution (Fig. 5.48).

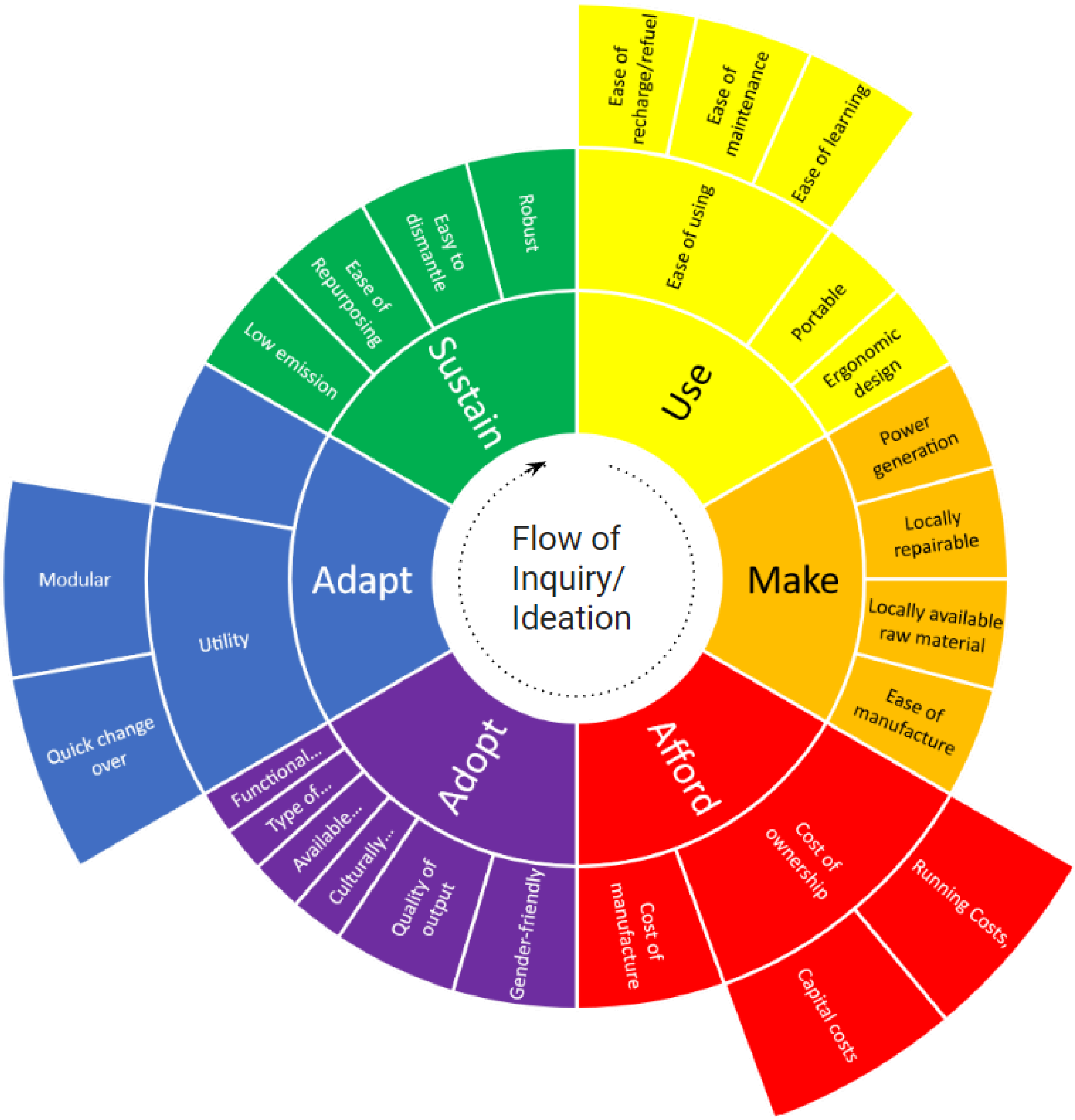


Figure 5.46: Categories and factors to aid as prompts for generating ideas during the 'discover' stage

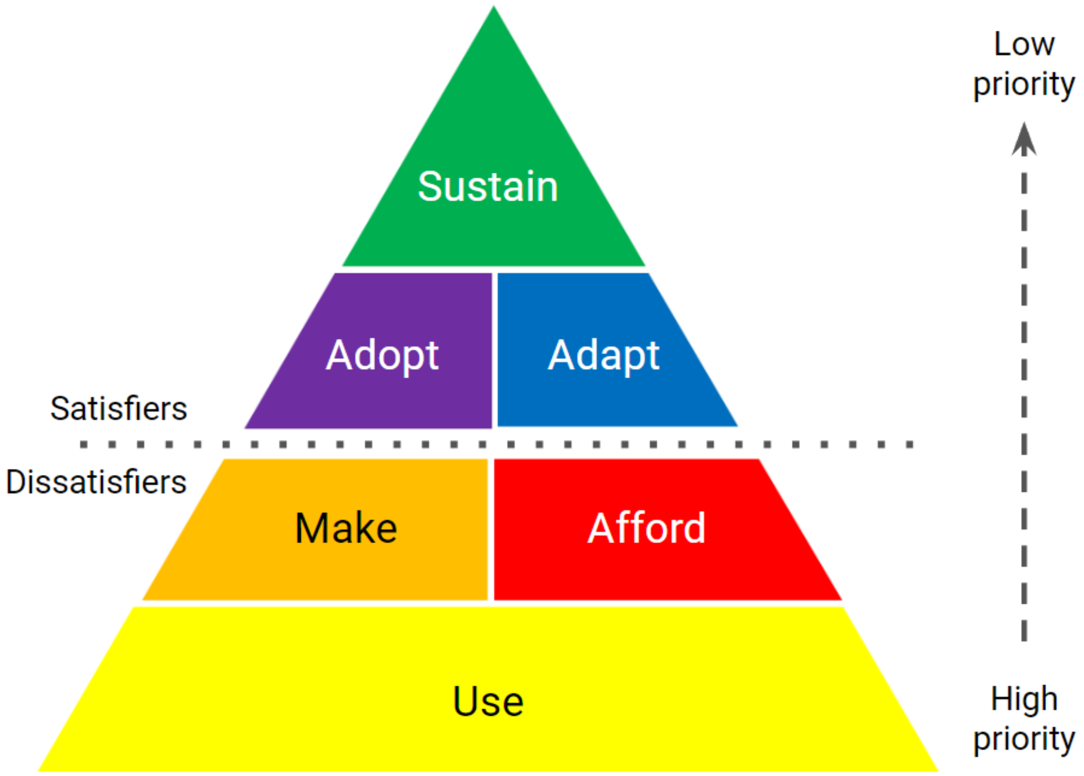


Figure 5.47: A tool for making design choices and concept evaluation for the 'define' stage

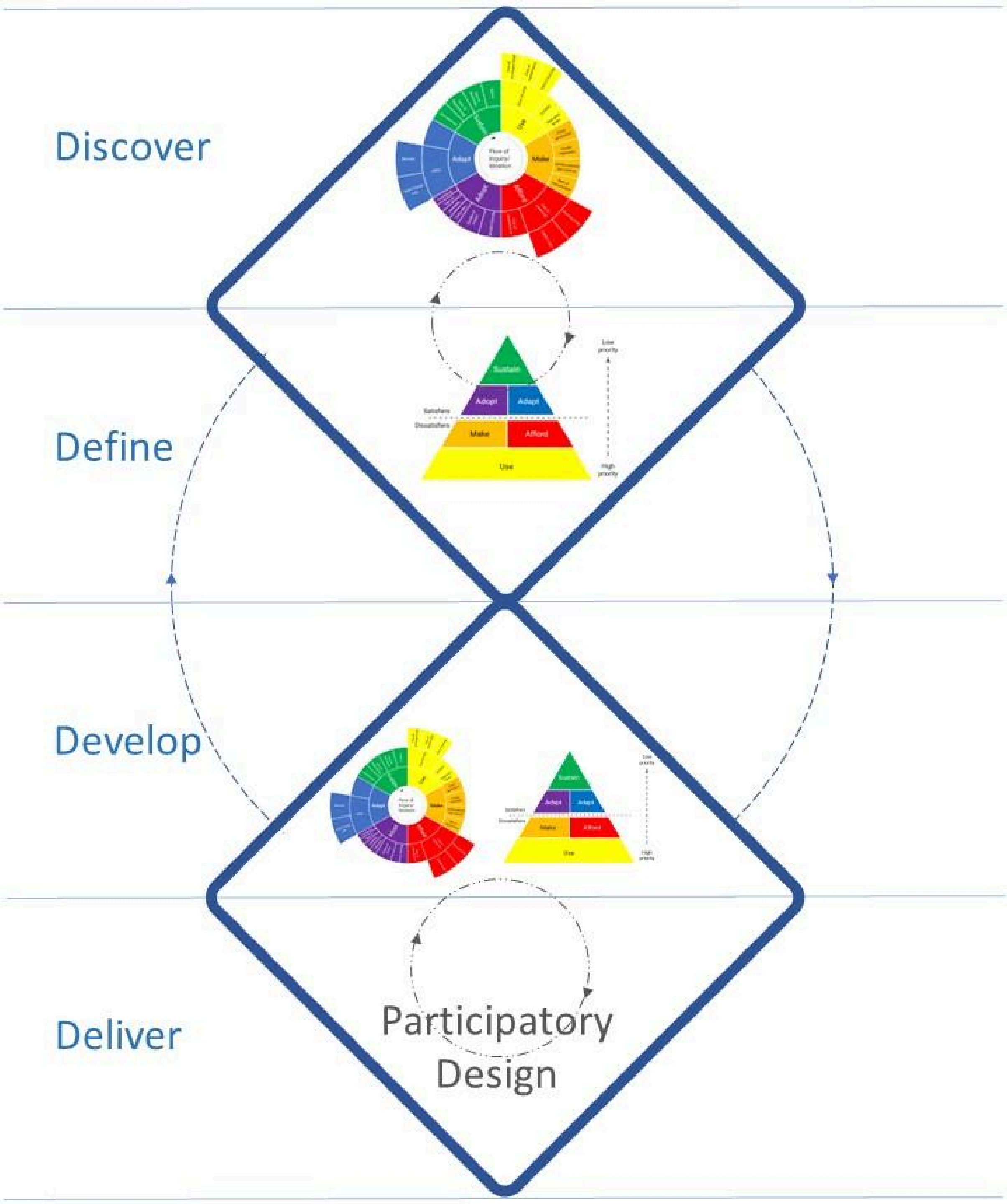


Figure 5.48: Proposed use of framework structures during the design process

5.8 Refining the design

Initial work developed a prototype thresher. Then the design of this thresher was refined in light of the discoveries from the new field visits and interviews with the farmers. Following aspects of the thresher were considered during refinement.

- Folding Design : Can ease of transport and storage be achieved with a rigid body?
- Effective human power use and use of bicycle chain drive to achieve required speeds: What should be the operator position and orientation
- Two person operation : Allows rest from pedalling and gripping without stopping the operation - arrangement in gender friendly taking into account weaker grip strength and stronger lower body strength of female body
- Number of wheels and footprints need to account for narrower bunds and possibility of single wheel design?

Multiple options of seating position of the operator generating power (Fig. 5.49) and frame designs (Fig. 5.50) were then generated. The researcher selected the most suitable ideas and developed them taking inspiration from wheelbarrows and prams (Fig. 5.51). The ideas were further simplified to develop a concept that could use a recumbent seating position for generating power (Fig. 5.52).

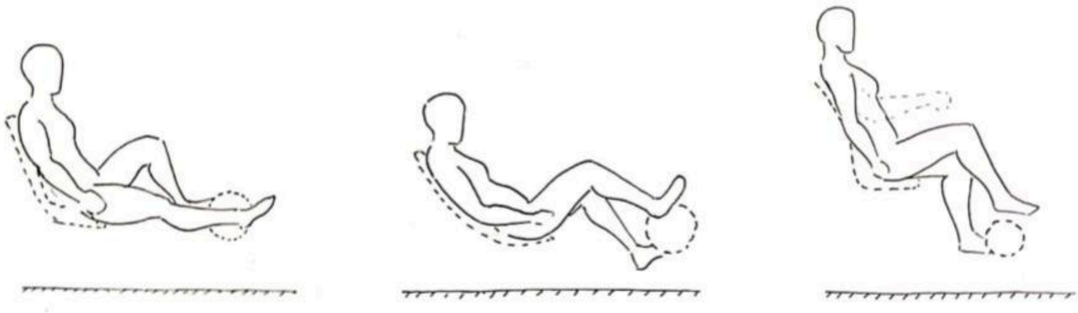


Figure 5.49: Options of frame and position of the operator generating power

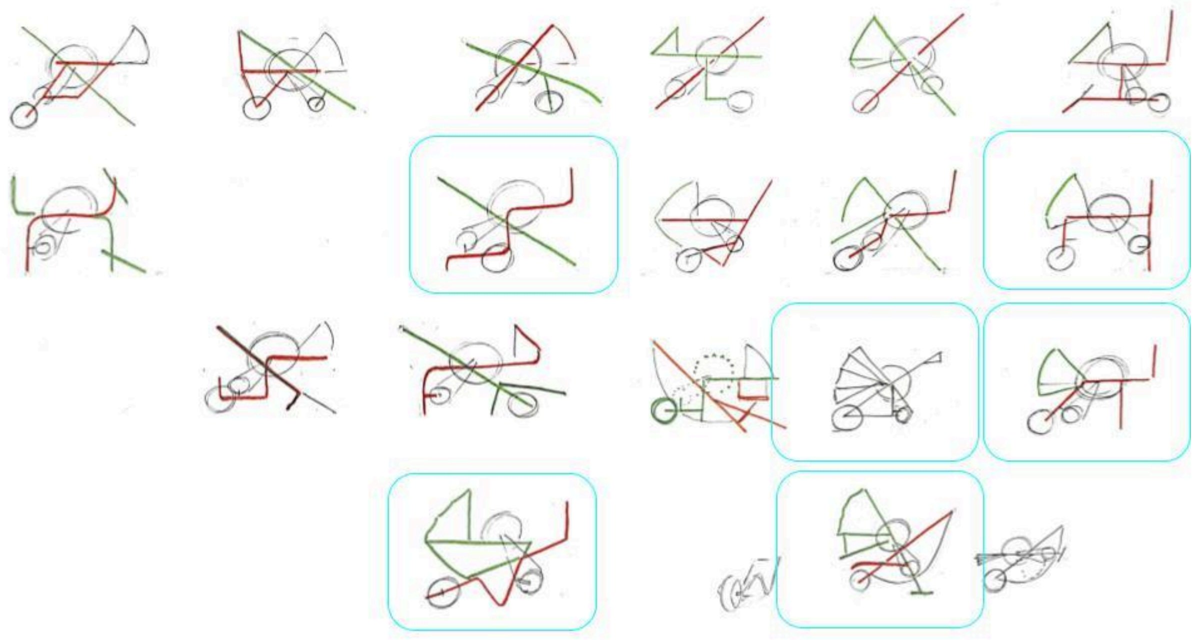


Figure 5.50: Options of frame and position of the operator generating power

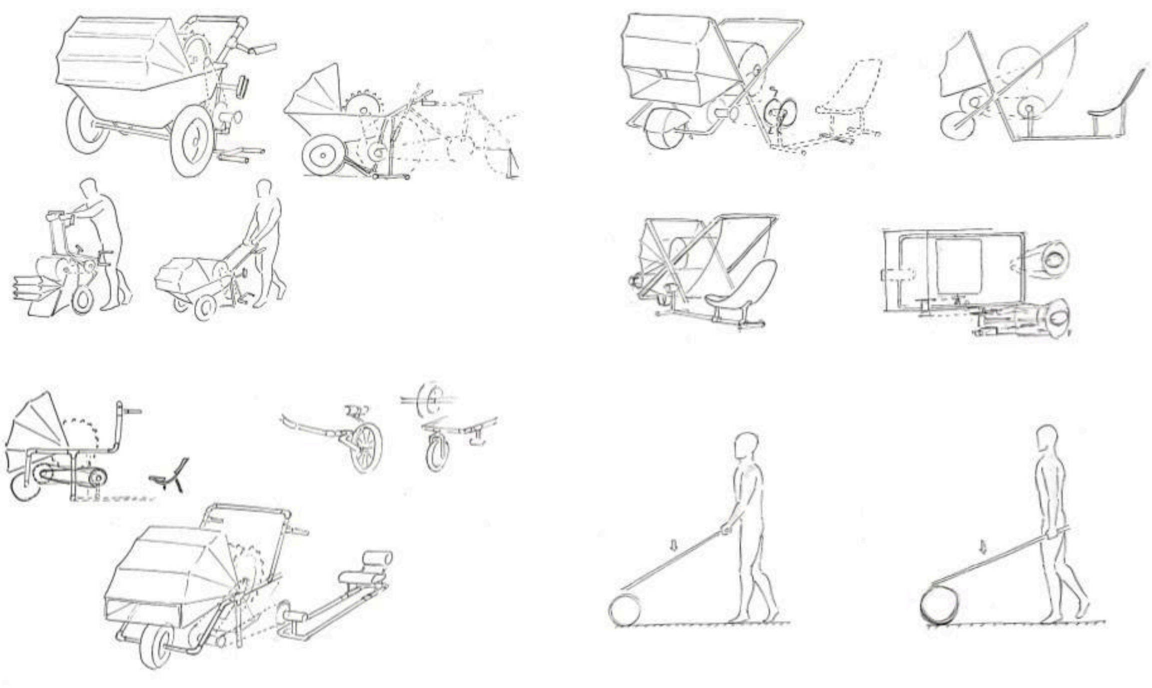


Figure 5.51: Initial concepts based on wheelbarrows and prams

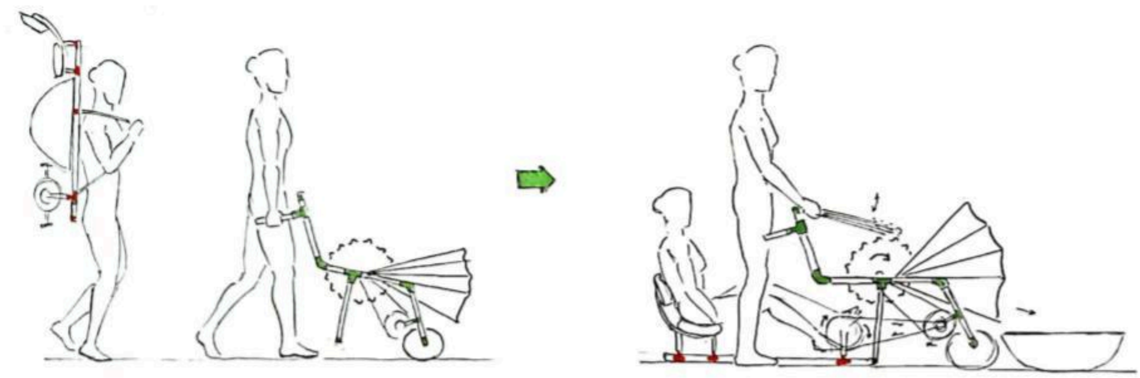


Figure 5.52: Simplified concept for recumbent operator position and a rigid device frame

The researcher then looked at the existing trade of traditional knife sharpening where a bicycle is used as a transportation as well as a power generating equipment. A simplified single-wheel, rigid frame design with an upright operator position (Fig 5.53) was chosen for further detailing.

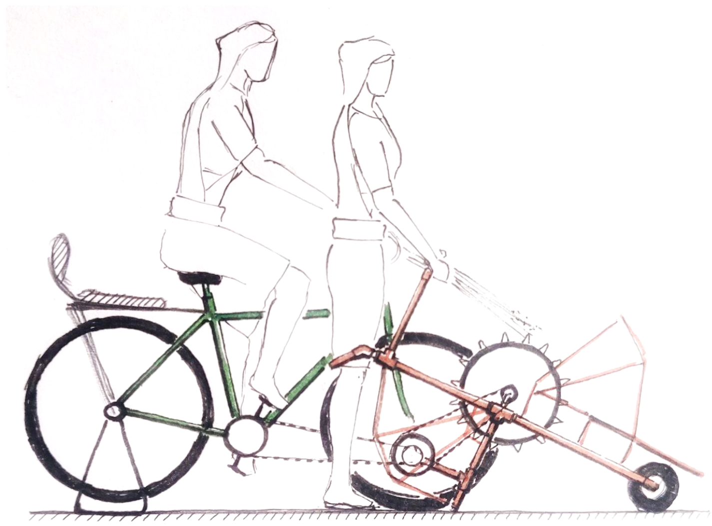


Figure 5.53: Simplified concept for upright operator position and a rigid device frame.

Two options for frame material were explored (metal tubes with connectors and welded angles), and the rigid guard design using CAD (Fig. 5.54) was developed. Various possibilities of forms for the front guard were also explored (Fig. 5.55).

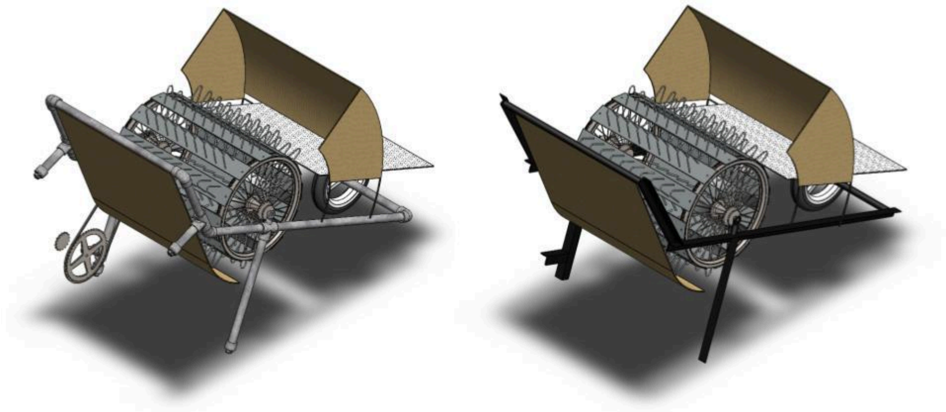


Figure 5.54: Two frame options of threaded GI pipe with connectors and MS L-angle weldment

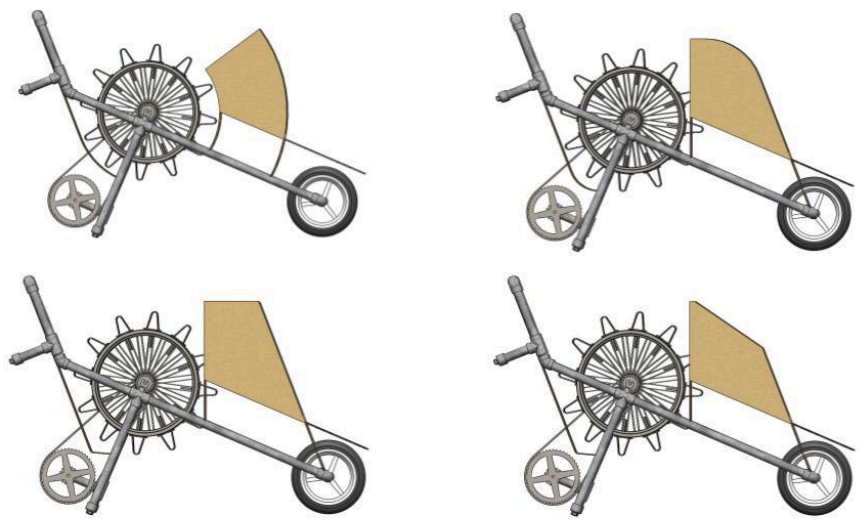


Figure 5.55: Two frame options of threaded GI pipe with connectors and MS L-angle weldment

The Indian design standards and specifications of single-wheel wheelbarrow (IS: 2431-1963), paddle threshers (IS: 2431-1963), and bicycle components were then studied to finalise hard points and some dimensions in order to develop a detailed CAD assembly (Fig. 5.56).

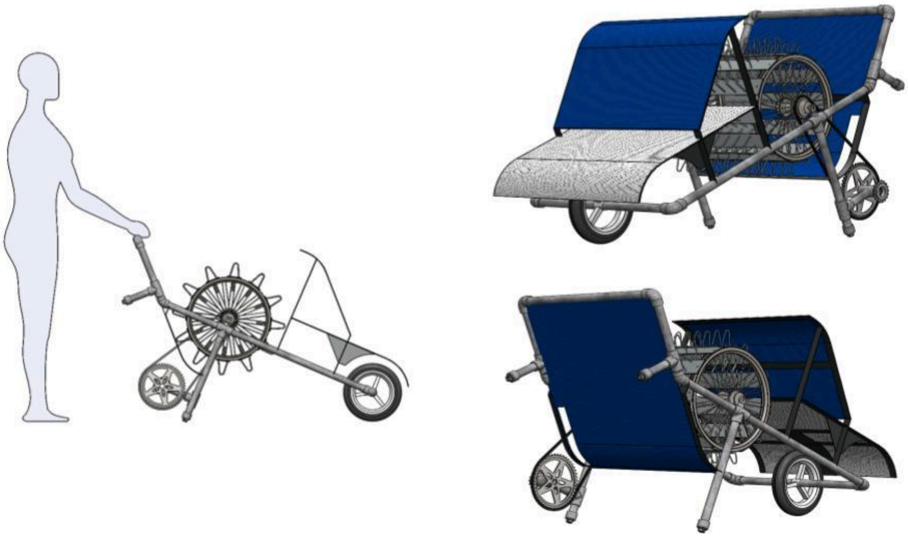


Figure 5.56: Two frame options of threaded G.I. pipe with connectors and MS L-angle weldment

Data from field observations and interviews was then to finalise on material of the frame (welded MS angles) and to simplify the design of the guarding. The design drivers of Use, Make, and Afford were also used to inform these design choices (Fig. 5.57).

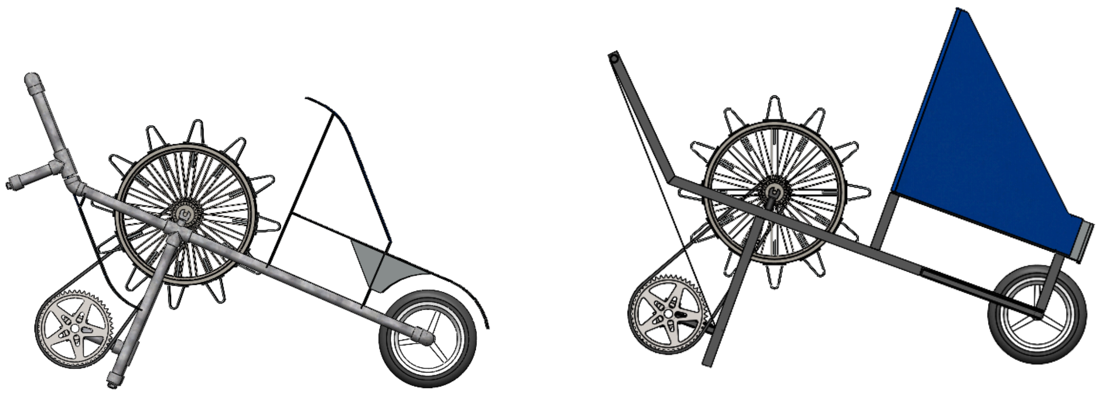


Figure 5.57: The improved MS angle based design (right) compared to the GI pipe version (left)

5.9 Design Outcome

The threshing equipment concept was refined and developed for manufacture of test prototypes (Fig. 5.58 and Fig. 5.59). The current concept uses a welded frame with a single wheel design. The threshing wheel and transmission dimensions are also modified to reflect Indian standards and material availability.

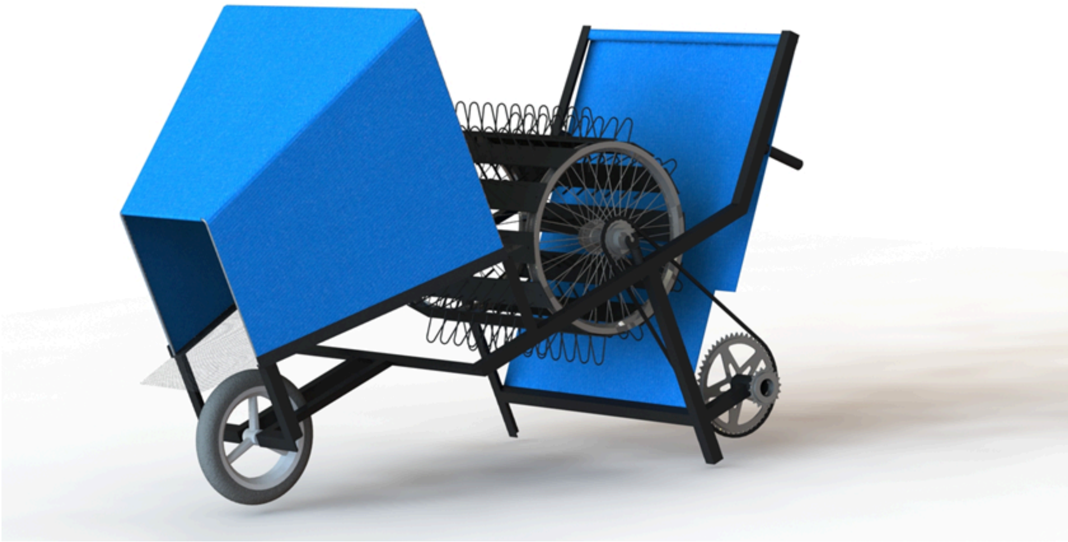


Figure 5.58: The concept selected for prototyping and field testing

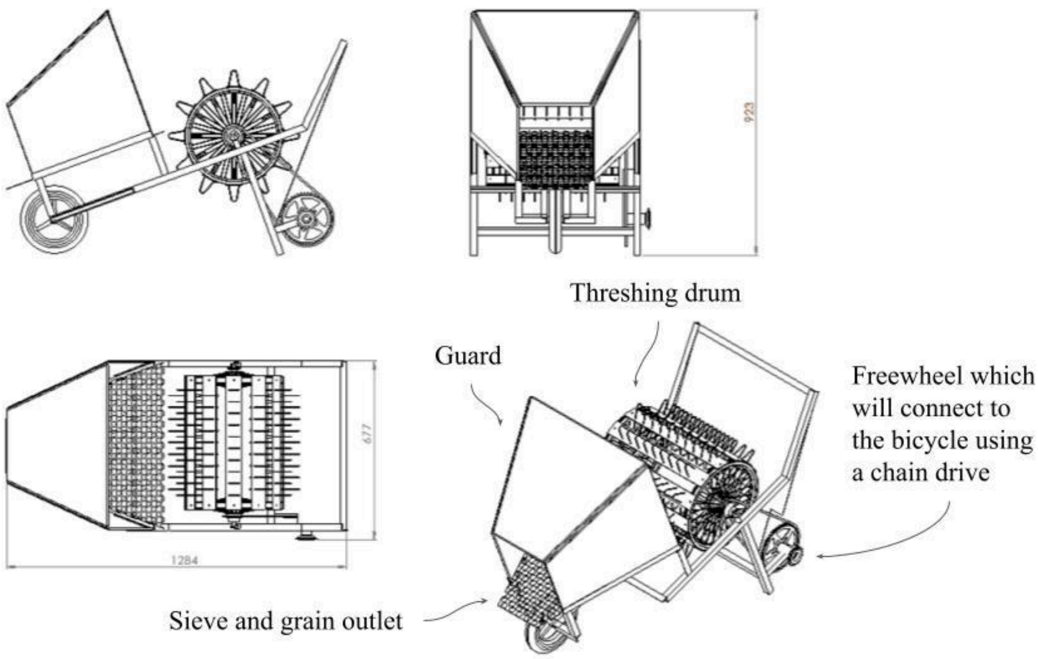


Figure 5.59: The dimensions and elements of selected concept thresher

5.10 Conclusion

The chapter has provided an outline of the initial design and ideation process that was followed to develop a threshing solution. The chapter also provides a summary of the second stage of field work that was undertaken to broaden the understanding of threshing process, needs and the way tools are manufactured and repaired in villages. Based on the experience and learning during these activities, the design framework was refined and the 26 parameters identified during previous stages of research were categorised into six design drivers of use, make, afford, adopt, adapt, and sustain. Then FBS ontology was used to generate and visualise the design framework as a set of tools and processes. The process of field observations, interviews and ideation was also used to further refine and simplify the thresher concept for manufacture and testing. The next chapter will provide an overview of prototyping, testing, and realisation of the design concept.

6. Evaluation of proposed intervention (Design + Realisation)

This chapter (Fig 6.1) provides an outline of the process of fabricating the prototype and subsequent field testing to validate the design against the product specification. The chapter also details the outcomes of the field testing and the incorporations of lessons learnt to generate a refined modular thresher design with add-ons to aid in power transmission depending on the need of the user.

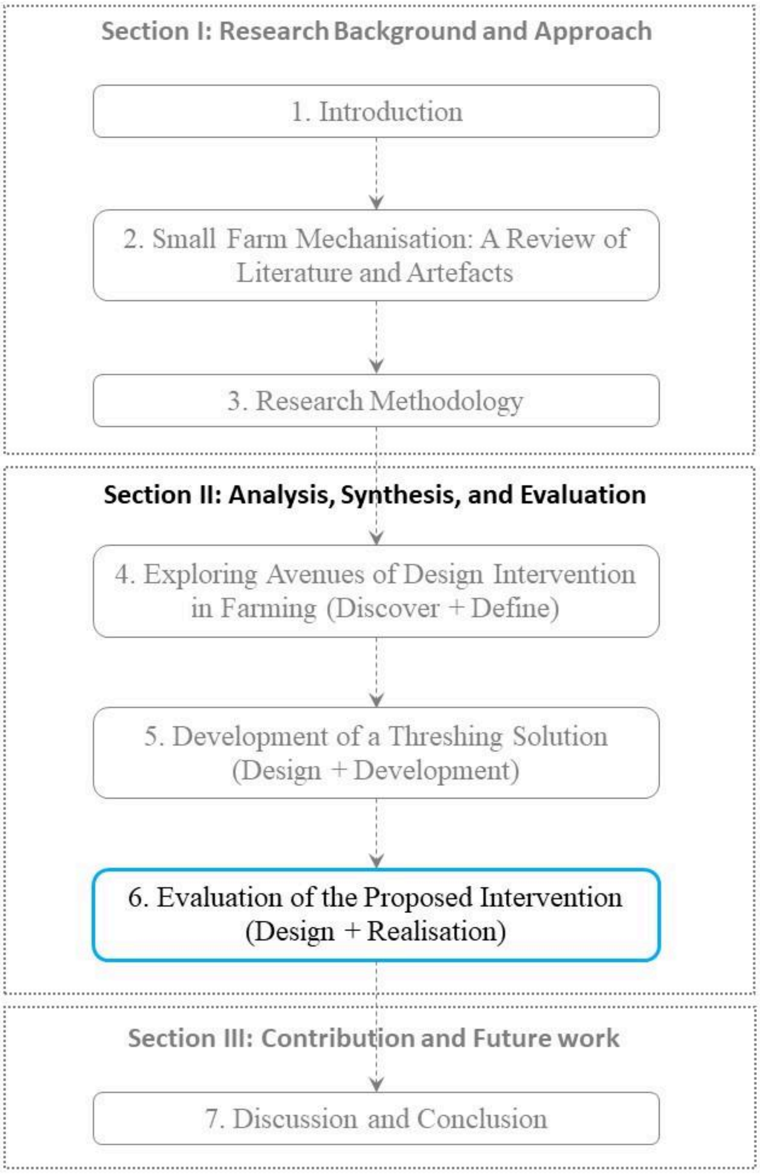


Figure 6.1: Evaluation of proposed intervention (Design + Realisation)

6.1 Fabrication of prototype 2.0

In order to fabricate the second prototype 2.0 a workspace and tools along with welding support in Suratgarh, Rajasthan was used. This was necessary due to lockdown restrictions in Goa and rising COVID-19 cases in surrounding states. The researcher procured materials, primarily from scrap yards and shops in surrounding villages and fabricated a prototype using essential bare minimum measurement tools, metal cutting and welding (Fig. 6.2). This activity was useful as it helped learn and understand how the design could be improved further for local manufacture. The pieces were then transported and assembled in Goa (Fig. 6.3).

Figure 6.2: The stages of manufacturing the thresher prototype 2.0

Following lessons were learnt during the course of manufacturing the components for the prototype.

1. Production drawings need to be simplified, and assembly instructions should be conveyed visually. Technicians and welders at small workshops have difficulty in reading and understanding production drawings prepared in the usual engineering style. They respond well to oral instructions along with quick rough sketching on paper during each stage of the process and a more detailed 3D image or photo on the screen.
2. A small mock-up or set of instruction drawings with images of each component and order of operations like drilling, welding etc., at each stage of assembly might help.

3. Most workshops have limited tools like only a 90 degree right angle and tape measure. Need to provide dimensions so that components with angles can be fabricated without the need for calculations or any additional expenditure on measuring tools and jigs.
4. The threshing drum will be the biggest bottleneck as it requires the most time and frequent measurements and checks during fabrication.
5. The frame design was modified during the fabrication process to simplify quick disassembly and ease of transport.

Figure 6.3: Assembly of the prototype 2.0

The initial observations after assembling the prototype were as follows:

- Manoeuvrable. Easier to lift, and steer.
- Handles at the side instead of the top helps in lifting and movement (possible interference with pedalling unless a longer chain is used during operation).
- Use of MS angles simplifies assembly and manufacturing.

6.2 Testing

A setup was created with a roadster bicycle for testing (Fig. 6.4). The setup involved a bicycle secured using a double stand at the rear wheel and a link connecting the top tube of the bicycle to the device frame in order to prevent the bicycle from being pulled towards the machine during pedalling.

Figure 6.4: Setup of prototype 2.0 for inhouse testing

The aim of the testing was to determine the effectiveness of the proposed concept with respect to an existing solution used by the farmers at a given location.

The study involved two participants at a time; one participant would pedal the bicycle while the other would hold 3-5 bundles of harvested rice panicles over the drum one at a time till the grains are threshed. The number of bundles threshed and pedal speed was observed and calculated. The participants were then asked to hold and push the machine on wheels to check the portability of the wheelbarrow inspired design of the frame. The post-test interview focussed on usability aspects like ease of transport, ease of use, and their perception of the machine's suitability for the task vis-a-vis the existing machines and traditional methods.

6.2.1 Design of the experiment

A detailed test protocol was developed for the in-house and field testing of the prototype.

6.2.1.1 Test protocol. The protocols for both in-house and field tests are as follows: Total time: one hour including setup time and time taken to teach and familiarise users with the device.

In order to validate the efficiency of the thresher with reference to traditional methods, dependent variables to be measured: number of bundles threshed in 5 minutes (the number of bundles per threshing speed depending on availability of yield), number of pedals for one minute. The type and description of different variables in the test are provided in table 3.

Table 3

Descriptions of variables in the experiment

Type of variable	**Description**
Independent variable	Thresher prototype 2.0
Dependent variable	Threshing rate (bundles/hr)
Control variable	Gender of the participant, rice variety, bundle size, days after harvest, the age range of participant, type of threshing teeth (peg/wire loop), harvest season, time taken to explain and learn the device
Random variable	The expertise of the participant with threshing activity
Confounding variable	Ambient temperature and humidity, age and expertise of participant, wind speed, time taken to pick and dispose of bundles, feed rate
Conceptual variables	ease of use, quality of output

6.2.1.1.1 Test prerequisites. The following conditions need to be ensured before each test.

1. The machine needs to be set up in a clear space with a bicycle connected to it.
2. The participants should test the machine for at least 5-10 minutes till they are familiar with the working and find the right pedalling speed,
3. The bundles should be kept next to the machine so that the threshing process can begin.

6.2.1.1.2 Steps during each test. Steps to be taken during testing are as follows:

1. The participant starts peddling until the machine reaches the steady drum speed at a 40-50 rpm pedalling rate.

2. The second participant picks up the bundle and threshes it against the drum while rotating the bundle as needed.
3. The bundle is discarded.
4. 3-5 bundles should be threshed (depending on availability) using the prototype and then the existing technique/device in use at that location.
5. Note the time for threshing the bundles
6. If possible, a sample of threshed grain should be examined and winnowed to check the amount of straw and other impurities.

6.2.1.1.3 Acceptance criteria. The hand threshing typically occurs at a rate of around 110-140 bundles/hr, and the existing pedal-operated thresher can thresh around 140-160 bundles/hr (Selco Foundation, 2013). The acceptance criteria for the machine should be the same or more than 150 bundles but not less than 140 bundles/hr.

6.2.1.1.3 Post-test briefing. Semi-structured interviews to be used after each test to understand the improvements needed in the concept. The interviews will revolve around two areas, 1) Difficulties faced by farmers while using existing tools, and machinery; and 2) Experience of using the prototype and their suggestions for improvement, if any.

Examples of some questions that will be asked are as follows:

1. Which tools or machines do you own for post-harvest activities?
2. What is the frequency of buying/renting farm tools for these activities?
3. How do you decide which tool to buy and which one to rent? Why?
4. Were there any difficulties or discomfort while using the machine?
5. What would you change in the prototype setup?
6. Are there any features that you would like us to add?

6.2.2 Validation against product design specification

A test protocol and design FMEA (Failure mode effect analysis) were created to validate the design against product specifications. Ethics approval for testing was provided through Monash University Human Research Ethics Committee (ID 30978) as well as the IITB Institutional review board. The design prototype 2.0 was then tested both in-house and in the field.

6.2.2.1 In-house tests. The in-house tests were conducted with two participants. The objective was to conduct a pilot test before using the prototype for field testing and to ensure that the test protocol was sufficient for the purpose.

Two tests of the participants alternating between pedalling and cycling (Fig. 6.5) were conducted where two bundles were thresherd by each user. At this stage the participants could achieve an approximate speed of 110 bundles per hour after extrapolating the time taken to pick up, thresh and discard two bundles. This is similar to the rate of threshing done using a traditional method of beating but with much lesser drudgery involved. The researcher also asked the users to then try to lift and move the device in a small room to check the portability and manoeuvrability (Fig. 6.6).

Figure 6.5: In-house test for threshing bundles of harvested rice panicles

Figure 6.6: In-house test for portability

Following feedback was received during the initial pilot test from the participants:

1. Pedalling the device is quite comfortable and does not require additional effort compared to regular riding.
2. Not much effort and up/down movement needed for threshing the bundle. Just rotation of wrists is sufficient.
3. We get an indication that the grain is threshed when the drum stops pulling at the bundle of plants
4. The device is light and can be manoeuvred comfortably
5. It is easier to reverse the device compared to moving forward
6. Physical link between the bicycle and the device should be simplified

After the pilot test, it was observed that the grain gets collected in the sieve as well as below the drum, the grain also tends to get thrown off from the top opening and spreads to both sides.

The researcher noted that grain gets threshed well at the speed of 36 pedals per min and above. Farmers might have a different way of holding and rotating the bundle on the grain which might be more effective if they have prior experience with pedal threshers and since there was a need to check the forward movement with the device on slopes and uneven terrain, it was decided to conduct field tests in a village with multiple farmers.

6.2.2.2 Field tests. The next step was to test the prototype in the field. Since the research was conducted during the Covid-19 pandemic, the restrictions for travel and movement had to be adhered to. Options for testing the device in the field were limited.

After visiting four different villages of Parcem, Shiroda, Poiguinnim and Pachavadi in Goa during the pandemic, a farmer was located who was about to start threshing the grain and was willing to participate in the field test by providing the farm and cut harvest for the tests. The tests were conducted at the villages of Parcem, Goa (Fig. 6.7). The frame, threshing drum, and the bicycle were disengaged and disassembled before loading them into a mini truck and travelled to the village.

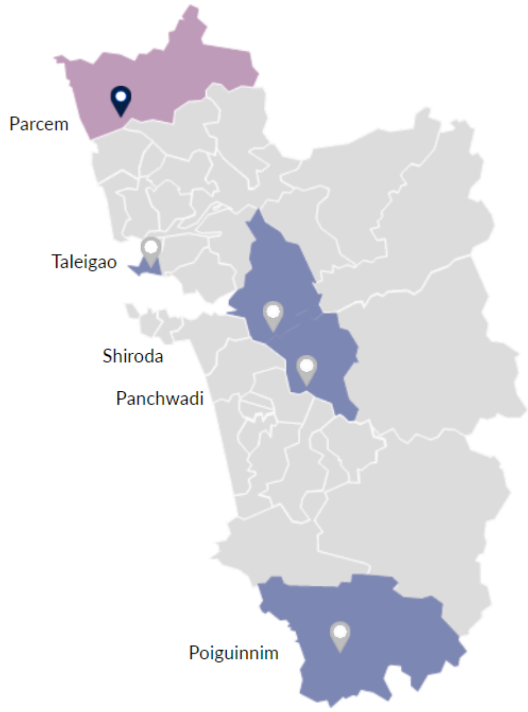


Figure 6.7: The location of the Parcem village in the state of Goa where the field-test was conducted.

The field test was conducted on a 0.8 hectare farm. An initial field test was conducted with three different farmers on the first day. The Sarpanch (elected leader) of the village and two other farmers were also present as observers for the test. The initial field test involved transporting the machine to the area demarcated for threshing activity, setting up and connecting the machine to the bicycle, threshing of grain bundles, collection of grain, and then followed by transport of machine and bicycle to a shed in the farm for storage.

The observations were as follows:

The rice was harvested manually using sickle and was stacked for drying to prepare for the threshing activity. Since the rice was harvested manually, the field was uneven and had stems of rice still jutting out of the ground throughout the field. Hence even the sheet used for threshing could not be laid flat on the ground (Fig. 6.8).

Figure 6.8: The site chosen for field testing where the rice was harvested by hand using sickles

The machine was transported to the farm (Fig. 6.9). The farmers liked the portability of the machine and the ease of transport over uneven farm terrain. Due to the uneven terrain and the stems of the rice plants left in the ground, it was difficult to align the machine and the bicycle. To prevent the bicycle from toppling, a metal post had to inserted into the ground and tied to the bicycle. Due to the nature of the terrain, and vibration of the machine, it was very difficult to keep the chains aligned. The machine kept disengaging from the bicycle. However the farmers could thresh a few bundles by initially pedalling the bicycle (Fig. 6.10) and then hand cranking the pedals while ensuring that the bicycle was aligned.

Figure 6.9: Transporting the device and the bicycle to the site location

Figure 6.10: Field testing of proto 2.0

6.2.2.2.1 Observations and insights from initial test. The following observations and suggestions were received from the participants and audience of the test.

1. The farmers appreciated the ease of transport and the speed with which the drum threshed the grain. They felt it would really help solve their labour issues and would reduce the time and the effort.
2. The power transmission module was too close to the ground, it needs to be raised by at least 50-100 mm.
3. The farmers felt that the need to transport an additional object (the bicycle) along with the additional activity of connecting and aligning it to the machine in the field based on conditions would require more time and work compared to set-up time of existing solutions.

4. They felt that the machine should be a compact device for all necessary attachments which would allow them to just carry it to the field and start threshing without need of any adjustment
5. They also felt that the people who still use a bicycle in the village are dependent on it for their daily trade/wage and hence keeping a functioning bicycle engaged in this activity for one or two days would affect the income of the bicycle owner.
6. The farmers requested for either a motor and at least a pedal or handle attachment to the device itself instead of a separate bicycle.
7. They also suggested a heavier and stronger base which can be firmly locked in place on an uneven field.
8. They want a larger sieve which allows the grain to go through but prevents the hay from mixing with the grain.
9. They also asked for a chute that would transport the grain to the front or the side of the machine.

Based on the participation interviews after the initial test and field observations, the following insights were noted.

1. Due to the nature of terrain, and vibration of the machine, it was very difficult to keep the chains aligned. And the device did not function as intended due to difficulty in set up and uncontrolled movement of the frame and the bicycle.
2. The farmers major concerns are regarding reduction of labour and increased speed of activity. They are fine with paying a slightly higher cost as it gets balanced due to costs saved on labour.
3. The ease of transport seemed to be the most attractive quality of the machine followed by the performance of the threshing drum.

***6.2.2.2.*2 Modification to the test setup.** Based on the initial observations and insights the researcher decided to modify the setup in the field before conducting the next round of tests. The farmers helped locate a welder in the village with portable welding and cutting equipment who performs various metal fabrication jobs for them. The researcher strengthened the frame and changed the location of the bottom bracket to improve tension in the chain. The height of the chainwheel from the ground and the strength of the structure holding the bottom bracket was also increased (Fig. 6.11). These changes were then using a bicycle on a flat ground. However the farmers were still not comfortable with mounting and pedalling a stationary bicycle. The alignment of the bicycle and the machine would also shift when a farmer tried to sit on the cycle. Based on suggestions of all the participants, the researcher decided to not use a separate bicycle for power generation. Another old bicycle that was not in use in the village was located, the researcher then cut the frame and created a fixed pedal arrangement on the device. The design for this solution was based on exploration of various design directions in the exploration stage where the possibility of cutting a bicycle to use the rear half for power generation of thresher was explored (Fig. 5.16 and Fig. 5.18). The solution also was derived from exploration of ideas for pedalling operator's posture and position where a recumbent position was considered (Fig. 5.49 and Fig. 5.52).

The fixed pedal arrangement kept the alignment of the chains firmly in place while adding additional stability to the machine. This design prototype 2.5 (Fig. 6.12) was then transported to the site (Fig. 6.13) and tested (Fig. 6.14) with rice bundles.

Figure 6.11: Modifications done to reinforce the chassis and improve power transfer

Figure 6.12: Thresher prototype 2.5 without the guard

Figure 6.13: Transporting thresher prototype 2.5 to the site

Figure 6.14: Field testing of thresher prototype 2.5

We then visited the villages of Konkan region in Maharashtra. The researcher showed the videos of a field test (conducted in a field in Goa) to two farmers of Konkan region of the neighbouring state of Maharashtra. The field conditions are a bit different when it comes to threshing activity in this region. Unlike the farmers of Goa, who traditionally thresh rice by trampling it under feet, small farmers in Konkan region thresh grain by beating the bundles on a wooden bench or metal drum. This process is usually done under a covered indoor area on a flat ground. Hence these farmers also seemed interested in the bicycle driven concept along with the new recumbent one.

6.2.3 Test outcomes

The observations after testing the new setup were as follows:

1. The new setup is easy to carry, easy to set up and easy to use
2. This would really help in accessing farms using traditional foot pathways especially in areas where other machines are difficult to carry.
3. The speed of grain threshing would help small farmers quickly thresh grains with minimum effort.
4. Ideally the machine should also at least come with a provision for mounting a motor in the future along with the pedal assembly, as a motor would help reduce labour requirement to just one person.

5. This thresher prototype worked well and the participants managed to thresh grains at an average speed of 17-18 seconds per bundle. The researcher estimates that with skilled workers and increased machine familiarity, it would be possible to reach an output of 180 - 200 bundles per hour, while the existing technique of beating the bundle used by these farmers generates output of 100-110 bundles/ hour per person (Fig 6.15).

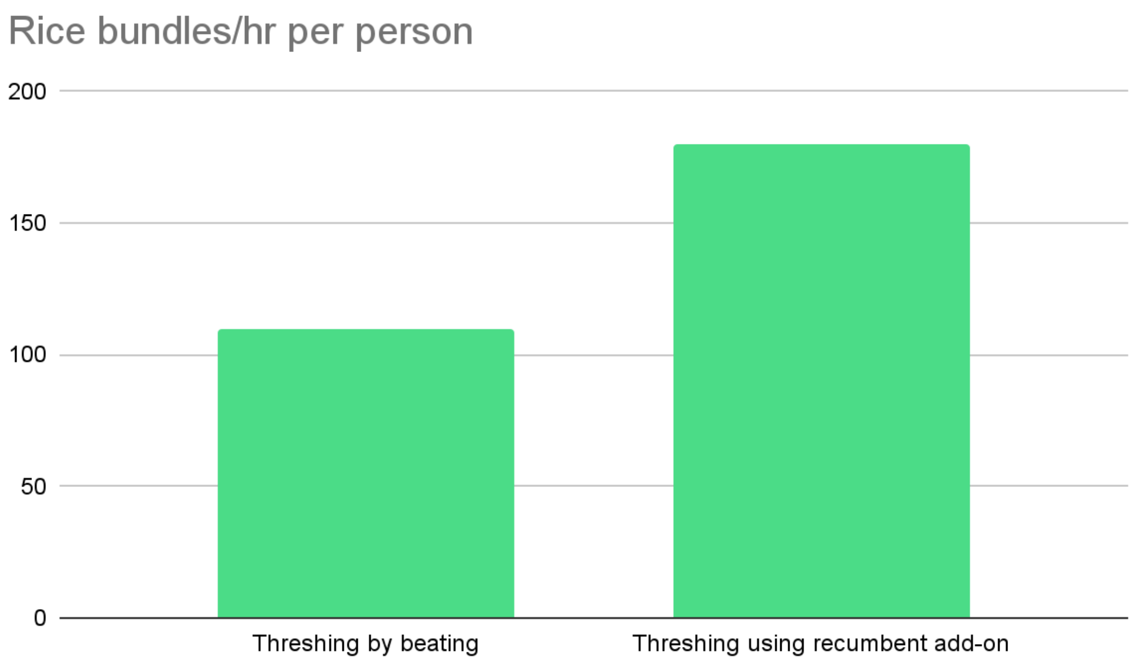


Figure 6.15: The estimated difference between rate of threshing by hand vs using thresher concept 2.5

6.2.4 Lessons learnt

The lessons learnt from in-house and field tests were then used to change and refine the next iteration of the thresher concept. Following tentative changes were planned based on farmer's feedback and experiences of the field tests.

1. A lighter threshing drum with more wire loops.
2. Using thicker MS angles or Square tubes with cross braces or trussed structure for frame
3. Generating a detachable/foldable seat with recumbent posture
4. Covers for power transmission components like chain and chainwheels
5. Front, side and top cover for the threshing drum
6. Large sieve to separate grains from hay

7. Chute for directing grains to the front or the side of the machine

6.3 Design refinement

Before refining the design ther researcher decided to revisit the activities required to set up, use and store the existing pedal threshing solution and the thresher concept 2.0 (bicycle driven), and 2.5 (with recumbent pedal attachment). Three activity maps were created in tabular form and analysed (Table 4 to 6). The researcher realised that the current setup of attaching and aligning the bicycle adds a lot of steps to the setting up process compared to existing solution and prototype 2.5 with recumbent attachment. Hence the design process also involved ideation to figure out a better way of attaching the bicycle to the machine for power transfer. This also resulted in an idea of using a base device with add-on. This would enable farmers to pick and choose the type of solution that they needed depending on the location and the requirement.

The lessons learnt from manufacturing and field testing of thresher concepts 2 and 2.5 were incorporated to create a new thresher concept 3.0 (Fig. 6.16). This concept has a base threshing unit with an improved, reinforced chassis, and with an addition of grain collection chute. Power generation is done with the help of two add-ons, a) a recumbent setup that can either be purchased with a seat or farmers can use their own chair or stool (Fig. 6.17), and b) an add-on module which allows any bicycle to be connected to the device without requiring any modifications (Fig. 6.18). This concept 3.0 was then further refined with the objective of design for manufacture of prototype 3.0.

Table 4

Activity map for exiting pedal threshing solution

Stages	Usage and change							
Steps	**Transporting machine to home/ shed**	**Store**	**Transporting machine to field**	**Setting up the machine (stacking the cut harvest)**	**Operating the machine (operator in case of rented m/c, labourer/family in case of owning/sharing)**	**Collecting grain and hay**	**Disengaging the machine /preparing for thransport**	**Transporting machine to shed/ home**
Job to be done (JTBD)	Arranging for transport		transport	set up the collection sheet for grain and the machine	gripping the bundle of plants	collecting the hay bundles		Arranging for transport
	loading the machine			keep the machine near the pile of harvested grain	pedaling the machine	collecting the grains		loading the machine
	unloading the machine				rotating the bundle of plants over the drum			unloading the machine
					discarding the spent bundle			

Table 5

Activity map for bicycle powered thresher concept 2.0

Stages	Usage and change							
Steps	Transporting machine to home/ shed	Store	Transporting machine to field + transporting bicycle to the field	Setting up the machine (stacking the cut harvest + assembling the machine+ connecting machine to bicycle)	Operating the machine + operating the bicycle	Collecting grain and hay	Disassembly/ disengaging the machine for transport	Transporting machine to shed/ home
Job to be done	Arranging for transport		folding/ collapsing/ packing	Keep the machine near the discarded grain	U1: holding the bundle over drum	collecting the hay bundles	Disengage the front bicycle stand to reduce tension in the chain	transport the machine by pushing
	loading the machine		transport	Disengage the chain from pedal to chainwheel	U1: rotating the bundle of plants over the drum	collecting the grains	Remove the chain from the chainwheel	pedaling bicycle to the field
	unloading the machine		pedaling bicycle to the field	connect the chain from machine to the bicycle	U1: discarding the spent bundle		Connect the chain from rear wheel to chainwheel	
				secure the bicycle on the stand	U2: pedaling the bicycle			
				Align the bicycle and the machine to ensure that chain is parallel to the threshing drum				
				Ensure that the chain has sufficient tension				
				Fasten the front wheeel stand to the machine				

Table 6

Activity map for recumbent thresher concept 2.5

Stages	**Usage and change**							
Steps	**Transporting machine to home/ shed**	**Store**	**Transporting machine to field + transporting bicycle to the field**	**Setting up the machine (stacking the cut harvest + assembling the machine)**	**Operating the machine + operating the bicycle**	**Collecting grain and hay**	**Disassembly / disengaging the machine for transport**	**Transporting machine to shed/ home**
Job to be done (JTBD)	Arranging for transport		folding/ collapsing/ packing	Keep the machine near the discarded grain	U1: holding the bundle over drum	collecting the hay bundles	folding the chair	transport the machine by pushing the wheelbarrow
	loading the machine		transport	unfold the chair and keep it behind the pedals	U1: rotating the bundle of plants over the drum	collecting the grains		pedaling bicycle to the field
	unloading the machine		pedaling bicycle to the field		U1: discarding the spent bundle			
					U2: pedaling while sitting on the chair			

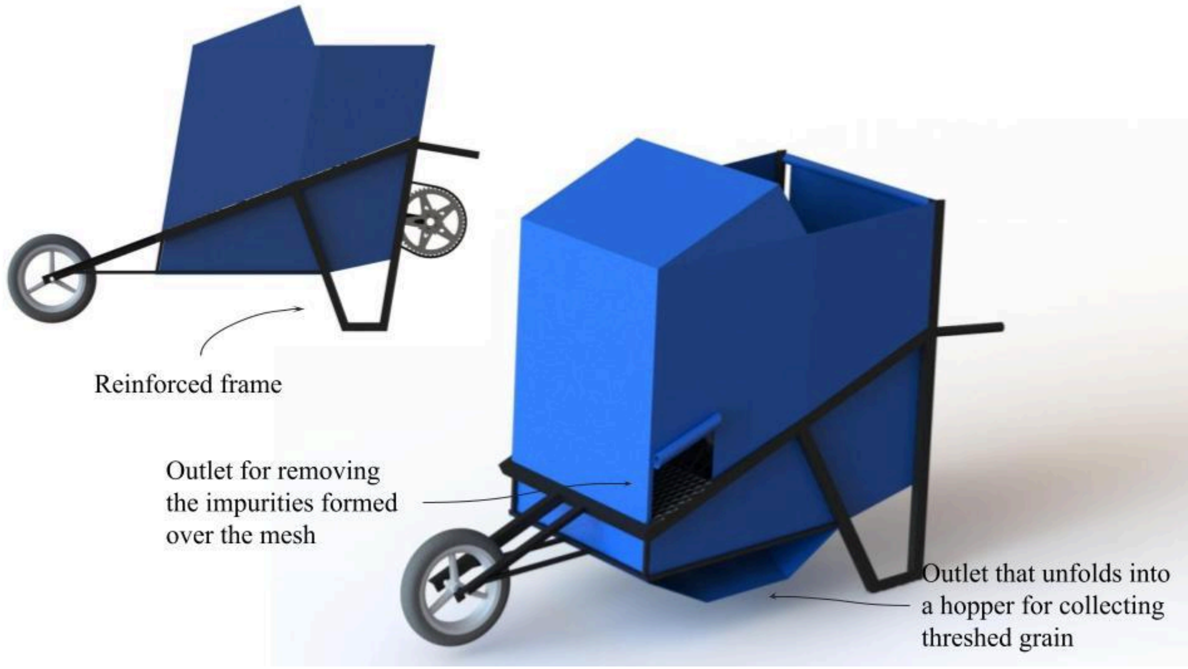


Figure 6.16: Thresher Concept 3.0

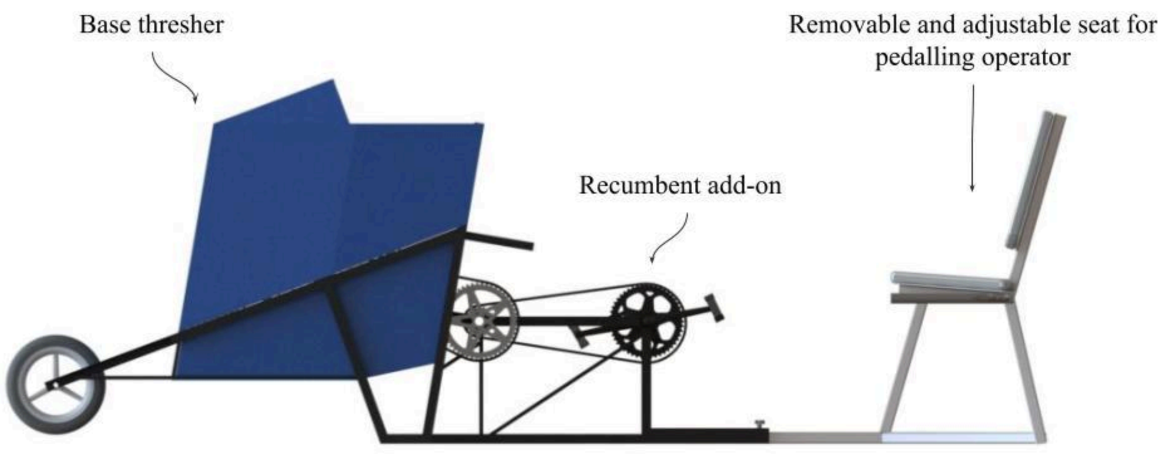


Figure 6.17: Thresher Concept 3.0 with recumbent add-on

Figure 6.18: Thresher Concept 3.0 with bicycle add-on

Before manufacturing the prototype, existing literature was studied for recumbent and upright pedalling. According to Hakansson and Hull (2004), "The musculoskeletal system inputs (i.e. muscle activation patterns) and outputs (i.e. segment kinematics and kinetics) are similar for both recumbent and upright positions". The difference in propulsive effectiveness between recumbent and upright position is approximately four percent which is quite small (Telli et al., 2016). This also helped us to then only focus on parameters of affordability, ease of manufacture, ease of use, and ease of transport for the design framework as with the recumbent add-on, only the machine should be transported to the field and additional steps of finding, transporting, and aligning the bicycle are avoided. Also considering that this activity will be done when the device is stationary, the researcher also had to check if there is a difference between recumbent and upright position during high intensity exercise. When the recumbent angle is above 30 degrees, the ability to sustain cycling exercise is not different between upright and recumbent cycling in healthy participants. Similarly, the duration of high-intensity cycling exercise and the dynamics of oxygen uptake are unaffected when the body inclination is lowered from the upright (90 degrees) to the 65 and 30 degrees recumbent postures (Egaña et al., 2010). Therefore, for the scope for further development and prototyping, the focus shifted to design of a thresher with a recumbent add-on.

6.4 Fabrication of concept 3.0

The lessons learnt from field visits and debriefing of farmers who participated in the field tests revealed further insights that were incorporated into the next version of thresher design 3.0. The researcher then started the process of fabricating the base thresher prototype 3.0 (Fig. 6.19). After completion of base thresher prototype 3.0 The dimensions of the thresher were used to design and manufacture the recumbent add-on. Thresher prototype 3.0 with the add-on was then assembled (Fig. 6.20) and usability issues as well as avenues of improvement and refinement were identified (Fig. 6.21).

Figure 6.19: Fabrication of base thresher prototype 3.0

Figure 6.20: Thresher prototype 3.0 with recumbent add-on

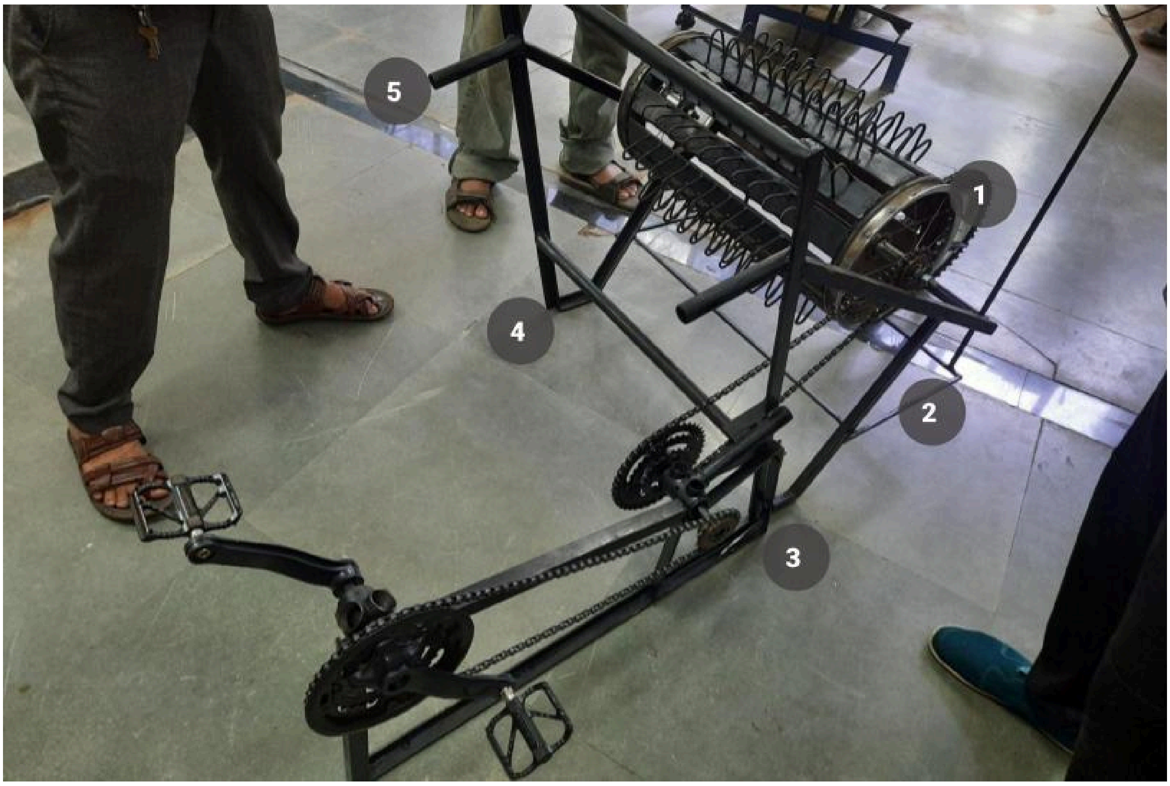


Figure 6.21: Issues and areas of improvement for the next iteration of thresher concept

Based on the lessons learnt during fabrication, initial testing, and brainstorming, the following possibilities of changes were considered for concept 4.0

1. A mechanical brake for threshing drum along with creating a physical rigid barrier between the operator and the threshing drum.
2. A tray in place of the existing chute to allow ease of accessing the grains or open space where grain can fall on the sheet placed below the machine.
3. Refining the interface between add-on and the machine so that it creates a rigid, balanced structure.
4. Addition of two smaller collapsible wheels for ease of portability or increasing the length of the handles so that the device is easier to lift and transport by either pushing or pulling.
5. Refining overall styling of the device to improve the aesthetics for a product design that can be mass-manufactured.

6.5 Refined design for thresher concept 4.0

The current concept 3.0 with minor additional modifications is already suitable to be further developed into a sort of locally manufacturable device that considers resource limitations of small and marginal farming communities. At the same time, the researcher also wanted to create a concept which would trade a little bit of affordability in return for additional usability and aesthetic appeal. Hence considering the learnings from concept 3.0, a new design concept (Fig. 6.22) was developed where the welded MS angle frames were replaced by bent pipes to reduce warping and weight. A perforated metal guarding reduces visual weight of the device. The length of the handles are now increased and fitted with bottom supports to reduce the effort of lifting and to balance the weight during transport. The increased length of handles also allows the device to be pushed or pulled which improves portability in uneven terrain and improves manoeuvrability in smaller farm spaces. This concept 4.0 (Fig. 6.23) also allows the scope for a broader range of colour options while providing rigid surfaces for placing branding of the NGO or the manufacturing company that will handle the technology dissemination. Unlike the previous concept, this concept is designed to be centrally manufactured while using simple joinery details that will help in local assembly if needed. The device also used standard bicycle components for functional modules to facilitate local maintenance and repair. In order to overcome literacy and language barriers, the instructions for use of the machine are simplified and depicted using Warli art aesthetic (Fig. 6.24). Warli art is a tribal artform from the state of Maharashtra in Inda.

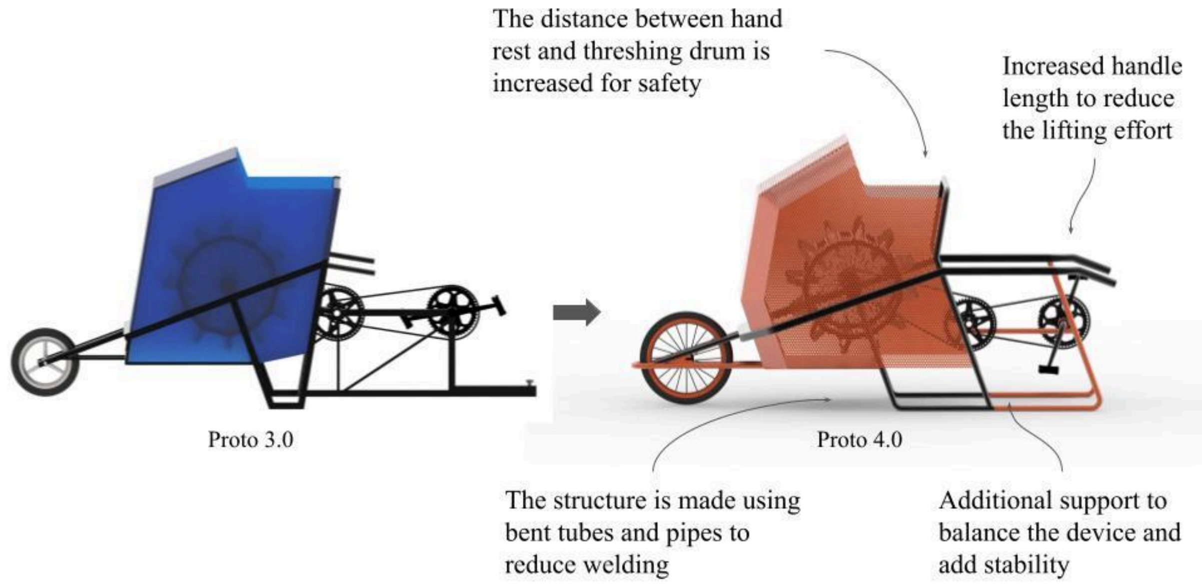


Figure 6.22: Changes in concept 4.0 with respect to concept 3.0

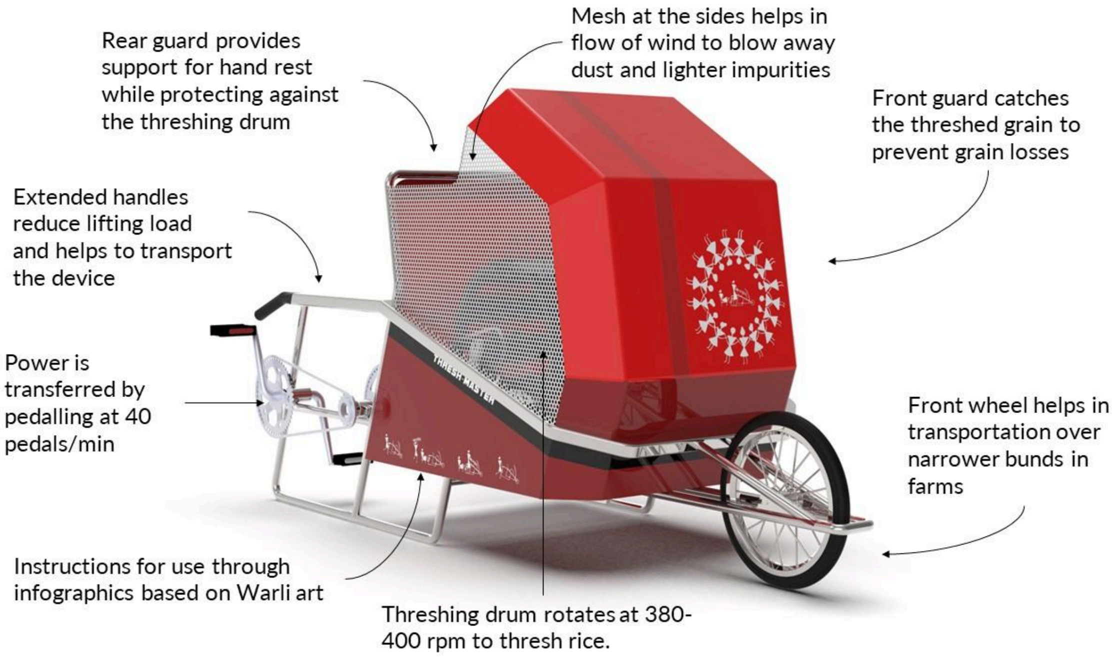


Figure 6.23: Thresher concept 4.0

Figure 6.24: Instructions for using the machine inspired by Warli art aesthetic

6.6 Conclusion

This chapter provided an outline of prototyping, and testing of concept prototype 2.0, concept prototype 2.5, and prototype 3.0. An iterative process has been followed where the lessons learnt from using each concept were incorporated for further design refinement of the next version. The process resulted in a thresher concept 4.0 where both functional aesthetic as well as usability issues from earlier versions have been resolved. The next chapter of the thesis details the discussion of the contributions to knowledge from this research study as well as conclusion of the exegesis.

7. Discussion and Conclusion

This chapter (Fig. 7.1) discusses the outcomes of research and design work conducted during the study. It describes the usefulness and effectiveness of the framework for design intervention in farm equipment. It also uses the design outcome of a low-cost human-powered thresher and its possible use and benefit of informing design decisions for making similar interventions for other farm activities.

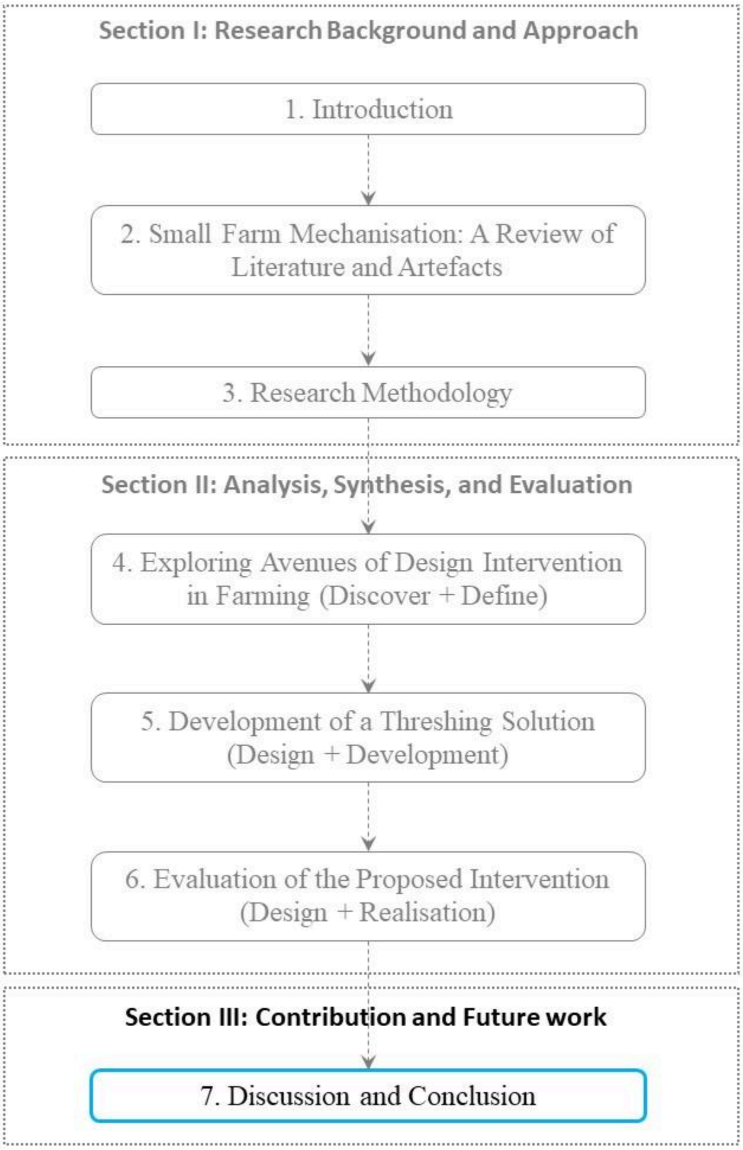


Figure 7.1: Discussion and Conclusion

The chapter summarises the findings and justifies the need for developing low-cost, context-specific, gender-friendly solutions for low-income farm economies of India and places the outcome with respect to the gaps identified during the study of literature and artefacts. The chapter concludes the research and answers the overarching research question. It also reflects upon the contribution to knowledge and the limitations of this research while providing possible scope for future work.

7.1 Discussion and positioning of exegesis

Two major contributions to knowledge have been identified during the course of this project. They are the design framework, and the threshing machine. As discussed in the exegesis, a review of literature, field visits, and interviews revealed that small and marginal farmers struggle to balance the income from farming with the input costs such as seeds, fertilisers, labour, equipment, etc. (IDFC Rural Development Network, 2013). This struggle is compounded by challenges that include, but are not limited to, lack of capital to afford machinery and its maintenance, low yields with high input costs, climate change, a lack of water resources, lack of awareness and unavailability of appropriate technology (Dev, 2011; Ministry of Agriculture & Farmers Welfare, 2016; Grant Thornton India LLP, 2015; Singh et al., 2002). Most small farmers also have low literacy rates and need more awareness about technology, government schemes and policies. The low level of education in rural areas also creates a barrier to attempts at public dissemination of technology or knowledge.

The rural areas in India are deeply rooted in traditions, which lead to social exclusion based on caste and gender, preventing access to education, institutional infrastructure, and support and limiting influence in influence in social, political and economic spheres (IDFC Rural Development Network, 2013). Therefore, the problem of designing farm equipment for small farmers is more than just a technical challenge of providing better-designed solutions. The challenge is also adaptive, where a slight change in beliefs and behaviour would be needed for these farmers to shift from traditional methods to modern solutions.

People have been disenchanted with existing models of rural development, which were technocratic and bureaucratic. These models depended on central-driven, top-down policy-driven economic control, rapid industrialisation and technological diffusion through developed countries' aid (Haque et al., 1975). However, these strategies have yet to be able to really solve the issue of rural poverty alleviation and development. Which led to two schools of thought for generating sound strategies. One approach, the ‘reformist approach, aims to make the system work by building equitable distribution into existing growth models. This stems from the beliefs that a) there is no real conflict between growth and equity and b)redistribution with growth is technically, economically and politically feasible under existing conditions in the third world.

On the other hand, the radical school of thought approach believes in redefining development objectives in the direction of rapid social change and redistribution of political power (Haque et al., 1975). However, while advocating different ways of implementing change for development, both these approaches agree on the need for technological transformation. Since the ontological stance of the researcher is pragmatic, a research through design methodology was adopted. Concepts of human-centred design, participatory design, and appropriate technology seemed well-suited to achieve this technological transformation. This transformation would then be achieved while providing avenues at different stages for creativity, self-reliance, non-alienation and democratic decision-making, which seem to be the proper measures of social development.

The scope of this research was limited to developing an approach to designing farm equipment for small and marginal farmers by trying to design and develop a solution to the selected activity of rice threshing. The researcher followed a studio-based design approach. Existing approaches to designing farm equipment, like design for development (DfD), grassroots development, design engineering and industrial design, were studied, and practices and tools appropriate for the context were selected. Existing design frameworks like the Framework of Product Experience (Desmet et al., 2007), the Design Futures Framework (Malhotra, 2016), the humanistic values model (Rokeach, 1973), and a framework for the assessment of products for low-income economies (Whitehead et al., 2016) were examined. Out of these frameworks, the researcher focussed on two frameworks: the DeF framework and the assessment tool for product development for low-income economies. The Def framework was selected as it was robust, detailed and could be easily adapted for the research domain. This framework contains 18 design drivers, classified under human, technical and environmental values. It is a comprehensive framework that can be used for forecasting design possibilities that are both meaningful and appropriate (Malhotra, 2016). Similarly, the framework for product assessment for Low-income economies (Whitehead, 2019) provides a spiderweb tool with six indicators. These indicators of affinity, usability, functionality, acceptability, affordability and reparability provide a holistic way of product and idea evaluation. However, the tool's scope does not expand to providing ideation or problem-framing paths. Hence, the researcher adopted learnings from these frameworks to create a new framework for creating artefacts for the rural domain of India.

The exegesis has been shaped through the process of Industrial design and design engineering and is informed by and developed through the practice of Research through Design. The researcher posits that a holistic approach that takes into considers the design values arising from context-specific problem framing and problem-solving can be used to generate meaningful, effective, and efficient solutions for socio-economically marginalised and underserved communities.

The data collection methods of literature study, observations, analysis of artefacts and semi-structured interviews were used to understand Indian agriculture and the challenges small and marginal farmers face. The outcomes of this research activity were then analysed, and twenty-six factors were considered while developing the design intervention. Based on the analysis of collected data, threshing activity was selected as the focus of the studio research project. The factors and drivers from the framework were used to develop ideas in multiple directions and to make design choices while evaluating and selecting concepts for thresher development. Mind maps, morphological charts, sketching, CAD, and quick prototyping have been used to develop, test, and refine concepts. An iterative design process was followed to create multiple concepts and four prototypes, which helped inform and refine the final concept solution of novel rice threshing equipment.

7.2 Contribution to Knowledge

The research and design work during the study has led to various major and minor contributions. This study presents significant contributions to knowledge in industrial design and frugal innovation for developing solutions for the communities underserved by design. The research process has two distinct significant contributions. The first contribution is a framework which can help other researchers, engineers, designers, and toolmakers to develop farm tools for small and marginal farmers. The framework eases the process of understanding and identifying factors for designing efficient and effective farm tools. The framework also aids in ideation and concept evaluation. The second contribution is a rice thresher that is human-powered and portable, allowing small farmers to take to farms located in remote places inaccessible by road. The design outcome aids the farmers by providing an intermediate technology solution between the inefficient, labour-intensive traditional solutions and unaffordable, fuel-intensive modern solutions. Apart from these two major contributions, the study has also resulted in various morphological visualisations of the flow of farm activities, techniques, and tools used by small and marginal farmers with an overlay of their needs, wants, and aspirations. The visualisation provides a useful method to identify and understand existing situations and gaps. These visualisations also make communicating with farmers easy despite language or literacy-related barriers. The ideation and documentation of various ways of generating, transferring and using bicycle power for rotary activities can also help as a starting point for generating similar solutions for other farm activities like winnowing, hulling, grinding, chaff cutting, etc.

7.2.1 Design framework to define and develop interventions for farm equipment

The study has resulted in a research outcome of a design framework that allows for design of context-specific, human-centred intervention in farm equipment for small and marginal Indian farmers and will aid researchers, designers and engineers to understand and be sensitive to specific aspects that need to be considered while approaching design of an artefact for the underserved in rural India. While aspects of Use, Make, and Afford might be deemed critical, it is also important to consider the aspects of Adapt, Adopt and Sustain to facilitate technology adaptation and dissemination. The primary design drivers and their constituent factors that need to be considered while developing a design intervention for Indian small farmers are as follows:

- Use - Ease of maintenance, Ease of using, Ease of learning, Ease of recharge/refuel, Ergonomic design, Portable
- Make - Ease of manufacture, Locally available raw material, Locally repairable, Power generation
- Afford - Cost of manufacture, Capital costs, Running Costs
- Sustain - Robust, Easy to dismantle/dispose of, Ease of Recycling, Low emission/pollution
- Adopt - Functional aesthetic, Quality of output, Gender-friendly, Availability of infrastructure, Culturally appropriate, Type of ownership
- Adapt - Utility, Modular/quick change over, Ease of upcycling

We feel that these drivers along with the structure of the proposed framework (Fig. 7.2). would help the researchers, designers and engineers at stages of field research, problem identification, ideation and concept evaluation to develop holistic, context- specific solutions that cater to the underserved in rural India.

The factors and the framework can be scaled, adapted and modified to serve not just small and marginal farmers of India but also low-income economies or communities underserved by design worldwide. The design drivers can be used for investigation, ideation and evaluation of solutions in other domains like healthcare, mobility, educational tools and other solutions that aid livelihood and improve quality of life. There are existing design frameworks like the Design Futures framework or product development for low-income economies framework, which also can be used to generate solutions for such domains. However, the proposed framework adds to this existing work and enhances the approach to developing farming solutions. The framework also provides different structures and considerations to be used while designing a new solution instead of focussing on only one of the following: evaluation of ideas or idea generation.

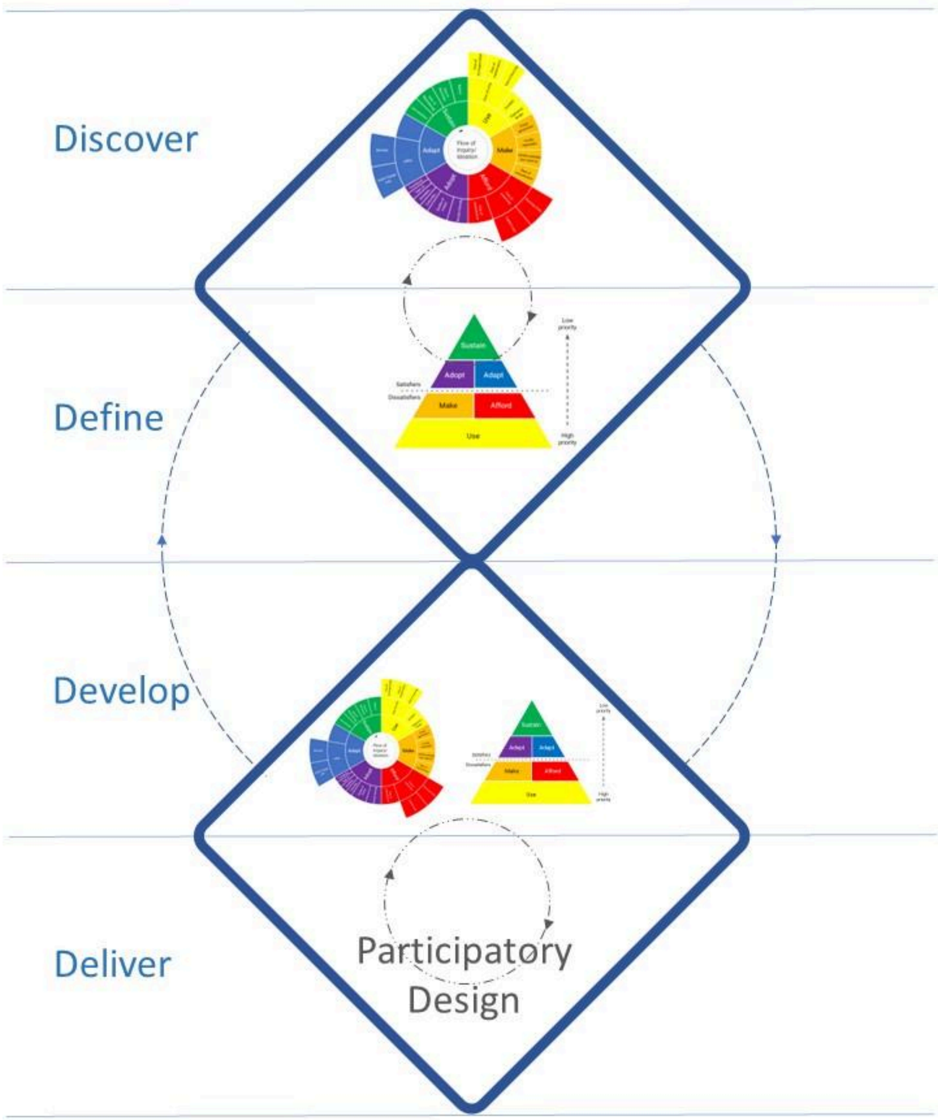


Figure 7.2: Proposed design framework

Along with a framework for developing future products and product assessment tools for NPD, our framework now fills the gap of providing a tool to design and develop solutions for low-income economies in not just the rural agrarian sector of India but also other sectors all over the world that could benefit from an approach of frugal innovation.

7.2.2 A low-cost rice thresher concept

A low-cost, portable, human-powered, rice thresher was designed and developed over the course of this research and studio project activity. This threshing unit is specifically designed to cater to needs of small and marginal farmers in western Maharashtra and Goa as it considers the locally available materials as well as skill sets of maintenance and repair. The thresher is also designed to be easier for the older generation and women farmers to learn and operate.

It considers the specific needs of the small and marginal farmers in the form of output that it delivers in the form of unbroken grain and slightly crushed but not cut hay. The portability allows the farmers to take it to fields on hills and plains which do not have road access. These features makes the solution unique and desirable compared to existing low-cost threshing machines and traditional methods.The guarding is designed to cater to the cultural needs of women farmers of making a machine their own. This is facilitated by designing the guarding in such a way that upcycled saree quilts can be used to make it, and this allows the rural women farmers to use colours and patterns of their choice to customise the look of the machine. The process of designing and refining this threshing device though multiple iterations has resulted in two major design directions.

The first design direction (Fig. 7.3) presents a solution as a locally manufacturable and repairable kit which considers severe resource limitations and lack of transportation facilities for marginal farmers living in the remote, difficult to access areas of rural India. Hence, the design allows the farming community to use locally available material and skill sets to create a solution that improves productivity and reduces grain losses at low cost while minimising the drudgery involved in traditional practices of threshing. Here, technology, material, and manufacturing choices make the design conducive to suit the needs of farmers in other regions with minimal modifications.

Figure 7.3: First design direction and prototype of a locally manufacturable thresher

The second design direction (Fig. 7.4) has resulted in a more refined product that adds improvements in usability and aesthetics for a higher cost. This product can be made in industrial facilities with pipe bending and welding capabilities along with sheet metal operations. The dissemination of this device will be targeted towards small-scale farmers who live in communities with sufficient connectivity. The device can then either be purchased by NGOs, Self-help groups, Farmers co-operative societies or can be rented through Government tool banks. This device is designed to facilitate local repair through use of standard bicycle components for functional modules.

Figure 7.4: Second design direction (a mass-manufactured, premium product)

7.3 Research limitations

The research was limited due to various constraints of scope, resources, finances, and the circumstances, The possible limitations of the research methods and outcomes are as follows:

1. The data collection methods followed during this study are qualitative methods like observations, semi-structured interviews, bodystorming, and brainstorming. Since the research is at the intersection of mechanical engineering, product design, and farm technology, the available academic research directly related to the topic was scarce. The researcher believes that along with qualitative methods, quantitative methods would have helped broaden and strengthen the gap identification and claims. Also, the researcher focussed primarily only on the locations of western Maharashtra and Goa for data collection due to language as well as travel constraints. A broader search could have also led to some more insights which could help the technology dissemination in other parts of the country.

2. The scope of this research was limited to verifying the theoretical framework with only one project of designing a rice threshing solution. The refinement of framework would have further benefited from designing solutions for other activities like winnowing, grinding, transplanting and weeding. However it was decided early on that these activities lie outside the scope of the research due to time constraints. Similarly other, more theoretical methods of validating the framework also lie outside the scope of current research but could be worked on in the future. The scope of the project was also limited to a single crop of rice. Generating and testing the thresher design for other crops by modifying the drum would have improved the design further while providing a lucrative option to farmers who do multi-cropping in different seasons.

3. Threshing is an activity that is done only once per every agricultural season of rice farming. Due to constraints imposed by the pandemic as well as financial and resource constraints, the researcher was able to conduct field tests only in one location with one iteration of the prototype. The other tests were conducted in-house for checking mechanisms, ease of use, and portability. More field tests in multiple locations could have also provided other overlooked issues, if any, while strengthening the claims of efficiency and effectiveness of the device. This is also a suggested starting point for future research in this area.

7.4 Future scope of research

The limitations of the research highlighted in the previous section also provide direction for future research. The first step would involve widening the scope of the research in terms of location for data collection as well as using quantitative methods to improve the quality of data gathered and identifying more gaps and insights.

The theoretical framework could be validated using other methods like a delphi group, and developing co-creative and participatory solutions for other farm activities with help of interdisciplinary groups consisting of farmers, agricultural engineers, and designers. The focus could also shift to other activities indirectly related to agriculture like storage and mobility solutions for farm produce to market logistics.

The morphological visualisations created during the scope of this project could also be improved further by adding more overlays based on various lenses focussing on availability of infrastructure, subsidies, policies, and multi-cropping possibilities. This could aid in understanding gaps as well as identifying existing connections and possibilities of growth.

The design concept could be tested in multiple locations and with different rice varieties during both kharif and rabi seasons. The testing could also be converted into a between subject experiment where A/B testing is conducted using traditional techniques, and mechanised solutions. The following phase of testing should include measuring grain output in terms of kg/hr along with measurement of grain losses. The difference of effort required between traditional trampling and beating methods, pedal cranking with foot, and bicycle pedalling could also be checked by testing for energy consumption. To ensure effective technology dissemination, a collaborative design approach (Chakravarthy, 2003) would be useful once the first pilot testing stage is completed. This approach would entail a process where a core team of designers, researchers, and primary consumers could then collaborate with expert teams of tool manufacturers, government agencies, NGOs, and local leadership to ensure effective implementation and realisation of the solution.

The design concept could be further modified by changing the wire loops to rasp bars and flail for multi-crop threshing functionality. The design concept could also be adopted for other farm activities where rotary motion could be used. For example, the frame and power transfer module could be adapted with minor modification for activities like hulling, grinding and winnowing.

7.5 Conclusion

The research began with an understanding of small and marginal farmer's needs for farm equipment that could help balance input costs with yield. During the course of this research the domain of small scale farming as well as existing farm equipment was studied with a focus on post-harvest activity of rice threshing. The study of the domain helped identify that a gap existed between simple, cheap hand tools and costly, large scale powered tools like tractors. Though farm implements like power tillers and motorised threshers reduce drudgery and enhance efficiency, small farmers struggle to balance investment towards expensive farm equipment and crop yield. It was also identified that there is an urgent need for intermediate technology that can bridge this gap, however, the injuries caused by the lack of appropriate tools and ergonomic considerations also need to be considered.

This research aimed at developing interventions that can ameliorate small farmers needs and wants concerning farm implements. To fulfil this aim,approach based on both 'design based research', which is research by practice of designing and testing an intervention, and 'action research' which can be defined as the act of combining theoretical research and design practice through change and reflection while solving an identified problem was used. The researcher then used design methods of field observations, semi-structured interviews, case studies, analysis of artefacts, sketching, physical prototyping and field testing throughout the research journey to define and fulfil research objectives.

The data collection methods of literature study, observations, analysis of artefacts and semi structured interviews were used to understand Indian agriculture and challenges faced by small and marginal farmers. These were used to generate morphological visualisations of activities, tools and needs of small farmers for rice farming. These visualisations helped in identification of gaps and opportunities for design interventions. The outcomes of this research activity were then analysed and twenty six factors were defined for consideration while developing the design intervention. Threshing activity was the focus for the studio research project. A theoretical framework to inform and drive ideations, design choices and design decisions during concept generation and evaluations was also developed. The factors and drivers from the framework were used to develop ideas in multiple directions and to make design choices. While evaluating and selecting ideas for thresher concept development, mind maps, morphological charts, sketching, CAD, and quick prototyping to develop, test, and refine concepts were used. An iterative design process was followed to create multiple concepts and four prototypes which helped inform and refine the final concept solution of novel rice threshing equipment.

The two primary objectives of the research were defined based on the knowledge gap that was identified using review of literature, review of artefacts, and field observations. The first objective was ‘to develop a design framework which could help other researchers, designers and engineers to work more effectively in design and realisation of farm equipment’. The research outcome of a theoretical framework directly responds to this objective. The research has led to a generation of a design framework that allows for the design of context-specific, human-centred intervention in farm equipment for small and marginal Indian farmers. The framework;

A. aids researchers, designers and engineers to understand and be sensitive to specific aspects that need to be considered while approaching design of an artefact for the underserved in rural India
B. helps the researchers, designers and engineers at stages of field research, problem identification, ideation and concept evaluation to develop holistic, context- specific solutions that cater to the underserved in rural India.

The second objective of the research was ‘To design and develop appropriate, affordable, context-specific and gender-friendly rice threshing solution for small scale Indian farmers’. As a response to this objective the project based iterative design approach has led to design of a low-cost, portable, human-powered, rice thresher which considers the locally available materials as well as skill sets of fabrication and repair while allowing an ease to learning and operating. It also aids in secondary income by providing output of both unbroken grain and slightly crushed but not cut hay. The process followed to design the device also helped verify the steps and structure of the theoretical design framework.

During the course of this research, it was observed that developing interventions for small and marginal farmers is not just a technical challenge of providing better-designed solutions. The challenge is also adaptive, where a slight change in beliefs and behaviour would be needed for these farmers to shift from traditional methods to modern solutions. Consequently, at this stage in the research project, one cannot speak of the user-centred and participatory design leading to successfully overcoming the socio-technical inequality of this vulnerable/marginalised social group. The participatory design approach was used to understand the situation of the users better and to dive deeper into the complex problems to create a framework to help develop innovative solutions. Thus, the project leans towards an industrial design approach. However, this approach also intensively brings out and incorporates issues arising from the adaptive problem of effective technical dissemination in the social space. The researcher feels that the outcomes of this research project would act as an aide and recipe to ensure a more holistic way of problem-framing and solving in not just farming but also sectors which are underserved by design. The researcher also hopes that the approach used and the design drivers identified would lead to an expanded and refined framework that would ameliorate adaptive problems of adopting appropriate systems and methods and the technical problem of creating effective and efficient artefacts.

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9. Appendix

9.1 Appendix I - Patent. Design registration, and publication details

Design of the threshing device has been registered and response to the first examination report has been submitted to the Patent office on 12th May 2021. Design registration number is 335250-001

Complete specification of the threshing device has been filed for Patent on 4th December 2021. Patent application number is 202021049764.

Presented two papers at ICoRD ‘21 (8th International Conference on Research into Design) which was Conducted on 7-10 Jan 2021. Both full papers have been published as part of a conference proceedings book in Springer titled “Design for Tomorrow : Smart Innovation, systems and technologies’ on 6th May 2021.

1. Design intervention in farm equipment: Using a studio research approach to design a sustainable, human-powered solution for small and marginal Indian farmers
2. A design research study to understand factors affecting tool design for small-scale rice farming in Western Maharashtra

Presented a paper at Asian CHI 2021 Symposium conducted in Japan on 7-8 May 2021. Paper is published in ACM Digital Library (ACM DL).

● The Larger Picture: A Designerly Approach to Making the Invisible Domestic Workloads of Working Women Visible

Design of the threshing device has been registered and response to the first examination report has been submitted to the Patent office on 12th May 2021. Design registration number

is 335250-001

9.2 Appendix II - Definitions

Gross domestic product: the total value of goods produced, and services provided in a country for one year.

Kharif: The autumn crop sown at the beginning of the summer rains. E.g. Rice, maize, pearl millet, finger millet, cotton etc

Marginal farmer: A farmer with operational land holding of less than 1 ha.

Non-Governmental Organization: a non-profit organization that operates independently of any government.

Operational land holdings: All land which is used wholly or partly for agricultural production and is operated as one technical unit by one person alone or with others without regard to the title, legal form, size or location

Rabi: The grain crop sown in September and reaped in the spring. E.g. wheat, barley, oats (cereals), mustard etc

Small scale farmer: A farmer with operational land holding between 1 to 2 ha.

Crop calender: A crop calender is a schedule prepared during each season of growing of crops, it covers important dates of all activities from land preparation to harvest and post harvest activities.

Land preparation: The activitiesof cleaning, clearing, and preparing the soil in the field for planting of crops.

Seeding: The process of distributing and sowing of seeds across the farm.

Transplanting: The activities involved in sowing the seeds separately in a seed-bed and then transferring the saplings to the field once they have grown a bit.

Water management: The activities involved in locating the water source, transferring it to the farm. And irrigating the plants.

Soil fertilisation: The activities involved in improving the soil nutrient content to make it conducive for crop growth.

Weeding: The activites involved in restricting and removing unwanted plant growth from the cropping area.

Harvesting: The activities involved in collecting the crop from the mature plant.

Threshing: The process of separating the grain from harvested plant

Winnowing: Process of removing lighter impurities from the thresherd grain

Milling: Milling is the process of removing the outer layers of bran and husk from the grain

9.3 Appendix III - Ethics approvals

Ethics approval for interviews and field observations

Monash University Human Research Ethics Committee

Approval Certificate

This is to certify that the project below was considered by the Monash University Human Research Ethics Committee. The Committee was satisfied that the proposal meets the requirements of the *National Statement on Ethical Conduct in Human Research* and has granted approval.

Project ID: 25875
Project Title: Cycle based threshing machine for small scale farmers in India
Chief Investigator: Assoc Professor Selby Coxon
Approval Date: 09/10/2020
Expiry Date: 09/10/2025

Terms of approval - failure to comply with the terms below is in breach of your approval and the *Australian Code for the Responsible Conduct of Research.*

1. The Chief Investigator is responsible for ensuring that permission letters are obtained, if relevant, before any data collection can occur at the specified organisation.
2. Approval is only valid whilst you hold a position at Monash University.
3. It is responsibility of the Chief Investigator to ensure that all investigators are aware of the terms of approval and to ensure the project is conducted as approved by MUHREC.
4. You should notify MUHREC immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.
5. The Explanatory Statement must be on Monash letterhead and the Monash University complaints clause must include your project number.
6. Amendments to approved projects including changes to personnel must not commence without written approval from MUHREC.
7. Annual Report - continued approval of this project is dependent on the submission of an Annual Report.
8. Final Report - should be provided at the conclusion of the project. MUHREC should be notified if the project is discontinued before the expected completion date.
9. Monitoring - project may be subject to an audit or any other form of monitoring by MUHREC at any time.
10. Retention and storage of data - The Chief Investigator is responsible for the storage and retention of the original data pertaining to the project for a minimum period of five years.

Kind Regards,

Professor Nip Thomson

Chair, MUHREC

CC: Mr Sanket Pai, Dr Robbie Napper, Assoc. Prof. Sugandh Malhotra

List of approved documents:

Document Type	File Name	Date	Version
Explanatory Statement	explanatory-statement	21/09/2020	1
Supporting Documentation	Introductory email	21/09/2020	1
Explanatory Statement	explanatory-statement-V2	30/09/2020	2
Consent Form	Consent Form _ Participant group 1 & 2	30/09/2020	1
Consent Form	Consent Form _ Participant group 3	30/09/2020	1
Supporting Documentation	Introductory email_V2	30/09/2020	2

Ethics approval for in-house and field testing

Monash University Human Research Ethics Committee

Approval Certificate

This is to certify that the project below was considered by the Monash University Human Research Ethics Committee. The Committee was satisfied that the proposal meets the requirements of the *National Statement on Ethical Conduct in Human Research* and has granted approval.

Project ID: 30978
Project Title: Testing prototypical threshing machine in India
Chief Investigator: Assoc Professor Selby Coxon
Approval Date: 11/11/2021
Expiry Date: 11/11/2026

Terms of approval - failure to comply with the terms below is in breach of your approval and the *Australian Code for the Responsible Conduct of Research.*

1. The Chief Investigator is responsible for ensuring that permission letters are obtained, if relevant, before any data collection can occur at the specified organisation.
2. Approval is only valid whilst you hold a position at Monash University.
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List of approved documents:

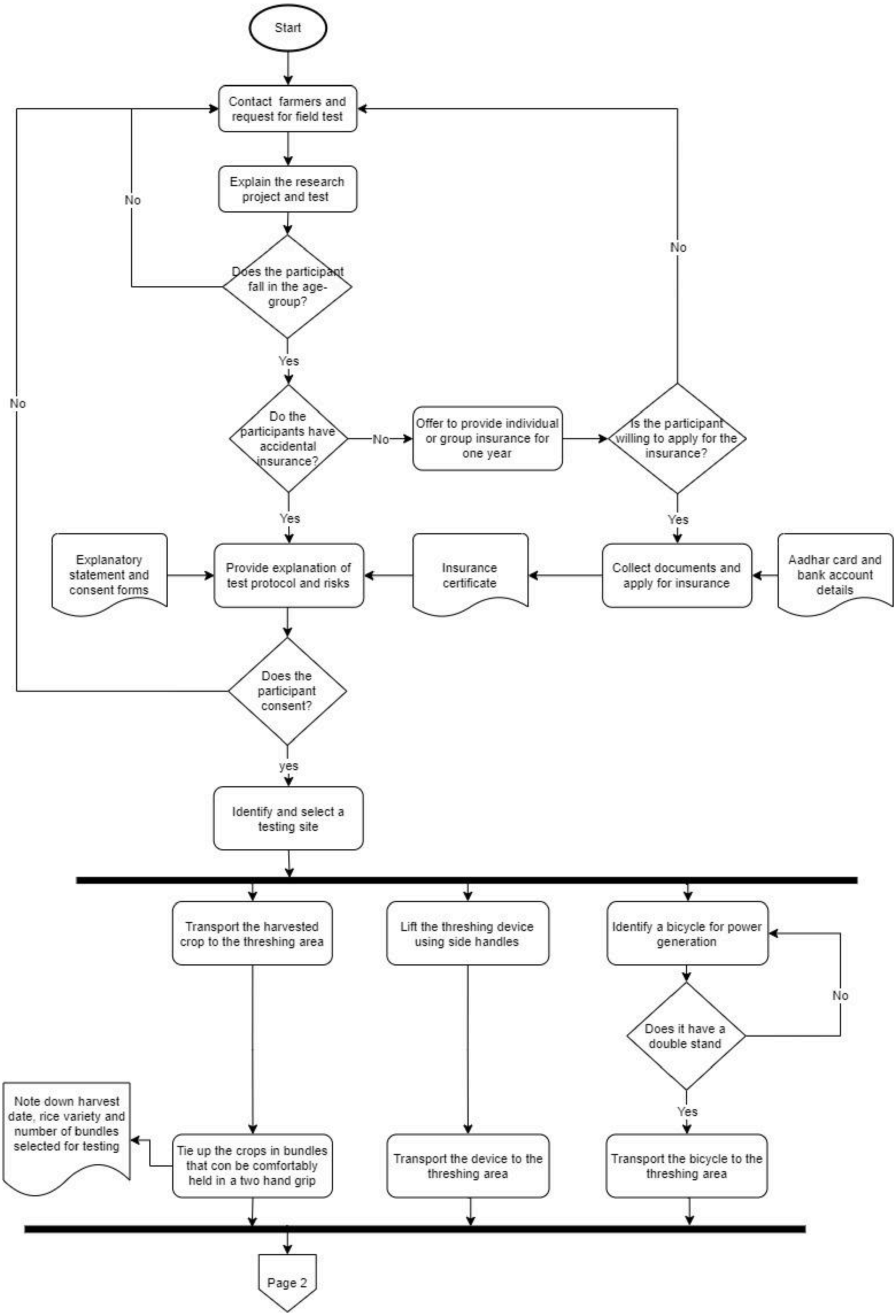
Document Type	File Name	Date	Version
Supporting Documentation	Safety FMEA	18/10/2021	0
Supporting Documentation	Test protocol flowchart	18/10/2021	0
Explanatory Statement	Human Ethics_Explanotary statement	18/10/2021	0
Consent Form	Human Ethics_Consent form	18/10/2021	0
Supporting Documentation	Left hand side view_thresher prototype	18/10/2021	0
Supporting Documentation	Right hand side view_thresher prototype	18/10/2021	0
Supporting Documentation	Position of participant wrt threshing prototype	18/10/2021	0
Supporting Documentation	Position of grain and hand wrt threshing drum	18/10/2021	0
Supporting Documentation	Human Ethics_Introductory email	06/11/2021	1
Explanatory Statement	Human Ethics_Explanotary statement_Ver 1	08/11/2021	1

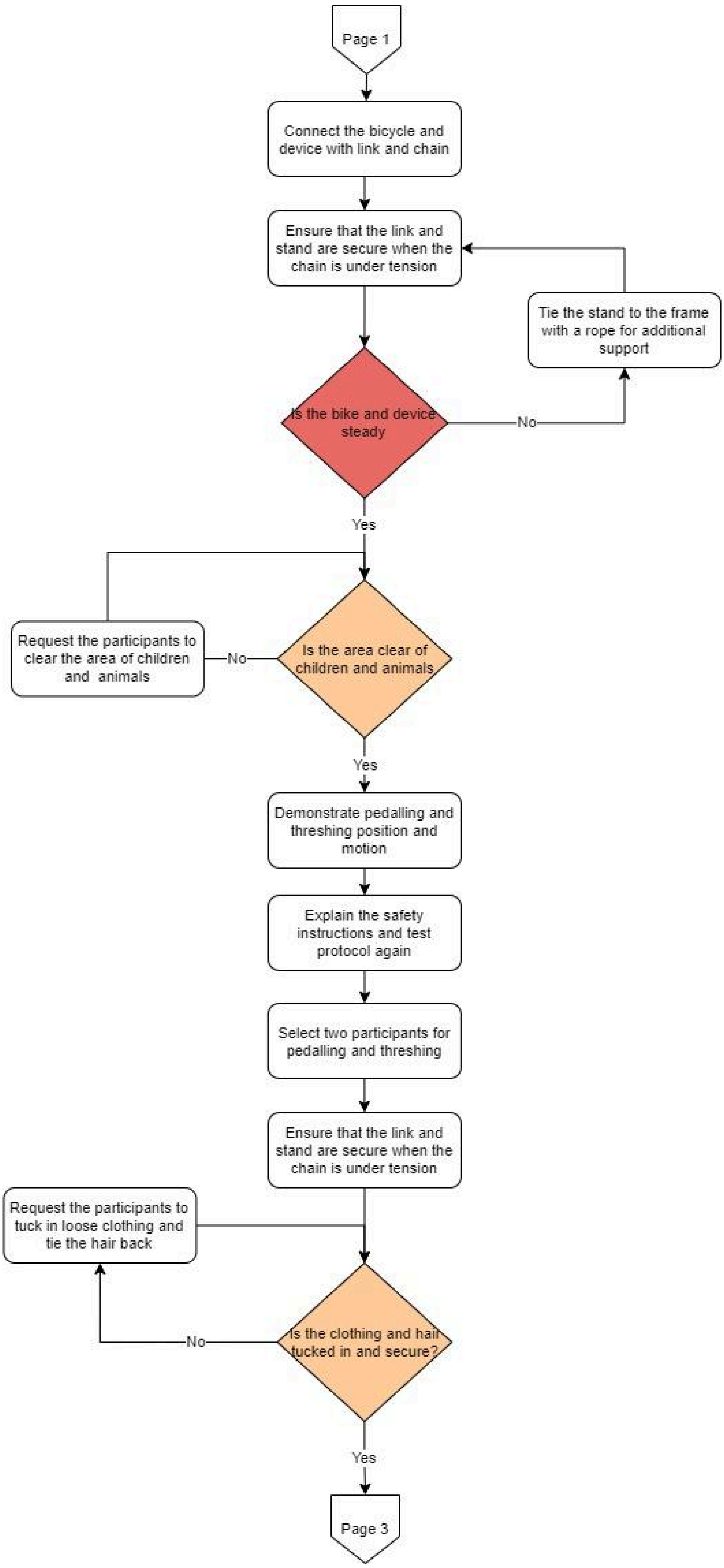
9.4 Appendix IV - Design FMEA and flowchart of test protocol

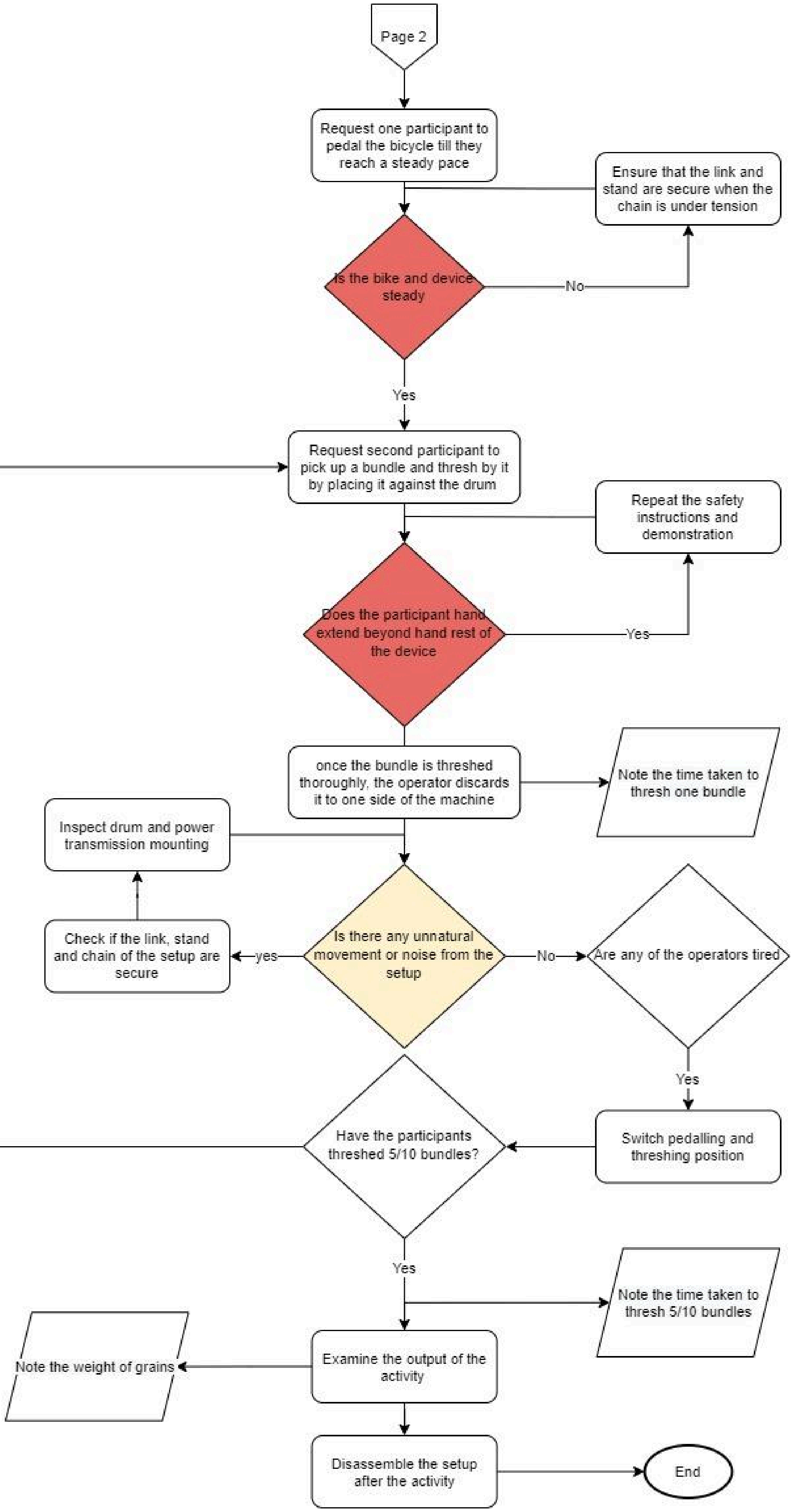
Design FMEA

Activity	Sr. No.	Process step	Potential Failure mode	Potential Failure Effect	Potential causes	Current process controls
Setting up the machine and briefing the participants	1	Transporting the machine to the clear space in the field				
	2	Connecting the bicycle				
	3	Researchier will give instructions about safety				
	4	Researcher would demonstrate the working of bicycle and approx. pedalling speed	Bicyle falling	Injury due to bicycle falling on the operator	Unsteady or unlocked stand	We have tied the stand to the frame after setting up with strong nylone rope
Preparing crop for threshing field test	5	Harvested plants are tied into smaller bundles that can be held in hand				
	6	The bundles should be measured for overall length, the diameter of bundle and length of panicles.				
	7	Harvest date and rice variety should also be noted.				
	8	The bundles should be kept next to the machine so that the threshing process can begin.				
Thresher test	9	The operators should pedal the bicycle till they are familiar with the working and find the right pedalling speed,	Bicycle falling	Injury due to bicycle falling on the operator	Unsteady or unlocked stand	We have tied the stand to the frame after setting up with strong nylone rope
	10	The second operator picks up the bundle and threshes it by placing it against the drum and rotating it.	hand hitting the threshing drum	Injury to the hand due to blunt force	If the operator bends too much or doesnt let go of the bundle in case it gets entangled in the drum	We have reduced the height of the drum compared to the hand rest to prevent accidental contact beteen the hand and the drum
					A child touches the drum from the side during operation	We will not allow children near threshing area. We will also cover the sides of the machine with a guard
			clothing entangled in threshing drum	Injury due to blunt force	If the operator bends too much or wears loose flowing clothing that gets entangled in the drum	We have introduced a flexible guard between the body and the drum. The operators will also be instructed to ensure that the clothing is secure and not too loose during the test
	11	The bundle is discarded				
	12	Repeat step 10 -11 for 10 bundles				
	13	The time for threshing the bundles, and the total output of grains in gms to be noted.				
	14	A sample of threshed grain should be examined and winnowed if possible to check the amount of straw and other impurities				
Debriefing the participants	15	collecting all the threshed grain				
	16	Collecting the discarded bundles for hay				
	17	Disconnecting the bicycle from the machine				
	18	Transporting the machine out of the field				
	19	Participant interview				

Flowchart of the test protocol




Page 1
Connect the bicycle and device with link and chain
Ensure that the link and stand are secure when the chain is under tension
Tie the stand to the frame with a rope for additional support
Is the bike and device steady
No
Yes
Request the participants to clear the area of children and animals
No
Is the area clear of children and animals
Yes
Demonstrate pedalling and threshing position and motion
Explain the safety instructions and test protocol again
Select two participants for pedalling and threshing
Ensure that the link and stand are secure when the chain is under tension
Request the participants to tuck in loose clothing and tie the hair back
No
Is the clothing and hair tucked in and secure?
Yes
Page 3



Page 2
Request one participant to pedal the bicycle till they reach a steady pace
Ensure that the link and stand are secure when the chain is under tension
Is the bike and device steady
No
Yes
Request second participant to pick up a bundle and thresh by it by placing it against the drum
Repeat the safety instructions and demonstration
Does the participant hand extend beyond hand rest of the device
Yes
once the bundle is threshed thoroughly, the operator discards it to one side of the machine
Note the time taken to thresh one bundle
No
Inspect drum and power transmission mounting
Check if the link, stand and chain of the setup are secure
yes
Is there any unnatural movement or noise from the setup
No
Are any of the operators tired
Yes
Switch pedalling and threshing position
Have the participants threshed 5/10 bundles?
Yes
Note the time taken to thresh 5/10 bundles
Note the weight of grains
Examine the output of the activity
Disassemble the setup after the activity
End

9.5 Appendix V - Interview transcripts

Interviews at Darakwadi

Group discussion

Researcher: In rice farming we have a lot of difficulties, right? For example, it is not easy to grow rice.

Farmer 1: We don't get labourers.

Researcher: Yes, we need to somehow improve the yield using less labourers.

Farmer 2: We also face difficulties in weeding in rice farms

Farmer 3: Irrigation has also become a big problem now. Earlier we could easily route water to our farms. Now the water level has gone down and we cannot raise the water to the farm. It is not possible to put electrical or fuel pump in all the farms. And if we fit solar pumps then drunkards steal the batteries. So we need a non electricity, manual, small portable machine that we can carry around.

Researcher: So we need something that you can keep at home, bring to farm when needed and take it back. And it should not require fuel or electricity.

Farmer 3: We need this pump to raise the water to at least 15 feet and fill the plot up to at least 1 inch. And this is a major issue with all farms.

Researcher: You also mentioned that weeding is difficult. But we have those manual conical implements na?

Farmer 4: It only works on dry soft soil. It doesn't work is wet farms.

Farmer 3: Will it be possible to transplant without puddling?

Sanjay: Yes, puddling is a difficult process and it tires the animals as well. We need a solution to plant seeds without puddling. What about constant bending while transplanting?

Farmer 4: It would be nice to have something that doesn't require us to bend. If we like the solution, then we will definitely adopt it.

Researcher: Can we have something so that we can transplant while standing up?

Farmer 3: We need a solution for dribbling where the farmer should be able to plant seeds while walking along the farm. For example it can be an attachment on the legs.

Farmer 5: We also need a solution for harvesting. We need a small device that can cut and thresh at the same time.

Farmer 2: We need a small machine that can dehusk rice without polishing it. It should be like the traditional grinding stone that we have in our homes.

Resource person: We have a machine for it but it is too large and takes up a lot of space. Its almost as big as this shed.

Resource person: We need a small machine that's manually operated.

Farmer 6: Can we have something that can be attached to a furrower or a weeder which keeps dropping seeds on both sides as you take it along the farm? The seeds should fall at least 9-10 inches apart. It should till the land, drop the seed and then cover it as you push it. It should work manually.

Resource person: Can we use a cycle in the field for various operations?

Farmer 6: Can we create rice saplings in a nursery? Something that can be locally made using bamboo strips and old cloth.

Resource person: Digging for transplanting is one of the most laborious tasks. Transplanting should be easy so that during the process the roots should not get damaged.

Farmer 7: The way they have sell square beds of lawn, can we have portable nurseries or=f rice which can be transplanted directly? Some farmers can take this up as a business where they supply saplings to the whole village. We should avoid burning hay to prepare land for planting.

Researcher: Threshing is also an issue, right?

Farmer 3: There are machines available but they are too big. We need something smaller. Currently the crank pedal operated machine that is available does not work. We need a rotary motion.

Farmer 6: Can we use something like a rotating cycle wheel that can thresh grains?

Researcher: What about storage of grains?

Farmer 3: Oh we get a lots of pests. It's difficult to avoid.

Resource person 1: We need to plant the type of rice with thicker husks. We need to follow the old traditional way of tying the harvest before threshing. Then the grains last for a long time.

Resource person 2

Q: How long have you been working with farmers?

A: This will be the fifth year. Started working in 2016

Q: You work at Dharakwadi, Sahayadri School?

A: Yes. We work with four villages around the school – Dharakwadi, Gundalwadi, kurudewadi and wada. We work with the farmers on the farms itself and we have also opened up farms in the school campus. Almost 9acres of school campus land is used for farming.

Q: Are students called to work on the farms as well?

A: Yes, students participate. They have a packed academic schedule but during their Biology or Environmental Science lectures they visit the farms. Sometimes they merely observe what is happening; sometimes they get involved with the farm work or learn through simple activities like identifying the crops planted and more such activities that involve them with the farm.

Most of the urban children or population for that matter is not exposed to farming or a farm because of which they're not familiar with the process of growth of the fruits or vegetable plants around them. I was not aware of these things before familiarising myself with farming either. Fruits like Brinjal, Chillies, Tomatoes and Potatoes belong to one plant family, so details like this are more effectively observed on a farm visit than in an academic discussion.

For the last three years we're focusing on Rice farming and since the last two years we've been growing vegetables too. Every season we have some or the other seasonal produce growing and that helps to bring in more understanding and exposure for the students as well.

Q: Now we see women working more than men on the farms. Have you observed that as well?

A: We have a good mix of men and women farmers who work together as a team. We have ten women and six men. However, the kind of farming activities done are generally divided for instance, weeding and sowing is always done by women where are tilling the land or taking care of infrastructural needs around the farm like providing added support to the plants for growth and work that involves using a tractor, that kind of work is done by men. Definitely though, the women are involved more in the farms.

Q: Do the women stick to the kind of activities they do because it gives them a flexible schedule? For instance tilling has to be done in one go but not necessarily weeding and sowing, which allow the women to take breaks when needed.

A: I am not in a position to answer this question. Perhaps the women in the village do, or if there is a household without a man and the woman alone is farming then she probably has to do the tilling too, but here, at our farms I have not really observed if that is the case.

It has been observed, not only in Pune but other areas as well that while there is availability and usage of modern machinery for farming activities done by men, the women and the activities they are involved in like sowing, wedding, threshing sometimes, is still done the traditional way. Do you think marginal farmers hesitate to use modern machinery?

There is a change happening but it is a slow process and it will take time. A change in mindset is required first.

Q: Women are more involved in the process of threshing rice?

A: No, we have a good mix of men and women working together. The women mostly handle the winnowing work where as the men do the rest.

Q: Is the threshing done by traditional methods or is a pedalled thresher used?

A: Since we work with smaller quantities it is done by hand only mostly, we did build a threshing machine on campus itself but it was built after the rice crop season and we could not use it. We will now use it for Wheat. It is a motored contraption which can work with a cycle as well.

Q: Have you seen a shift in the way farmers are using accepting new tools and innovative methods of farming over the years?

A: Yes, there is a change but what is required is a change in the mindset because accepting new techniques requires time, requires some discipline which these farmers are not willing to give currently. The technique we use is called SRI technique of rice intensification where in we plant different species at a certain distance from each other. Planting at a distance means demarcating the exact distance between seeds before planting, hence, the work that can be done in a day takes around three days and the farmers prefer completing it in a day. The yield though is definitely the highest with this technique as the seedlings instead of competing with each other are involved with promoting their growth. The quantity of seeds used with this technique also cuts down to 1/10th of what is normally used, which reduces the cost as well. If the farmers are purchasing the seeds then it is direct cost saving for them ad if they're using home grown seeds then that amount of seed is available for consumption. So it is a huge advantage to the farmers.

The reason we open our farms for demonstrations is so that they witness these innovative practices rather than just hearing about it and hence the message is conveyed more effectively.

Q: Your workshops have definitely helped the farmers. What are the issues discussed?

A: Our workshops these days are more discussion oriented, we do not just impart knowledge rather we focus on educating the farmers on importance of chemical free cultivation, avoiding monocrop cultivation and encouraging mixed crop farming and informing them about the advantages of this on their diet and sustenance habits as well.

monocrop prices are dictated by the market, especially when large tracts of land are cultivating the same crop their market price is bound to drop cutting back on the farmers profits.

Over the last few years we are trying to convince farmers that they can have a control over the nutritional aspects of their produce, over their food and diet as well.

We have two goals- one is going back to cultivating native greens, native vegetables and the other is to going back to natural farming. Often, in the process of making money we neglect health and then a large part of the money we earn is spent on medical expenses. Farmers can focus on building their health through natural farming and avoid medical expenses as much as possible. This process of convincing a farmer to prioritise self sustenance over market profits is slow, but in the long run it is better economically as well.

In mixed farming, weeding tends to be an issue and often farmers use weedicides to serve the purpose but studies have linked weedicides to incidents of cancer. We're trying to find out if some tools can be created to aid the process of weeding when there are less farm hands available and avoid the use of chemicals as well. We have also built some weeding tools and once it is used almost fifty percent of the work is reduced.

Interviews at Amale

Researcher: How was the harvest this year. When did you finish harvesting?

Farmer 1: During Diwali season, we would be busy with harvesting rice and other grains. Fields used to be green at this time. But this year the rains stopped early and the fields dried out.

Farmer 2: Since we have only solar pump line, most of the farmers could not irrigate their fields properly. Now we fetch water from the river manually for all water requirements. At the moment only the Jasmine flower plots are irrigated using the pump. But since the number of plots has increased, the water pumped using the pump is not enough. Only two farmers can irrigate their plots in a day.

Researcher: How many farmers are there in the village?

Farmer 2: 18 farmers

Farmer 1: If the harvesting was done as scheduled, then people would have immediately started planting vegetables. But since the pump cannot cater to all farmers, they have to wait and that affects the schedule.

Researcher: Did you try using the treadle pump available for pumping water?

Farmer 1: When we use the pump, our thighs really hurt and become sore.

Farmer 2: Just to fill one tank of a toilet, it takes around 3-4 people working alternately through the day which is labour intensive and tiring.

Farmer 3: For spraying pesticides, we use the pump which we take on our back. But we have seen these new stationary pumps which use sprinklers to spray. Now the sprayer over there, it takes 15 litres of liquid and the entire load comes on the shoulders and the back. Smaller plots (200 flower plants) need around 2 sprayers but bigger plots (500 plants) takes around 4-5 sprayers.

Farmer 1: It really hurts our shoulders when we use it.

Farmer 3: Water is also a big issue, we have provided drip irrigation in this jasmine plot. This pipe is 1 and half inch thick. We used to plant vegetables here earlier, but we switched to flowers as the weight of vegetables was too heavy for transporting manually. When we tried planting vegetables the first year, we managed to load them by getting a vehicle in the village. But since there is no proper approach road to the village, the vehicle must cross a river to reach here. Now the vehicle has stopped coming and we find it difficult to carry the vegetables on our head.

Farmer 2: Therefore, we stopped selling vegetables and started planting jasmine flowers.

Farmer 1: But to harvest these flowers is a problem. We use these long shears to cut the flowers, but it puts a lot of strain on our forearms and elbows. After a day of cutting, a person needs to take rest for the entire next day due to pain and sore body.

Researcher: how long does it take to cut these flowers?

Farmer 3: Now this plot has 250 plants, so we need at least 2 days to harvest it. Recently Pandurang bhau harvested his plot of 500 plants. He took five days to do it. Since we don't get labourers, we need to do the harvesting by ourselves which takes a lot of time.

Farmer 1: No matter how big the plot is , we are doing harvesting by hand implements only. If we can get a better solution for cutting and harvesting, then it would really help.

Researcher: What about threshing and dehusking?

Farmer 1: For dehusking we currently take the grain to the mill. But right now we have just stored the grain.

Researcher: How do you store the grain before threshing, do you tie it up

Farmer 1: Yes

Researcher: And how do you store it after threshing?

Farmer 2: We store it in bags.

Researcher: But don't you have pest issues?

Farmer 3: We mix Nibarga's (a local plant) leaves, Nirguda's (Chinese Chaste tree) leaves and salt along with the grain to protect it from insects.

Researcher: Now that you have water issues, rice farming must be difficult. How do you transplant?

Farmer 1: We start with creating a bed of hay and leaves. We allow it to dry, then we collect a lot of grass and put it on top of the hay. We spread it in a circle and then turn the mud so that it gets mixed. Then we burn this heap and till the land to plant rice.

Researcher: Do you still use animal drawn traditional ploughs for tilling?

Farmer 1: yes

Researcher: So you don't use tractors or any machinery?

Farmer 3: During the tilling season river is usually flooded so the tractor cant reach the village as the approach road passes through the river.

Researcher: When do you start tilling and puddling?

Farmer 1: Once the rain starts, we end up working through the monsoon season. Transplanting, tilling and levelling requires a lot of continuous hard work. There is no escape from it.

Researcher: How do you store seeds?

Farmer 3: Depending on the size of the land, we decide the quantity of seeds to be stored.

Farmer 1: Currently we store seeds in a cotton bag.

Farmer 3: But we do have a traditional way of storing seeds. We take a small bucket of bamboo, cover it with cow dung. And we create a lid of mud mixed with cow dung too.

Farmer 1: To store grains we used to create a big basket of woven bamboo strips. But since the bamboo in the forest has regerminated, currently the length of the bamboo available is small and we cannot use it. So we use plastic drums but grains don't last that long.

Researcher: When you use a hoe for weeding, are you able to completely remove the weeds?

Farmer 4: No, we are not able to.

Farmer 3: This method will only remove the top layer, the roots remain in the ground and grow again after a few days. Even for jasmine, we create the saplings separately. We then plant it at 5 feet from each plant.

Farmer 4: We fill these small bags with soil and plant a twig from existing plant after harvesting to create saplings. We then water them regularly and store them together in the field.

Researcher: And how do you measure while transplanting rice?

Farmer 3: We usually do it with practice. The distance between saplings is approximately one to one and a half ft. which we measure by hand and thenplant them like this in a square pattern.

Researcher: Would it be easier if by some way you could stand and plant instead of constantly bending?

Farmer 4: Yes, that would definitely help.

Farmer 2: This is the wooden plough that we use for tilling and the leveller to level the land. It is difficult to turn with this plough. Mud completely sticks to the plough, so it becomes heavy. And while turning we have to lift it with one hand and turn, since in the other hand we hold the stick and the ropes to steer the bulls. The wood gets wet in the rain and becomes heavier, so the total weight increases almost to 30-35 kg during tilling. It would be better if it was made from metal.

Researcher: but then wouldn’t it become costlier?

Farmer 2: Yes, currently this wooden plough can be made in the village itself and costs around Rs. 500/-

Researcher: What do you use as pesticides and fertilizers?

Farmer 3: We use cow urine and cow dung.

Interviews at Goa

Farmer 1

Q: What tools do you use harvesting?

A: We use the power tiller for harvesting and there’s no hay left.

Q: What’s the cost incurred?

A: We do not spend on the machine, we get it for free, the MLA provides it and we pay the operator around 200-500rupees for their work.

Q: What’s the area of land owned?

A: 4000sq mtrs, split amongst four of us.

Q: When do you cultivate the rice crop?

A: Only during monsoons we cultivate, nothing else is planted the rest of the year. We do not have a well hence planting vegetables for the rest of the year is not possible. We only cultivate rice.

Q: How much rice do you get from your yield?

A: We do not measure our rice in Kilos. We do not sell our rice crop to the government, we use it for self consumption and if we have any surplus rice left we sell it in 1-2kg bundles.

Q: How would you harvest earlier?

A: We would cut the crop manually and thresh with feet or truck/tractor tires or with the help of sticks. We face a water problem. There’s a sewerage line, which also passed through our field. Because of that people have created band which hampers our water flow. Too much water can also ruin the crop. It can also hamper our movement into the field. Now three of us cultivate our parts respectively, one man doesn’t. his share of the land has been barren for many years.

Q: How many years have you been cultivating?

A: Earlier my father would work the fields, it has been 25 years since he dies, I would accompany him as a child but now for the last 25 years I cultivate the land myself.

Q: How long have you been using the machine for threshing?

A: Around five years, but we have been using the power tiller for a longer time. It is given to us by the MLA, we don’t pay a rent for it, we just pay around 200-500 rupees as a small free.

The harvesting machine rent is around 500-600rupees per hour. We end up paying around 4000 rupees per day for it. The smaller machine we would hardly spend around 300 rupees but now the Petrol costs are also high, so we have to incur these costs. We cannot use a tractor because our land is uneven, we have to use the smaller two tired machine.

The harvester can be used easily on our land. We do not cut the crop manually now.

Earlier we would cut the crop manually but it is too expensive now and the labour is scarce too, even if we do find labour, it is difficult to afford their wages, along with the food and tea that we have to give them. One woman wage worker is paid 500 rupees. There’s hardly any profit that way. As it is we spend on tilling and harvesting and fertilizers. We do not spend on the seeds though, we get it for free but it is around 600 rupees per bag. One bag of fertilizer is also given free by the MLA. You cannot cultivate without spending twenty thousand rupees minimum and if your crop is destroyed you are at a loss. We do not cultivate vegetables either but everyone else here does since they all have wells on their land.

We sow the crop manually but harvest with machine. One female in the neighbour used to sow with the machine as well but nobody else does.

We cultivate the Jyoti variety of rice crop which matures in two and half to three months, faster than other varieties. The people who cultivate other varieties start the sowing process early; we sow around twenty days after them because harvesting can then be done together. It’s easier to get a machine together for harvesting hence we do that. We weed manually as well and around 22 days later we fertilize the crop.

Ever since we use the machine farming has become convenient, time efficient and cost efficient for us. We barely need any extra labour as well. some farmers have to pay for the machine, they pay around 1200 per hour but even that is better than paying wage labour which can easily come up to around 5000 rupees.

Farmer 2

Q: How many years have you been farming?

A: My mother has been farming since her childhood, around sixty years probably.

Q: How much land do you all have?

A: We have around 1000sq mtrs.

Q: Now you use machines?

A: Earlier the women would sow and then we would harvest with the help of some wage labour, we would do the threshing by stacking and hitting by hand, then the cattle would trample it. Now with one machine we can do the entire process. Now my mother doesn't work, I manage along with my brother. We cultivate rice only once a year, during monsoons and rest of the year we cultivate vegetables. Currently we have planted red amaranthas, radish, onions, vir-vir, Lady fingers and more such vegetables. We use well water for irrigation. In the month of June we cultivate rice and once that is harvested in November we plant vegetables.

Q: How do you prepare your land for sowing?

A: We use the small machine. And for harvesting we use the harvester. We barely have to bear any expenses for it. We do not get hay from the machine harvested crop. Now we don't need labour as well. It saves our cost and time as well.

Q: Do you find machine cultivation more convenient?

A: Yes we do but there is more scope for wastage this way. Sometimes if there's more than expected rainfall the crops bend and the bent crops are not cut by the machine hence there is scope for loss. With manual labour that wasn't the case but affording labour today is not easy either.

Many people had stopped cultivating but now because of the availability of machines they're growing again. The land needs to be level though for a machine to work well on it. The problem with Canacona farmers mostly is that many of them cultivate in mountainous regions hence making it difficult to introduce machinery on the land. They still have to rely on manual work entirely.

First we sow the seeds and wait for them to sprout and then we transfer them to the soil to mature.

Q: How did you go about cultivating earlier?

A: I would till the land with the help of bulls and thresh manually by feet. Now we rely on machines. We buy the seeds, fertilizers, and we would plant manually. We do not keep the seeds from the harvest for next cultivation as it spoils sometimes. We use the rice for self consumption and sell our vegetables.

Now with the help of machines it's easier for us to cultivate and utilise the land available. Spending 500 rupees on every labour and getting the work done is not necessary now that we have machines to do the same in a cost effective manner. If the family members decide to work together on the field we can profit from the yield, hiring labour hardly leaves any profits for the farmer. The younger generation is less interested in taking up farming as well.

Earlier we would till with the wooden tiller, some people still follow that here as well.

Farmer 3

Q: What issues do you have with weeding and threshing?

A: Earlier we would leave the bulls in the field, once the soil is loosened by them we would do the weeding process, then we would level up the ground with the help of fawda and then we would sow, after a week or so we would fertilize the land and follow up with some weeding process if there were any weeds. Then we would manually cut the crop and thresh with our feet, now we use the machine for the same.

Yes we don't get hay but we don't really need it. Earlier we had a wooden tiller as well but now we use a machine. There's a machine to sow the seed as well now.

Kormuta: we use tractors for kormuta, in April-May and then after June-July we level the land and then harvest i. Itt doesn't need fertilizers. We have to harvest it manually since it grows in muck in the khazan lands. We would thresh with our feet and then on the tree but now we use the harvester machine. Some farmers lend us their machines at reasonable rates.

Q: Do you use machines to sow as well?

No, some people use it around Velsao, you need a level piece of land for that.

Q: Which breed of rice do you grow?

A: I don't cultivate the land here anymore. I was the only farmer cultivating here, and the cattle would ruin my crop, then eventually I stopped. Now I have another field of 5000sq mtrs wherein I cultivate the land, in the khazan land area and most of my yield is used for consumption only. I do not sell it. I need a krishi card to sell my yield but the Agriculture department does not complete the formalities as there is a problem with my name on identity proof documents.

Most of the villagers are interested in fish and not farming. There are a handful of us who are cultivating rice.

Q: Do you grow only rice?

A: Yes because we cannot plant anything else. A few years back someone convinced me to grow black eyed beans, and we planted them and the yield was great. A couple of others also grew them after witnessing the yield, I must've grown it for around three years, now I don't. The land needs to be filled with water making it impossible to plant something else.

Q: Do you benefit from the machine?

A: Yes definitely. It saves our time as well. Agriculture is becoming profitable. The work that could be done in 5000 rupees earlier is now done in 1000rupees only. The wage labour cost is saved. The weeding is done by some women but weeding is not really a problem. To avoid damaging the crop, the machine needs to be used only when its partly dried.

Q: How many times do you till the land?

A: In the khazan land area we till only once around April-May, on the other land we need to till around two or three times to avoid weeds.

Q: What is your main problem for cultivation?

A: We grow only during the monsoons, there aren't too many problems. We have a land at Cansaulim as well. My brother cultivates black eyed beans there.

Q: How do you cultivate the field at Cansaulim?

A: We use machines there right from sowing process. Very few people rely on bulls now.

Farmer 4

Q: What has been your experiencing with farming manually as opposed to with the use of machinery?

A: Earlier we would harvest manually, it would cost us more. Currently with the use of machinery and government subsidies farming has become cost efficient for us.

Now we can harvest the crop within 2000 rupees, earlier we need 6000 rupees for the same. Sowing expenses are around 25000 rupees. We sow only once a year and rest of the year the land remains barren. We do not practice mixed farming but many others do so with the help of government subsidies.

Q: What do you use for cutting?

A: We rent the bigger machine for 1000 rupees per hour. This is the subsidized rate. The time taken to harvest our land is two hours, the land is split between my brother and me and we both use the machine to reap the harvest.

We do not get hay since we harvest with the machine, we can make some if we wish to but it is redundant.

Q: How would you harvest the crop earlier?

A: First we would leave the cattle in the farm so they'd stamp the crop and bend it and with their help we would harvest it manually. Some crop was wasted as well. Ever since we're using the machine the wastage has reduced as well.

Q: How many years has it been since you've switched to using a machine?

A: About ten years. The machine has proved advantageous though with respect to reducing labour cost and saving time as well. We need around 65 women for sowing, who can be called across days and per day they are paid 500 rupees where as the harvesting/threshing labour is paid 1000 rupees per day, and we needed around 40 of them earlier. Now with the machine the work is done faster, within a day mostly and without extensive manual labour as well. We still use labour for sowing, we're dependent on the machine for the harvesting only.

Q: What about weeding?

A: Some stretches we use the weed cutting machine and the stretches in between the sowed seeds is cleaned by around 12-15 women manually. If a weed cutting machine operator is hired, their wages are 500 rupees per hour and so is the power tiller operator wage. The weed cutting machine is very easy for me to operate. Almost like learning how to drive. I've been using the power tiller for ten years now.

Earlier we would rely on cattle then we would rely on labour and machines owned by other people, now we invested in the machines ourselves with the help of government subsidies. Since we have a larger piece of land it is easier to avail for government subsidies. The machine was costing around one lakh and sixty thousand rupees but the government paid one lakh and I incurred a cost of sixty thousand only.

Q: What about the ones with smaller farming areas?

A: They do not get subsidies. They rent the machines from the ones who have it, they have to pay the labour as well. It is difficult to gain profits for them.

It's important to till your land at least twice. We plant the seeds first and once they're saplings we transfer them into the soil to grow. It is better and fast if done manually only. It may not be cost friendly, but the harvest is better.

Q: Do you practice multi-crop farming with rice?

A: No we grow only rice, also the rainwater that is collected in the farm does not help the cultivation of other crops. I have been considering it, but it's not something we currently do.

Recently I came across some farmers in Pernem who have created raised beds around their paddy fields and they cultivate vegetables in those stretches of land.

It is not possible to do so during monsoons as rains destroy vegetable crops . We grow our rice crops only during monsoons hence practicing something like this is not possible.

Q: Do you keep the harvest for consumption or sell it?

A: I sell it. We cultivate the breed called Parja. It is white rice and we get ample grains.

Q: Where do you do the milling process?

A: There are quite a few local mills that we take service from.

Q: Do you save the seeds for cultivating next year?

A: Yes we do

Q: Do you purchase fertilizers?

A: Yes we do. There are subsidies on that as well but we haven't availed them till date.

A: If you sell the harvested grains directly there's hardly any profit on it. I sold it for 20 rupees per kg. it was barely enough to cover my costs, where are if you sell processed rice it can fetch you around 50rupees per kg. There's hardly any profit if you sell the grains to the government. The mill you sell it to pays you 10rupees per kg and the government pays 10rupees as well.

Farmer 5

Q: Is it difficult to find labour?

A: Yes. There are people we can approach but none of them are willing to work. I have to bring in labour from sancoale every time and their work timings also aren't conducive with 800 rupees per day, it isn't a cost friendly option.

A: Most of the time the women work more than the men and yet the women have less daily wages than the men, also the ones who have a basic graduate degree do not prefer working on the fields, they prefer working in factories.

Farmer 6

Q: You own plantations only, not fields?

A: No. we only have plantations, earlier we would have a share in the fields but post independence we have lost that right. The land and its produce now belong to the one who tills it.

We have our plantations only. We plant the coconut trees, we take care of the land, we only employ labour for coconut plucking.

We have three large plantations and two small ones covering around 1 hector of land wherein we grow areca nut, coconuts, black pepper, jackfruit, bananas and kokum.

Q: What is the difference between a Bhatkar and Mundkar?

A: The one who owns the land is called Bhatkar and the one who is given the duty of taking care of the land is called a Mundkar. The plants are watered by us, cared for by us, the duty of the mundkar is to only keep a watch on the plantation and for that they're given ten percent of the share of coconuts.

Q: How many times do you pluck the coconuts in a year?

A: The coconuts are plucked after every three months so four times a year. It takes around ten years for a coconut tree to mature and around six years for areca nut tree to mature. Areca nuts are plucked only once a year but the plucking time from tree to tree may vary a little. Around November we start watering the areca nut plantation till the arrival of monsoons.

Q: Do you use manual labour or machines for plucking?

A: We use manual labour only, no machines. The only machine we use is the water pump and the sprinklers used to water the land.

Q: What are wages of the labour you hire for the plucking process?

A: Their rate varies. The ones we call take 1200 rupees per plucking session, per person to pluck coconuts. If they start at around 7am they are done by 10am and they take ten coconuts per person as well. We require around three of them. For the areca nut plantation we require only one man to do the job and he takes 2000 rupees. The jackfruit, pepper is gathered or plucked by us.

The land has been passed down to us by my grandfather; we have been taking care of it for three generations. Nothing has changed except for the installation of the sprinklers and the water pump. We fertilize the land with soil and cow dung only.

Q: One cannot see the younger generation working at the plantations now, can they?

A: No, most of them prefer to work at factories now

Q: What happens to the plantations that cannot be managed by their owners?

A: Most people sell their plantations today. Some of it is now sold to builders. Some build houses on cultivation land, they prefer a fixed income from the factories over working for their land.

Farmers 7 and 8

Q: What is your field area?

A: 1000sq mtrs

Q: Which season do you cultivate your crop in?

A (Farmer 7): Only one season – we did try growing twice a year earlier but the cattle ruined our cultivation – vainguinik

Q: Do you grow vegetables as well?

A (Farmer 8) Yes but in on a different piece of land.

Q: What are the difficulties you all face? Do you use machinery?

A (Farmer 7): Yes we do use machines provided by Agriculture department. We use the power tiller and our own machinery as well.

A (Farmer 8): we harvest manually as we need the post-harvest crop as hay fodder for our cattle.

Q: Do you do weeding manually as well?

A (Farmer 7): Yes but we don't have a weed problem because we sow manually as well. if you observe the stretch that is cultivated with the help of machinery you'll find more weeds there. We don't have that many because we sow manually.

Q: Do you do the cutting process manually?

A (Farmer 7): Yes but we use the power tiller for threshing. There's no harvesting cost involved as we help each other to harvest on our respective fields. Everyone who has fields joins in the process and we get the job done in a day.

A (Farmer 8): We prefer doing the cutting manually as we need the hay for our cattle as fodder. We don't have cattle but we sell the hay for around 3000 rupees.

Q: When will the harvesting/threshing process happen?

A (Farmer 7): Usually we start around March or April.

Q: What breeds of the rice crops do you cultivate?

A (Farmer 7): Jyoti and during the monsoons Jaya.

Q: How did you manage the field work before using machines?

A (Farmer 8): We had a pair of bulls to help us till with the wooden tiller. That also helped to avoid growth of weeds. That is not possible with the machine.

Q: What is the harvesting process you follow post cutting?

A (Farmer 7): We stack the cut crop first for around eight days then we start the threshing process by ourselves. We do not invest in labour. We help each other out.

Q: How many years has it been since you invested in machinery?

A (Farmer 7): Around 20 years. Earlier we had bulls but they need to be left out for grazing which causes damage to the surrounding plantations like cashew trees and the owners then complain. It is not possible to keep the bulls tied all the time, hence eventually we sold them.

Q: Now you only focus on farming?

A (Farmer 8): Yes and I help out with construction work as well.

Q: Do you keep the rice for your consumption or sell it?

A (Farmer 7): We sell it. We keep half for ourselves and sell half to the government since we get subsidies on it. We need the produce to last us the entire year before we cultivate again.

A (Farmer 8): The agriculture department decides the subsidy based on the amount of rice obtained from the respective land area. We have 1000sq mtrs of land, if our produce is more than the fixed limit we do not get the subsidies. We've requested for a meeting but it doesn't happen. We can profit more by selling processed rice directly. We can earn around 50-60rupees per kg that way.

Q: Where do you avail for water for cultivation purpose from in this season?

A (Farmer 8): We use the water from the stream nearby. We use a pump, and it is sufficient.

Q: What is your biggest difficulty while cultivating?

A (Farmer 7): We do not really face a problem of a larger magnitude. The more we work manually we maintain our health, the machine can compromise on our health, if we work manually we can ensure our fitness as well. we have not welcomed many modern ways of cultivation, we've been growing like this for the last forty years.

Q: What fertilizers/manure do you use?

A (Farmer 7): We use cow dung and coconut husks to cover the land and that pretty much does the job because we barely we have any weeds as well. The land looks cleaner than the machine cultivated land and you can observe that most manually planted fields are as clean as ours.

A (Farmer 8): We have bought some machines by availing the government subsidies as well. The water pump is bought with the help of government subsidies, so is a cutter. Some farmers were given machines through the government but nobody is using them becaure they're not working. They're lying unused.

Q: Have you been informed about the various government schemes you can benefit from?

A (Farmer 7): Yes, quite a few times but we hesitate to avail the schemes. We believe in the productivity of manual work. Since we do the work ourselves there's no labour cost as well. The harvest achieved from manual cultivation and with the help of machines is almost the same, there's hardly any difference but sometimes there is crop wastage if we rely on machines and more importantly we can control the amount of water used if we stick to manual cultivation.

A (Farmer 8): If you're sowing with the help of the machine you need to mark out a distance of 25cms. We tried that once. It involves a lot of work though and we cannot control the water supply to the land as well.

A (Farmer 7): First we sow the seeds on a stretch and once they're saplings in about fifteen days we transfer them into the cultivation land.

Q: Do you do the threshing manually?

A (Farmer 7): Yes we beat the crop around four times on a wooden plant. That does the job.

Q: Have you not heard of the pedalled thresher? It is available on a subsidy.

A (Farmer 8): No. We have not heard of it. Using a power tiller with the help of a stone is a really fast process.

Q: Do you keep the seeds for planting again?

A (Farmer 8): Yes we do. It reduces our work as well and they last well the seeds.

Q: What about the fields cultivated up on the hill?

A (Farmer 7): We cultivate them just like these low lying fields but their returns are less, they don't need fertilizers as well, cow dung and coconut husks are enough and we cultivate rice only during monsoons. Rest of the days we cultivate vegetables. Using machinery is not a problem either. We have roads to transport our power tiller. We grow black eyed beans, black gram and green gram in those fields and rice crop during the monsoons.

Q: When is the monsoon rice crop planted?

A (Farmer 7): We sow in around June-July and it takes around four months for the crop to mature. The jaya crop grows quite tall and it is a white rice breed. Earlier we grew another breed called Pani, now we do not have that seed. It is available at Ella Farm, but we don't grow it now. Another breed we grew was called Mutta Adu, the rice gruel made with this breed is considered extremely nutritional for infants. Rice gruel made with Jyoti breed rice is also beneficial for people who do not keep well health wise.

Q: Have you thought of investing in any other machinery in the future?

A (Farmer 8): No, in case we do, it'll only be a power tiller, nothing else. It is better if the machine is handled and managed by one person. It needs to be cleaned and serviced on time. It comes with two types of wheels, iron and tires. During the monsoons the iron wheels are preferred.

Q: Do you use the traditional technique for cutting?

A (Farmer 8): Yes we do. Now the Agriculture department sells new ones for 110rupees and they last well.

Farmer 9

Q: Can you please tell me how the crop is harvested?

A: The Agriculture Department makes provision for cultivation as well as harvest of the rice crop. The department makes provisions for tilling the land at hand with the help of machinery, the size of the machine used depends on the terrain and the size of the land owned. They take charge of the entire process of cultivation. They provide the seeds, sow them, and harvest the crop as well with the help of machinery. The harvesting cut made is a little higher than the manual cut sometimes. If carefully done though, that can be avoided as well. The harvest is usually split into half between the farmer who owns the land and the government but since it is inconvenient for them to take their share they leave that as well.

One such case wherein a 700 sq mtr land was cultivated and harvested by the government, the land owner received 4 quintals of harvested rice as his share and the only expense borne by him was two thousand rupees.

Here women now rarely step out to cultivate the fields unlike Maharashtra, hence the heavy reliance on government machineries right from tilling the land and sowing the seeds to harvesting the crop. The size of the land also plays an important role here. Larger farms are better cultivated with government aided machinery and supplies, in smaller areas it is not convenient to do so.

Q: Do you not have any smaller fields in your village then? What about Upland farming? Do the machines work on Upland farms as well?

A: We do not have upland farms. In any case, they are usually created with the onset of monsoon, on a dry, raised land or on a hillock.

The only setback of using machinery in the process of harvesting is the loss of hay in the form of fodder for the cattle. They do not consume machine waste. Over the years though, the need for this has declined as well. One needs it to feed their cattle or their bulls who aid the process of cultivation but with the onset of machinery based cultivation and harvesting, less farmers own bulls and don't really need the hay for fodder.

Today, with the help of government schemes a farmer can buy a machine within 1-1.5lakh rupees and avoid manual labour to a large extent as well hence save costs too.

Q: Are the machines terrain-friendly in all the fields?

A: Yes there are two kinds of machines; a basic one for smaller terrains and a bigger one for the difficult terrain. You can pretty much use both as per requirement.

10. Publications by the candidate

1. Pai, S. . (2019, November). Big Design Interventions for small farmers. IITB Monash. Retrieved December 16, 2022, from https://iitbmonash.org/researchStoriesInternal/14

2. Pai, S., Malhotra, S., Coxon, S., & Napper, R. (2021). Design Intervention in Farm Equipment: Using a Studio Research Approach to Design a Sustainable, Human-Powered Solution for Small and Marginal Indian Farmers. In Design for Tomorrow—Volume 3 (pp. 449-460). Springer, Singapore.

3. Pai, S., Malhotra, S., Coxon, S., & Napper, R. (2021). A Design Research Study to Understand Factors Affecting Tool Design for Small-Scale Rice Farming in Western Maharashtra. In Design for Tomorrow—Volume 3 (pp. 461-469). Springer, Singapore.

4. Dhaundiyal, D., Pai, S., Cramer, M., Buchmueller, S., Malhotra, S., & Bath, C. (2021, May). The Larger Picture: A Designerly Approach to Making the Invisible Domestic Workloads of Working Women Visible. In Asian CHI Symposium 2021 (pp. 221-228).

11. Acknowledgements

Firstly, I would like to acknowledge and thank my PhD supervisors Associate Professor Sugandh Malhotra, Associate Professor Selby Coxon, and Dr Robbie Napper, for their pertinent guidance and tireless support throughout the course of this research journey. You helped shape me into a better person, teacher, designer, and researcher. Thank you.

I would also like to acknowledge and thank members of my Research Progress Committee, Professor B. K. Chakravarthy and Professor Daphne Flynn, for their timely guidance and feedback throughout my PhD candidature. I would also like to take this opportunity to thank Dr Jesse Berry, Dr Myra Thiessen, Dr Ilya Fridman.

I am grateful to Prof. Vijay Bapat and Mrs Bapat for their unconditional love, support, and encouragement throughout the course of my academic journey at IIT.

I want to thank the staff of the IDC School of Design, Pragati Yadav, N. G. Navale, Nikhil Samant, S. B. Shelar, Deepak Nalawade, and Prashant Patekar for offering suggestions, resources, and support whenever needed. I want to also thank Sanjay Patil and Deepa More, the resource personnel who helped me through the field studies conducted during the research.

From the beginning of my research, I was blessed with a few amazing friends who have been with me, riding the ebbs and flows of not only my research but also my personal and emotional growth: Janhavi, Sivaranjini, Sangeeth, Madhuri, Mitali, Abhinav, and Joanne—thank you so much for being with me.

I would also like to thank my colleagues at the IDC School of Design and Monash Department of Design for their valuable feedback, criticism, and encouragement: Dhanashree, Dhriti, Shruti, Nebu, Bishal, Faizan, Yash, Shivam, Nabajit, Amit, Dave, Sarah, Troy, and Lisa. Thank you. I am really grateful to Agnivesh for helping with the prototype, Krishnanunni for help with renders and posters, Piyush for helping with the animation.

My sister Siddhi, brother in law Ramakrishna, and my friends from Goa, Tejas, Vaibhavi, Vaishnavi, Dinesh, Nakita, Calvin, and Jayant helped me during the prototyping, fieldwork, and testing stages; heartfelt gratitude to all of you.

My sincere gratitude to a few Institutions which also provided invaluable support during various research stages during my candidature; Indian Army, BAIF and Shivaganga.

Lastly, I would like to thank my parents Satish and Shweta, extended family, cousins, and friends for believing in me and standing by me all these years.